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Zyoptix wavefront-guided versus standard photorefractive keratectomy (PRK) in low and moderate myopia: Randomized controlled 6-month study

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PURPOSE. *To evaluate the refractive and aberrometric outcome of wavefront-guided photorefractive keratectomy (PRK) compared to standard PRK in myopic patients.*
METHODS. *Fifty-six eyes of 56 patients were included in the study and were randomly divided into two groups. The study group consisted of 28 eyes with a mean spherical equivalent (SE) of -2.25±0.76 diopters (D) (range: -1.5 to -3.5 D) treated with wavefront-guided PRK using the Zywave ablation profile and the Bausch & Lomb Technolas 217z excimer laser (Zyoptix system) and the control group included 28 eyes with a SE of -2.35±1.01 D (range: -1.5 to -3.5 D) treated with standard PRK (PlanoScan ablation) using the same laser. A Zywave aberrometer was used to analyze and calculate the root-mean-square (RMS) of total high order aberrations (HOA) and Zernike coefficients of third and fourth order before and after (over a 6-month follow-up period) surgery in both groups. Preoperative and postoperative SE, uncorrected visual acuity (UCVA), and best-corrected visual acuity (BCVA) were evaluated in all cases.*
RESULTS. *There was a high correlation between achieved and intended correction. The differences between the two treatment groups were not statistically significant for UCVA, BCVA, or SE cycloplegic refraction. Postoperatively the RMS value of high order aberrations was raised in both groups. At 6-month control, on average it increased by a factor of 1.17 in the Zyoptix PRK group and 1.54 in the PlanoScan PRK group ($p=0.22$). In the Zyoptix group there was a decrease of coma aberration, while in the PlanoScan group this third order aberration increased. The difference between postoperative and preoperative values between the two groups was statistically significant for coma aberration ($p=0.013$). No statistically significant difference was observed for spherical-like aberration between the two groups. In the study group eyes with a low amount of preoperative aberrations (HOA RMS lower than the median value; <0.28 µm) showed an increase of HOA RMS while eyes with RMS higher than 0.28 µm showed a decrease ($p<0.05$).*
CONCLUSIONS. *Zyoptix wavefront-guided PRK is as safe and efficacious for the correction of myopia and myopic astigmatism as PlanoScan PRK. Moreover this technique induces a smaller increase of third order coma aberration compared to standard PRK. The use of Zyoptix wavefront-guided PRK is particularly indicated in eyes with higher preoperative RMS values. (Eur J Ophthalmol 2006; 16: 219-28)*

KEY WORDS. *Wavefront-guided procedure, Photorefractive keratectomy, Wavefront error*

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INTRODUCTION

In the last decade, the safety, predictability, and efficacy of excimer laser procedures such as photorefractive keratectomy (PRK) and laser *in situ* keratomileusis (LASIK) have been demonstrated particularly for the correction of myopic refractive errors (1, 2).

Nevertheless, a decrement of visual performance, particularly in scotopic conditions, has been reported as one of the common complications of these techniques (3-6).

Different studies have demonstrated that excimer laser procedures modifying the physiologic corneal shape lead to an increase of high order aberrations (HOA) and mainly of spherical-like and coma-like aberrations (3-6).

Several factors seem to account for the variation of the corneal shape and thus of the corneal asphericity, such as amount of tissue removal, biomechanics of the cornea, ablation profile, and healing response (7-9). These aspects, in turn, are strictly dependent on the amount of correction performed. The greater the refractive error, the higher the disruption of the corneal anatomy, and, consequently, higher increment of HOA, particularly of fourth order spherical aberration (10).

The increase of third order aberrations such as coma is mainly related to the decentration of ablation and is higher for high refractive errors due to the duration of the treatment (10, 11).

Wavefront-guided surgery is a new excimer laser keratorefractive technique combining the correction of pre-existing HOA and prevention of surgery-induced aberrations combined with a reduction of spherocylindrical errors. It has been introduced recently in order to improve optical quality in normal eyes and to solve problems of low vision quality related to laser ablations procedures (12, 13).

Several studies reported a smaller increase of postoperative HOA after wavefront customized ablation compared to conventional ablation (14-19).

The aim of our study was to evaluate refractive and aberrometric results after correction of low and high order aberrations by means of Zyoptix wavefront-guided PRK compared to standard PRK.

PATIENTS AND METHODS

Fifty-six eyes of 56 patients with myopia and myopic astigmatism, referred to the Ophthalmology Department of Chieti University from October 2003 to June 2004, were enrolled in this prospective, randomized control study.

Inclusion criteria were as follows: patient at least 20 years of age, no contact lens wear for the 2 weeks prior to the baseline examination, a spherical equivalent (SE) cycloplegic refraction between -1.5 and -3.50 diopters (D) with -2.25 D or less of astigmatism, stable refractive error for at least 2 years, and best-corrected visual acuity (BCVA) of 1.0 or better.

Exclusion criteria included the following: ocular pathologies impairing visual function, corneal dystrophies, keratoconus or keratoconus suspect, corneal thickness lower than 500 μm, previous anterior or posterior segment surgery, glaucoma, diabetes, and systemic diseases (such as collagen vascular diseases) that could affect corneal wound healing.

Preoperatively and at 90 and 180 days after surgery, all patients underwent a complete ophthalmic examination that included best corrected (BCVA) and uncorrected (UCVA) visual acuity, SE cycloplegic subjective refraction, keratometry, intraocular pressure measurement by applanation tonometry, slit lamp biomicroscopy of anterior segment, ophthalmoscopy, corneal topography (Orbscan IIz), ultrasound pachymetry, pupillometry, and ocular wavefront aberration measurements.

Every patient gave informed written consent before being enrolled in the study and the study was approved by the Ethical Committee.

Wavefront aberration analysis and ablation profile calculation

The high ocular aberrations were measured by using the Zywave II aberrometer (Bausch & Lomb, Rochester, NY) based on the principle of the Harmann-Shack wavefront sensor technique (20). It uses a near infrared 785 nm wavelength diode laser source that projects several light flashes onto the retina. The wavefront reflected from the retina is focused by a system of lenslet of the Hartmann sensor into points called centroids. In an ideal optical system the bundle of lights coming out from the eye generate a grid with equidistant points and the three-dimensional reconstruction is represented by a flat wavefront. In an imperfect eye the deformed wavefront is reconstructed by the difference between ideal points and individual points of the analyzed eye.

The Zywave defines and calculates aberrations in terms of Zernike polynomials up to the fifth order. The second

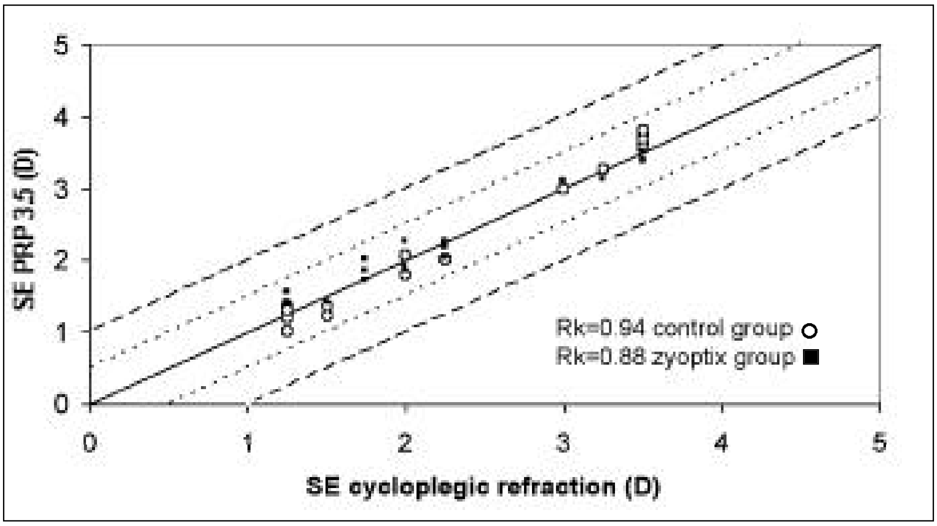


Fig. 1 - *Intraclass correlation coefficient (R_k) and confidence band (±1 D and ±0.5 D) between spherical equivalent (SE) predicted phoropter refraction 3.5 and SE cycloplegic refraction.*

(Z_2^0, Z_2^2, Z_2^{-2}), third (Z_3^1, Z_3^{-1} , Z_3^3, Z_3^{-3}), fourth (Z_4^0, Z_4^2, Z_4^{-2}, Z_4^4, Z_4^{-4}), and fifth (Z_5^1, Z_5^{-1}, Z_5^3, Z_5^{-3}, Z_5^5, Z_5^{-5}) order aberrations are expressed as Zernike coefficients values and are measured in μm.

The total wavefront error, HOA (from third to fifth), and HOA without Z_4^0 spherical aberration (without Z_4^0) are expressed in root-mean-square (RMS) representing the average of the square root of the wavefront error, measured in μm (11).

The shape of the wavefront deformation is analyzed and converted to the best spherocylindrical refractive values that optimize the retinal image for 3.5 mm or the entire pupil, called predicted phoropter refraction.

During Zywave examination, after obtaining proper patient alignment, focusing on the edge of the pupil and centering on center of the pupil entrance, the patients were invited to fixate the fixation target and five consecutive measurements were taken at 1.5-second intervals.

The total and higher order wavefront error (6 mm pupil entrance diameter) and predicted phoropter refraction for every single acquisition were obtained by averaging the three measurements with the lowest repeatability criteria value.

The predicted phoropter refraction for 3.5 mm pupils, the RMS value of HOA, HOA without Z_4^0 , and single Zernike terms were calculated for each patient before and after pupil dilatation preoperatively and at each postoperative examination.

The wavefront aberration examinations of patients undergoing wavefront-guided ablation along with refractive error correction were elaborated by the Zylink Customized Treatment Calculation Software combining data from the topographer Orbscan IIz and the Zywave II aberrometer.

The Zywave II aberrometer creates an ablation profile that corrects both the pre-existing HOA and the spherocylindrical errors. The Orbscan is a screening tool that provides additional information concerning the cornea. When the ablation profile had been calculated, the data profile was transferred to the laser.

For each patient the ablation profile was based on the predicted phoropter refraction for a 3.5-mm pupil size and the HOA for a 6-mm pupil diameter. Only patients with a cycloplegic refraction similar to the wavefront refraction (predicted phoropter refraction) were included in the wavefront ablation group (Fig. 1). The optical zone for each patient was chosen on the basis of the scotopic pupil diameter.

Surgical procedure

Patients were randomized to receive one of the two treatments. The randomization list was generated by the method of randomly permuted blocks of two patients. A study group (Zyoptix wavefront-guided PRK group) and control group (PlanoScan PRK) were included. The wavefront-guided PRK group, comprising 28 eyes, received customized PRK in order to treat myopic and astigmatic refractive error and higher order aberrations. The PlanoScan PRK group consisted of 28 eyes treated with PlanoScan PRK for the correction of refractive errors.

The PRK treatment was performed in every patient of both groups using a Tecnolas 217z excimer laser (Bausch & Lomb Inc., Rochester, NY). The Tecnolas 217z is a flying-spot excimer laser using a truncated Gaussian and a flat top beam for the Zyoptix and PlanoScan procedures, respectively. In the Zyoptix group a 2.0 mm and 1.0 mm spot diameter were used for the correction of low order and high order aberrations, respectively, while a 2.0 mm spot corrected sphero-cylindrical errors in the PlanoScan group. The repetition frequency of the laser was 50 Hz and the radiant exposure was 120 mJ/cm^2. All operations were performed by using topical anesthesia of oxybuprocaine chlorohydrate 0.4%. After mechanical removal of the corneal epithelium by means of a blunt spatula, the laser was focused on the surface of Bowman's layer and the cornea was ablated while the patient fixated the target light, under a constant eye-tracking control.

Postoperatively, preservative-free gentamicin 0.3% was administered four times daily for the first week in both groups after protecting the debrided cornea with a soft contact lens. After the first week, ofloxacin 0.3% and fluorometholone 0.1% eyedrops were given four times daily for 10 days and 1 month, respectively.

Main outcome measures and statistical analysis

The aim of the study was to verify that Zyoptix wavefront-guided PRK does not significantly increase HOA for a given pupil diameter and, in particular, that after the treatment it is possible to obtain a reduction of high order wavefront error at 6 months.

This study was designed to show the lower increment of wavefront error obtainable with Zyoptix wavefront guided PRK compared to standard PRK in terms of HOA RMS reduction at 180 days after surgery. Assuming a difference of at least 0.10 µm in HOA RMS, using a one-sided t-test for unpaired data at a level of 0.05 with 80% power and the common standard deviation of 0.11 µm, 25 patients in each treatment arm were required. Subsequently, based on the Pitman Asymptotic Relative Efficiency (ARE) of the Mann-Whitney U test, we adjusted the sample size by dividing it by 0.955, which indicated that 27 patients were required for each arm. Therefore, we enrolled 56 subjects.

The main parameters evaluated in this study included UCVA, BCVA, SE cycloplegic subjective refraction, predicted phoropter refraction 3.5 mm, HOA RMS, HOA RMS without Z_4^0, and Zernike coefficients of third (Z_3^1, Z_3^{-1}, Z_3^3, Z_3^{-3}) and fourth order (Z_4^0, Z_4^2, Z_4^{-2}, Z_4^4, Z_4^{-4}) preoperatively and at 90 and 180 days after surgery.

The high contrast UCVA and BCVA were recorded using the Early Treatment of Diabetic Retinopathy Study (ETDRS) visual acuity chart logarithm of the minimum angle of resolution (log MAR) for statistical analysis.

The safety index (mean postoperative BCVA/mean preoperative BCVA) and the efficacy index (mean postoperative UCVA/mean preoperative BCVA) were evaluated at 6 months after surgery in both groups.

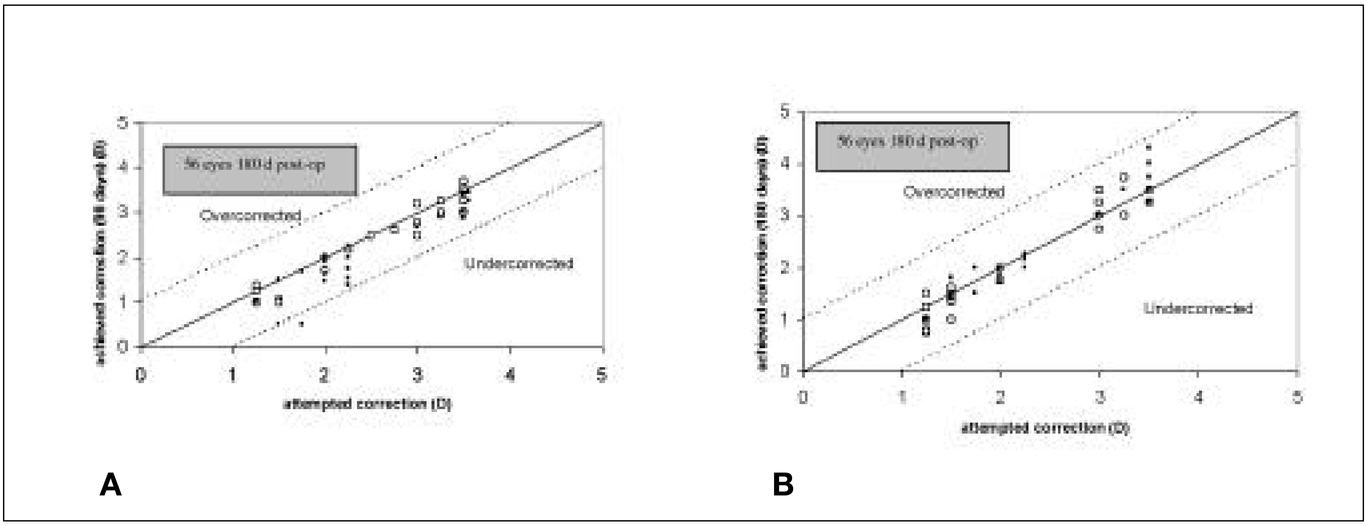
Moreover, the predictability was analyzed in the Zyoptix and PlanoScan patients calculating the correlation between achieved correction and intended correction and the percentage of eyes within ± 1.00 D and ± 0.50 D of desired postoperative refraction (21). The between group differences within the bands were tested using chi-squared test.

The visual parameters (SE, UCVA, and BCVA) and the aberration parameters (HOA RMS, HOA RMS without Z_4^0, and Zernike coefficients) were expressed as mean ± standard deviation (SD) (shown in the Tables). The variation of HOA RMS and HOA RMS without Z_4^0 between preoperative values and the values at 90 and 180 days (postoperative) were expressed as average ratio (postoperative value/preoperative value).

The statistical analysis was performed using nonparametric tests. The differences between the Zyoptix and PlanoScan groups at each time point (pretreatment, 90 days, and 180 days) relative to three visual parameters were evaluated with Mann-Whitney U test. The same test was applied to evaluate the between-group differences for each Zernike coefficient at each follow-up time. The Wilcoxon test was applied to separately evaluate the variation between different time points for the two groups. This test was applied to both visual parameters and Zernike coefficients.

The preoperative RMS values were divided into two subgroups (less than and greater than the median). The mean percentage variation over the follow-up period for each subgroup was calculated for the Zyoptix and PlanoScan groups. Mann-Whitney test was applied to evaluate the differences between the variations for each of the two subgroups.

The concordance between predicted phoropter refraction 3.5 and the SE cycloplegic subjective refraction was evaluated with the Intraclass Correlation Coefficient (Rk) (shown in the Figure) (21-23). Spearman's rank correlation coefficient (rho) was applied to evaluate the relationship between achieved correction (SE before - SE after surgery) and intended correction in the two groups at 90 and 180 days after PRK (shown in the Figures) (21, 22). Spearman's rank correlation coefficient (rho) was also applied to evaluate the relationship between the induced



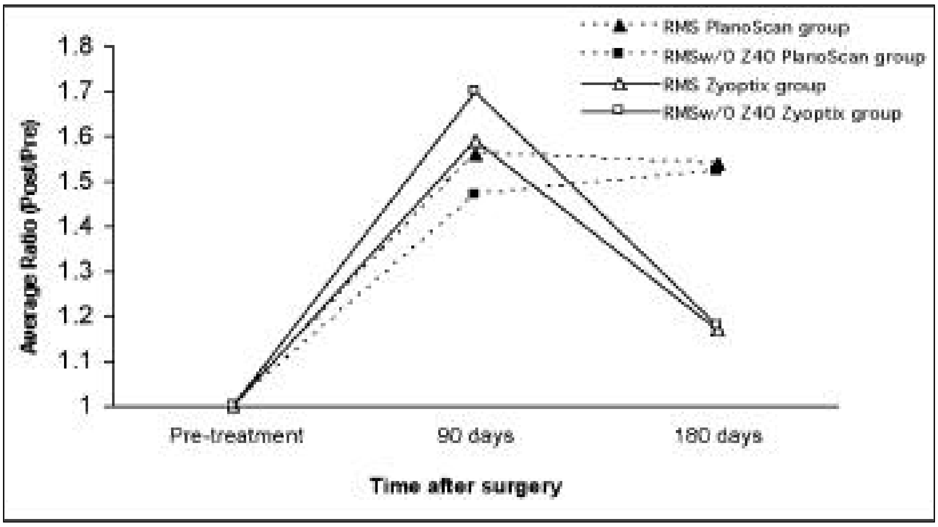


Fig. 2 - *Scattergram of achieved correction vs intended correction with confidence bands (±1 D) for the two groups at 90 days after photorefractive keratectomy (PRK) rho=0.94 and rho=0.91 in the PlanoScan and Zyoptix group, respectively (**A**) and at 180 days after PRK rho=0.84 and rho=0.99 in the PlanoScan and Zyoptix group respectively (**B**). PlanoScan group (o); Zyoptix group (■).*

Fig. 3 - *Average ratio (postoperative/preoperative) of root-mean-square (RMS) and RMS without Z_4^0 in Zyoptix group and PlanoScan group over time.*

aberrations (RMS HOA) and either visual acuity (BCVA or UCVA) for the Zyoptix group or the PlanoScan group.

Statistical analysis was performed using SPSS Advanced Statistical 10.0 software (Chicago, IL).

RESULTS

Preoperative values of SE, UCVA, BCVA (Tab. I), and RMS for total wavefront error did not show statistically significant differences between the two groups (Mann-Whitney test). Single Zernike terms were not significantly different between the two groups except for Z_3^3, which was significantly lower in the Zyoptix group compared to the PlanoScan group (p<0.05) (Tab. II).

Visual outcome

In the Zyoptix group the mean UCVA significantly increased from 0.73±0.24 to -0.03±0.14 (p<0.01) and -0.08±0.10 (p<0.05) at 90 and 180 days, respectively, and in the PlanoScan group it changed from 0.79±0.30 to -0.03±0.09 at 90 days (p<0.01) and -0.08±0.08 at 180 days.

The mean BCVA decreased from -0.08±0.09 to -0.09±0.08 and -0.14±0.05 (p<0.05) at 90 and 180 days, respectively, in the Zyoptix group. In the PlanoScan group it varied from -0.07±0.06 to -0.11±0.05 at 90 days and -0.15±0.04 (p<0.05) at 180 days (Tab. I).

The differences between the two groups for BCVA and UCVA at each time point were not statistically significant (Tab. I).

The safety index of the procedure was 1.7 in the Zyoptix group and 2.1 in the PlanoScan group at 6 months and the efficacy indexes were 1.0 and 1.1, respectively.

Refractive outcomes

The mean SE decreased from -2.25±0.76 D to -0.16±0.22 D at 90 days ($p<0.01$) and -0.08±0.28 D (range: -0.75 D to 0.50 D) at 180 days ($p<0.01$) in Zyoptix group and from -2.53 ± 1.01 D to -0.14 ± 0.18 D at 90 days ($p<0.05$) and -0.06 ± 0.30 D (range: -0.75 D to 0.50 D) at 180 days in the PlanoScan group (Tab. I).

Both groups showed a high correlation between achieved correction and intended correction at 90 days (rho = 0.91 and 0.94 in the Zyoptix group and the PlanoScan group, respectively) and 180 days (rho = 0.99 and 0.84 in the Zyoptix group and the PlanoScan group, respectively) (Fig. 2).

Six months after surgery 100% of eyes of both groups were within ± 1.00 D and 96.1% of the Zyoptix group and 92.5% of the PlanoScan group were within ± 0.50 D of desired postoperative refraction (p=NS).

Ablation depth and optical zone size

The mean central ablation depth calculated by the laser system was 49.74 ± 22.21 µm in the Zyoptix group and 60.79 ± 17.45 µm in the PlanoScan group.

The mean optical zone diameter set by the software was 6.62±0.22 mm (range 6.50–6.80 mm) and 6.62 ± 0.13 mm (range 6.50–6.80 mm) in the Zyoptix and PlanoScan groups, respectively.

Wavefront error

HOA RMS value. The mean preoperative HOA RMS and HOA without Z_4^0 RMS were 0.35±0.10 µm and 0.31±0.10 µm in the Zyoptix group and 0.32±0.14 µm and 0.29±0.14 µm in the PlanoScan group, respectively.

At 90 days the average ratio of HOA RMS and HOA without Z_4^0 RMS increased to 1.59 and 1.70, respectively, in the Zyoptix group and 1.56 and 1.47, respectively, in the PlanoScan group (Fig. 3).

At 180 days the average ratio of HOA RMS value decreased compared to the 90 days value in the Zyoptix group and remained constant in the PlanoScan group (1.18 and 1.54, respectively).

The HOA without Z_4^0 RMS value was increased by a factor of 1.17 in the Zyoptix PRK group and 1.52 in the PlanoScan PRK group.

The mean preoperative Z_4^0 RMS was 0.03±0.02 µm in the Zyoptix group and 0.02±0.02 µm in the PlanoScan group.

At 90 days Z_4^0 RMS decreased to 0.02±0.02 µm in the study group and increased to 0.07±0.04 µm in the control group ($p<0.01$). At 180 days Z_4^0 RMS increased in the study group and decreased in the control group compared to the value at 90 days (0.04±0.05 µm and 0.06±0.04 µm, respectively).

In the Zyoptix group, eyes with a low preoperative value of aberrations (HOA RMS lower than the median value; <0.28 µm) showed a 35% increase of HOA RMS while in the patients with a preoperative RMS ≥0.28 µm, an 8% decrease was observed.

The difference between Δ% of the subgroups was statistically significant ($p<0.05$) (Tab. II).

Correlations between the induced aberrations (RMS HOA) and either visual acuity (BCVA or UCVA) were not statistically significant for the Zyoptix group and the PlanoScan group.

Zernicke coefficients

Third order aberrations, also known as coma-like aberrations, are represented by coma (Z_3^1, Z_3^{-1}) and triangular astigmatism (Z_3^3, Z_3^{-3}) aberrations. Fourth order aberrations, also known as spherical-like aberrations, are represented by spherical aberration (Z_4^0) and quadratic astigmatism (Z_4^2, Z_4^{-2}, Z_4^4, Z_4^{-4}).

Horizontal coma (Z_3^1) decreased (reaching negative values) in the Zyoptix group during the follow-up period but increased in the PlanoScan group.

The variation between 90 and 180 days versus preoperative values was statistically different between the two groups ($p<0.05$) (Tab. III). The spherical aberration was negative preoperatively in both groups.

At 90 days it showed an increase in the control group while it decreased in the study group ($p<0.01$). At 180 days after surgery it decreased in the control group and increased in the study group (Tab. III).

Clinical result

Slit-lamp biomicroscopy showed normal corneal wound healing in all eyes and normal intraocular pressure during the entire follow-up period.

TABLE I - VISUAL AND REFRACTIVE PARAMETERS FOR THE ZYOPTIX GROUP AND PLANOSCAN GROUP AT PRETREATMENT, 90 DAYS, AND 180 DAYS AFTER PRK, EXPRESSED AS MEAN ± SD

Follow-up time	UCVA*		BCVA*		SE cycloplegic refraction†	
	Zyoptix	PlanoScan	Zyoptix	PlanoScan	Zyoptix	PlanoScan
Pretreatment	0.73±0.24	0.79±0.30	-0.08±0.09	-0.07±0.06	-2.25±0.76	-2.35±1.01
90 days	0.03±0.14‡	-0.03±0.09‡	-0.09±0.08	-0.11±0.05	-0.16±0.22‡	-0.14±0.18§
180 days	0.08±0.10*	-0.08±0.08	-0.14±0.05§	-0.15±0.04§	-0.08±0.28‡	-0.06±0.30

*Expressed as logMAR
†Expressed as diopter
Not statistically significant: Mann-Whitney test comparing two groups at the same time point. §p<0.05; ‡p<0.01 Wilcoxon test, versus the previous time point
PRK = Photorefractive keratectomy; UCVA = Uncorrected visual acuity; BCVA = Best-corrected visual acuity; SE = Spherical equivalent

TABLE II - HOA RMS VALUES FOR THE TWO SUBGROUPS IN THE TWO TREATMENT GROUPS AT PRETREATMENT, 90 DAYS, AND 180 DAYS AFTER PRK, EXPRESSED AS MEAN ± SD, AND THE MEAN PERCENTAGE VARIATION (Δ%) OVER THE PERIOD

HOA RMS (µm)	Zyoptix group				PlanoScan group				
	Pretreatment	90 days	180 days	Δ%		Pretreatment	90 days	180 days	Δ%
< 0.28 (n=13)	0.26±0.01	0.53±0.19	0.35±0.09	35.0	(n=14)	0.27±0.04	0.42±0.12	0.35±0.12	30.0
≥ 0.28 (n=15)	0.40±0.10	0.55±0.10	0.37±0.08	-8.0*	(n=14)	0.56±0.24	0.55±0.20	0.75±0.10	34.0*

p=0.05 Mann-Whitney test, HOA RMS ≥0.28 vs <0.28
HOA = High order aberrations; RMS = Root-mean-square; PRK = Photorefractive keratectomy

TABLE III - ZERNIKE COEFFICIENTS AT PRETREATMENT, 90 DAYS, AND 180 DAYS AFTER PRK FOR THE TWO GROUPS, EXPRESSED AS MEAN ± SD

Variable	Pretreatment		90 days		180 days	
	Zyoptix	PlanoScan	Zyoptix	PlanoScan	Zyoptix	PlanoScan
Z_3^1	0.09 ± 0.19	0.10 ± 0.15	-0.08 ± 0.25*	0.12 ± 0.17	-0.06 ± 0.18*	0.14 ± 0.14
Z_3^{-1}	-0.08 ± 0.10	-0.01 ± 0.17	-0.05 ± 0.21	0.02 ± 0.19	-0.08 ± 0.15	0.02 ± 0.17
Z_3^3	-0.02 ± 0.15*	0.17 ± 0.10	-0.14 ± 0.14*	0.03 ± 0.16†	-0.07 ± 0.12†‡	0.16 ± 0.06†
Z_3^{-3}	-0.09 ± 0.10	-0.03 ± 0.19	-0.04 ± 0.14	-0.02 ± 0.21	-0.01 ± 0.05	-0.01 ± 0.19
Z_4^0	-0.13 ± 0.06	-0.13 ± 0.07	-0.08 ± 0.11‡	-0.24 ± 0.09†	-0.16 ± 0.14	-0.18 ± 0.09
Z_4^2	0.01 ± 0.04	0.00 ± 0.05	0.03 ± 0.18	0.00 ± 0.07	0.01 ± 0.16	0.01 ± 0.04
Z_4^{-2}	-0.01 ± 0.08	0.05 ± 0.07	-0.13 ± 0.11†‡	0.00 ± 0.06	-0.08 ± 0.11	-0.02 ± 0.06
Z_4^4	-0.02 ± 0.04	0.00 ± 0.06	-0.01 ± 0.03	-0.01 ± 0.08	-0.01 ± 0.04	-0.01 ± 0.07
Z_4^{-4}	-0.03 ± 0.06	-0.12 ± 0.30	0.04 ± 0.13	-0.05 ± 0.05	0.03 ± 0.05	-0.03 ± 0.06

*p<0.05; ‡p<0.01 Mann-Whitney test, Zyoptix group versus PlanoScan group
†p<0.05 Wilcoxon test, versus the previous time point
PRK = Photorefractive keratectomy

DISCUSSION

In recent years, customized excimer laser refractive surgery, based on the correction of pre-existing HOA, has proven to be effective in reducing the postoperative increase of wavefront error compared to conventional procedures with better results in the PRK technique compared to LASIK (14-19). Mrochen et al demonstrated a decrease of HOA RMS in 22.5% of eyes and a third-order coma and fourth-order spherical aberrations reduction in 48.4% and 9.7% of eyes, respectively, after wavefront myopic LASIK (15).

McDonald observed a lower HO wavefront error in the eyes treated with custom PRK or LASIK compared to conventional treatment (12). In a previous study, we described a significant reduction of pre-existing coma aberrations and a lower increment of spherical and trefoil aberrations after

WASCA wavefront-guided PRK compared to conventional PRK. The lower increase of wavefront error was particularly evident for higher preoperative values (17). In myopic eyes treated with Zyoptix wavefront-guided LASIK, a decrement of HO wavefront error compared to preoperative values with reduction of scotopic visual complaints was observed (16, 24-26). To our knowledge this is the first comparative study evaluating wavefront error and visual performance between Zyoptix wavefront-guided PRK and conventional myopic PRK.

A variable range of increment of total and single HOA RMS has been reported by several authors after Zyoptix wavefront-guided ablations. A direct correlation between our results and data from the literature is limited by several factors: range of attempted correction, ablation technique (LASIK or PRK), optical zone, and wavefront diameter of analysis.

Kim et al found a 1.79 increment of wavefront error after wavefront-guided LASIK with Zyoptix system at 3 months (24).

Kohnen et al demonstrated, after 1 year, a 1.52 increase of total HOA after Zyoptix wavefront-guided LASIK compared to preoperative values with no change or reduction of HOA RMS only in 20.6% of patients for 6 mm diameter of analysis (25).

In our study the postoperative value of HOA RMS in the Zyoptix wavefront-guided PRK was increased by a factor of 1.18 for 6 mm of analysis and 22.2% of patients showed no change or reduction of HOA RMS.

The lower increment of HOA RMS of our patients compared to that reported by other authors can be partly due to the lower preoperative refractive error because of a higher increment of wavefront error with higher attempted corrections (10). Moreover, LASIK technique leads to a greater induction of HOA than PRK because of flap creation.

Third, the increase of HOA RMS values after surgery is mainly related to relationship between optical zone and pupil size. Spherical aberration increases when pupil dilates beyond the ablation zone; on the contrary, when the pupil is smaller, HOA and, particularly, spherical aberration show low values.

A significant increment of spherical-like aberration for patients with an ablation diameter ranging between 6.0 and 6.5 mm was only observed for 7.0 mm pupil diameter analysis and not for pupil diameter smaller than 5 mm (5). Martinez et al noticed a 19-fold increase of spherical-like aberration in eyes with a 5 mm ablation diameter for a 7 mm pupil diameter of analysis but not for a 3 mm pupil diameter (3).

Kohnen et al found a 4.11 and 4.31 increase for spherical aberration at 3.5 and 6 mm, respectively, of wavefront diameter of analysis with an optical zone (OZ) ranging between 5.6 and 8.5 mm (25).

In our study the wavefront diameter of analysis was lower (6 mm) than the mean OZ diameter and than the lowest OZ diameter (6.62 mm; range 6.5–6.8) and spherical aberration showed only a 1.16 increment.

This means that by increasing wavefront diameter of analysis, a higher increment of high order aberrations could have been found.

Nevertheless, when comparing the two groups at 6 months, the Zyoptix PRK showed a lower increase of total HOA RMS (1.18 times) compared to the PlanoScan group (1.54 times) but the difference between the two groups was not statistically significant. In particular the Zyoptix PRK group showed a lower increase of total HOA without Z_4^0 RMS (1.17 times) and of spherical aberration (1.16 times) compared to the PlanoScan group (1.52 times and 2.6 times, respectively).

The lower HOA RMS in the study group compared to the control group can be related to two factors. A lower ablation depth (49.74 µm) was observed in the Zyoptix group compared to the PlanoScan group (60.79 µm), probably related to a tissue saving effect of the wavefront-guided ablation software. A correlation between attempted correction and HOA increment has been demonstrated. This is probably due to the fact that the larger the amount of tissue removal, the larger the increment of HOA.

Therefore, the lower value of aberrations in the Zyoptix patients could in part be explained by the lower ablation depth in this group although the difference of AD between the two groups was not statistically significant.

Moreover the Zyoptix group showed a significant reduction of horizontal coma aberration compared to the control group and this was probably related to the ablation profile calculated from wavefront measurement, since in the preoperative cornea the wavefront error was mainly constituted by coma-like aberrations. Coma-like aberrations have been shown to constitute approximately 60% and 70% of total wavefront error for a 3 mm and 7 mm, respectively, pupil diameter of analysis (3, 5). In our patients the preoperative coma-like aberrations were the 80% of total high order aberrations for a 6 mm pupil.

Postoperative increase of spherical aberration was lower in the Zyoptix group compared to the PlanoScan group thus confirming that this treatment influences the amount of surgically induced spherical aberration.

When considering the changes of total high order aberrations according to preoperative HOA RMS values, we noticed that eyes with a HOA RMS lower than 0.3 μm showed a 35% and a 30% of increment of HOA RMS in the study group and control group, respectively, while for preoperative RMS higher than 0.3 μm an 8% decrement of this value in the Zyoptix group and a 34% increment in the control group was observed.

These results confirm the effectiveness of the wavefront-guided treatment for the correction of preoperative aberrations, particularly when high values of HOA are present. It is possible to conjecture that an equal tissue ablation over an irregular shaped cornea because of elevated amount of HOA reproduces at the level of the superficial-mid stroma an irregular profile that could enhance an abnormal wound healing process and a HOA increment; thus correcting preoperative wavefront error could lead to a more regular surface with consequent more physiologic cicatrization process.

Moreover, wavefront-guided ablation partially influences spherical aberration induction as demonstrated by our results.

Recently, aspheric patterns of ablation have been developed to obtain postoperative corneas with more physiologic profiles and a reduced increment of spherical aberration (27, 28).

Clinical studies comparing wavefront and aspheric profile of ablations should be undertaken in order to establish efficacy and future indications of these treatments.

Several authors analyzed the correlation between visual acuity and high order aberrations (3, 5).

The efficacy of wavefront-guided PRK or LASIK in ameliorating visual performance has been evaluated in some studies although contrasting results have been achieved. Nuijts et al did not find a significant variation of BCVA after wavefront-guided LASIK compared to conventional LASIK, while a higher percentage of patients had a 20/20 UCVA after standard LASIK than after Zyoptix LASIK procedure (18).

Cosar et al observed lower halos and difficulties in night driving in patients treated with wavefront-guided LASIK (26).

In our study no correlation was found between BCVA and HOA in the two groups. Nevertheless, we did not evaluate low contrast VA and contrast sensitivity, which are more sensitive methods for indicating possible differences in visual performance.

In conclusion, Zyoptix wavefront-guided PRK was as safe and efficacious for the correction of myopia and myopic astigmatism as PlanoScan PRK. Moreover, this technique induced a smaller increase of postoperative wavefront errors compared to standard PRK by correcting preoperative coma-like high order aberrations. The use of this technique is particularly indicated in eyes with higher preoperative RMS values.

The authors do not have any proprietary interest in the material described in this article.

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