Wavefront- Versus Topography-guided Customized Ablations With the NIDEK EC-5000 CX II in Surface Ablation Treatment: Refractive and Aberrometric Outcomes

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ABSTRACT

PURPOSE: To compare the long-term refractive outcomes and changes in higher order wavefront aberrations in patients undergoing photorefractive keratectomy (PRK) with topography-guided (CATz) or wavefront-guided (OPDCAT) ablation algorithm using the NIDEK Advanced Vision Excimer Laser System (NAVEX).

METHODS: A retrospective 12-month follow-up study was conducted of 226 eyes undergoing PRK. The NIDEK EC-5000 CX II excimer laser and Final Fit 1.11 treatment planning software were used. Sixty-eight eyes underwent OPDCAT ablation and 158 eyes underwent CATz ablation. Mean preoperative manifest refractive spherical equivalent (MRSE) was \(5.73 \pm 2.03\) diopters (D) (range: \(-11.25\ to \(-2.50\) D) in the OPDCAT group and \(3.77 \pm 3.78\) D (range: \(-12.50\ to \(-5.75\) D) in the CATz group.

RESULTS: At 12 months postoperatively, mean MRSE was 0.05 D for the OPDCAT group and plano for the CATz group. Stability was similar in both groups as were visual outcomes. No eyes lost 2 or more lines of BSCVA at 6 months postoperatively or later. Mean ocular wavefront higher order aberrations at 3 months postoperatively were \(0.44 \pm 0.17\) µm for the OPDCAT group and \(0.55 \pm 0.27\) µm for the CATz group.

CONCLUSIONS: Refractive outcomes were equivalent between eyes that underwent PRK with wavefront-guided ablation and those that underwent topography-guided ablation. [J Refract Surg. 2007;23:S1029-S1036.]

The normal corneal shape is aspheric with the center steeper than the periphery, thus minimizing the amount of spherical aberration. After conventional excimer laser ablation, the peripheral curvature becomes steeper compared with the center, causing spherical aberration to increase as well as symptoms such as glare and halos. This is due to the fact that laser ablation is calibrated on flat surfaces and does not take into account that the cornea is a curved convex surface on which the effect of laser energy is reduced due to the progressive oblique angle of incidence as the ablation is applied peripherally. Aspheric prolate ablations account for this loss of laser energy thereby reducing the total amount of spherical aberration by bringing light rays closer to a point focus on the retina.

To address the undercorrection of the peripheral cornea, laser manufacturers have started to incorporate radial compensation functions in the ablation profiles.

Custom ablation refers to the treatment of lower and higher order aberrations of the eye based on total ocular wavefront or corneal measurements. Some excimer laser manufacturers include ablation algorithms that allow a treatment based on total ocular wavefront, corneal wavefront, and corneal elevation data. The various options enable the surgeon to treat primary and secondary cases, taking into account whether the problem is due to the ocular wavefront or is of corneal origin, or a combination of both.

For primary cases, the selection of the appropriate ablation algorithm can be somewhat confusing. The ideal goal of custom ablation should be to achieve an aspheric corneal
profile and reduce preoperative astigmatism until it is no longer detectable on corneal topography or wavefront aberrometry. If these two conditions are fulfilled, a corneal front surface is created that is relatively insensitive to decenterations and pupil diameter, hence reducing the chances of scotopic symptoms.

The NIDEK Advanced Vision Excimer Laser platform (NAVEX; NIDEK Co Ltd, Gamagori, Japan) includes radial compensation in the following ablation algorithms: Customized Aspheric Treatment Zone (CATz), which is corneal topography-based ablation with an aspheric transition zone coupled with multipoint ablation to reduce corneal irregularities based on corneal elevation data; and OPD-guided Customized Aspheric Treatment (OPDCAT), which maintains corneal asphericity using an aspheric ablation over the central and peripheral cornea coupled with multipoint ablation based on the whole eye wavefront profile (Table 1).

To date, only two studies have compared the outcomes of OPDCAT and CATz.7,8 In this study, the outcomes of OPDCAT and CATz for the treatment of primary photorefractive keratectomy (PRK) were compared.

**PATIENTS AND METHODS**

A retrospective study was conducted using chart review of 226 eyes that underwent myopic PRK with OPDCAT treatment (OPDCAT group) or CATz treatment (CATz group).

Sixty-eight eyes (41 [60%] women and 27 [40%] men) underwent PRK using an OPDCAT ablation. Mean patient age was 34 years (range: 21 to 51 years). In this group, 33 right eyes (48%) and 35 left eyes (52%) were treated. Mean preoperative manifest refraction spherical equivalent (MRSE) was $-5.73\pm0.23$ diopters (D) (range: $-11.25$ to $-2.50$ D). Mean preoperative sphere was $-5.40\pm0.21$ D (range: $-11.00$ to $-2.25$ D), and mean preoperative cylinder was $-0.66\pm0.59$ D (range: $-2.50$ to $0.00$ D).

In the CATz group, 158 eyes (85 women [54%] and 73 men [46%]) underwent CATz ablation. Mean patient age was 37 years (range: 20 to 69 years). In this group, 80 right eyes (51%) and 78 left eyes (49%) were treated. Preoperative MRSE was $-3.77\pm3.78$ D (range: $-12.50$ to $-0.75$ D). Mean preoperative sphere was $-3.29\pm3.72$ D (range: $-12.00$ to $0.00$ D), and mean preoperative cylinder was $-0.95\pm1.09$ D (range: $-5.50$ to $0.00$ D).

Preoperative examination included general and ophthalmic medical history, uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), manifest refraction (“pushing plus” method), cycloplegic refraction, pupillometry, endothelial microscopy, slit-lamp microscopy, tear film testing using the Schirmer I/II “break-up time” test, Pascal Dynamic Contour tonometry (Ziemer Ophthalmic Systems AG, Port, Switzerland), corneal topography with CSO (CSO, Florence, Italy), pachymetry using the Pentacam (Oculus Inc, Dutenhofen, Germany), and a dilated retina examination. All patients underwent NIDEK OPD-Scan aberrometry (NIDEK Co Ltd). All patients signed an informed consent.

All patients received oral supplements containing amino acids starting 1 week after surgery until reepithelialization was complete.9

Exclusion criteria were active systemic or ocular diseases, tear film defects, topographic and aberrometric features suspicious of form fruste keratoconus, history of corneal or intraocular surgery, women who were pregnant or breastfeeding, and unstable refraction defined as $>0.50$-D change in the previous 12 months.

**SELECTION CRITERIA FOR CATz VS OPDCAT TREATMENT**

Pop and Bains7 recommended that the selection of CATz over OPDCAT treatment incorporate the preoperative corneal thickness because tissue removal with CATz can be 2% to 15% greater.

**SURGICAL PROCEDURE**

After topical anesthesia including two applications of drops, the eye undergoing surgery was draped and the ocular surface was washed with topical aminoglycoside and rinsed with balanced salt solution. A lid speculum was inserted. Photorefractive keratectomy was performed with the NIDEK EC-5000 CX II excimer laser (NIDEK Co Ltd) by the same surgeon (P.V.). The epithelium was removed using the laser prior to the refractive ablation. After the refractive ablation, phototherapeutic keratectomy smoothing was performed to remove corneal microirregularities smaller than the spot size (0.89 mm) and to the height of ablation (0.25 µm) to achieve a regular stromal bed, as similar as possible to the physiological Bowman’s layer. Smoothing was performed by applying a hyaluronic acid masking fluid (Laservis; Chemedica, Munich, Germany), which was continuously distributed over the corneal surface with a spatula (AE 2821; ASICO, Westmont, Ill) to avoid the formation of dry areas.10 The diameter for the smoothing ablation was 10 mm. To avoid overheating the tissue, frequency was set at 10 Hz and the ablation at 30 µm. Because of the surface tension created by the distribution of the masking fluid over the cornea, only corneal peaks and irregularities are ablated, and the remaining corneal surface is left unaffected.

After completing the smoothing, a protective contact lens was placed in position, and topical amino-
glycoside and a topical antibiotic-steroid combination were administered before removal of the lid speculum and discharge of the patient.

All patients underwent a complete ophthalmologic examination at 1 day, 1 week, and 1, 3, 6, 12, and 18 months postoperatively. At 1-day and 1-week follow-up, UCVA was measured and a slit lamp examination was conducted. From 1 month postoperatively onwards, patients underwent the same examinations as preoperatively with the exception of cycloplegic examination, ultrasound pachymetry, and a dilated retinal examination unless warranted.

Wavefront measurements for both groups pre- and postoperatively were performed for a 6-mm pupil diameter to the 8th Zernike order.

Refractive data were managed with Datagraph Med software (Datagraph, Wendelstein, Germany), and statistical evaluation was performed using the Student t test. A P value <.05 was considered statistically significant.

**CUSTOMIZED ASPHERIC TREATMENT ZONE**

CATz treatment uses an aspheric transition zone coupled with the treatment of corneal irregularity based on corneal elevation data. The optical zone can be changed in 0.10-mm increments from 3 to 6.5 mm and the transition zone can be changed in 0.10-mm increments to a maximum diameter of 10 mm. In all cases, the transition zone was at least 1.00 mm larger than the optical zone that was programmed into the laser. In this study, the maximum optical zone programmed into the laser was 4.00 mm and maximum transition zone was 10.00 mm. The optical zone and transition zone programmed into the laser for the treatment of ocular higher order wavefront were based on the magnitude of ocular wavefront yet were always the same diameter or smaller than the transition zone of the lower order wavefront corrections.

In both platforms it is possible to select or exclude any single order or component of the Zernike pyramid up to the 8th order and to simulate the postoperative shape of the cornea in the form of a target map and a topographic or wavefront map showing how the entry data influence the postoperative topography, the wavefront, and amount of tissue removed. In this study, topography and wavefront maps were simulated.

CATz is mainly a topography-based irregularity treatment; in retreatments, where ablation strategies are difficult to formulate (ie, the laser requests input for sphere and cylinder, values that are not sufficient to solve the problem) it is essential to predetermine a given curvature and diameter in the center of the cornea.

**FINAL FIT TREATMENT SIMULATIONS**

Prior to CATz or OPDCAT treatment, data and maps acquired from the OPD-Scan were examined by an experienced surgeon to ensure adequate pupil coverage of at least 6 mm and absence of measurement artifacts. Information on surface and total aberrometry generated in photopic, scotopic, and mesopic conditions by the NIDEK OPD aberrometer, refractometer, topographer and pupillometer, was integrated through Final Fit ablation planning soft-
ware (NIDEK Co Ltd) to provide a complete optimization of the corneal profile, and the amount of corneal ablation necessary to achieve a smooth corneal surface was evaluated.

Parameters such as optical zone, transition zone, laser profile, and amount of irregularity treatment were entered to determine an adequate postoperative simulation map. A satisfactory simulated corneal topography target map was one that created an aspheric cornea, minimized the dioptric gradient across the cornea, and maximally reduced preoperative astigmatism yet maintained adequate residual corneal tissue and reduced or eliminated the corneal irregularities in the CATz group and ocular wavefront in the OPDCAT group.

Once the treatment parameters were finalized, a simulation of postoperative corneal topography was generated and the shot data were exported to the CX II excimer laser equipped with a 200-Hz infrared eye tracker and a cyclotorsion error detection module. All treatments in OPDCAT were simulated by reducing aberrations to the 8th Zernike order and in some cases, single Zernike components or orders were excluded to obtain adequate simulations.

In all cases, the manifest refraction data were used to simulate the treatment. Profiles #5 to #7 were used for all cases based on the criteria cited above. All treatments were targeted for emmetropia with sphere and cylinder input values based on a nomogram adjusted to preoperative manifest refraction.

**CASE EXAMPLE SIMULATIONS**

Custom ablation of the higher order aberrations or corneal irregularities can unmask the genuine cylinder power and axis in some cases. The preoperative astigmatism can be a combination of higher order aberrations. In all simulations, close attention was paid to the origin of astigmatism and to determining whether cylinder was unmasked and to fully correct it.

**CASE 1—UNMASKING THE GENUINE CYLINDER AND AXIS**

A patient presented for an assessment for refractive surgery. Preoperative ophthalmic evaluation was unremarkable with the exception of a superior corneal irregularity seen on corneal topography of the right eye that was giving rise to coma aberration (Fig 1A). Preoperative manifest refraction was $-6.25 -0.25 \times 1^\circ$ with BSCVA of 20/20. Final Fit simulation was performed to fully treat the refractive error and the corneal irregularity. The simulated corneal topography map indicated the presence of 1.90 D of cylinder due to unmasked corneal cylinder, which would have to be treated to achieve emmetropia (Fig 1B).

**CASE 2—HIGHER ORDER ABERRATION CAUSING ASTIGMATISM**

An eye with mild preoperative corneal astigmatism was simulated to treat 10.9 µm of trefoil. Treatment of the high order wavefront eliminated the corneal astigmatism and maintained an aspheric corneal shape on simulation, indicating the astigmatism was likely due to higher order aberrations (Fig 2).

**RESULTS**

Pre- and postoperative MRSE over time is presented in Table 2. One year after surgery the MRSE was $0\pm0.05$ D in the OPDCAT group and $-0.05\pm0.99$ D in the CATz group. No eyes required retreatment. Stability was similar in both groups (Fig 3, Table 2).

Refractive outcomes for both groups over time are plotted in Figure 4. Efficacy, with percentage of UCVA calculated in logMAR units, is shown for both groups in Figure 5. Best spectacle-corrected visual acuity over time is plotted in Figure 6.

Safety of the procedure, assessed by lines of BSCVA, is presented in Figure 7; no eyes lost 2 or more lines of BSCVA at 6 months or later postoperatively.

The mean ocular wavefront higher order aberrations at 3 months postoperatively was $0.44\pm0.17$ µm for the
OPDCAT group and 0.55 ± 0.27 µm for the CATz group. The mean postoperative values for positive and negative spherical aberration are shown in Figure 8.

**DISCUSSION**

In this study of two different aspheric ablation algorithms available on the NAVEX platform, the refractive outcomes were found to be similar; however, the mean induced spherical aberration was lower in the OPDCAT group compared to the CATz group.

The refractive outcomes reported in this study are similar to those previously reported for OPDCAT and CATz. Pop and Bains, treating a lower mean MRSE than the current study, reported mean MRSE of −0.17 D for CATz and −0.31 D for OPDCAT 1 month postoperatively, whereas this study showed a mean MRSE of −0.21 D for CATz and −0.11 D for OPDCAT at the same time point (see Fig 3).

Kermani et al reported 90% of CATz-treated eyes and 78% of OPDCAT-treated eyes were within 0.50 D of the intended MRSE, which is similar to 92% for OPDCAT and 81% for CATz obtained in the current study.

Aspheric ablations account for the loss of ablation energy in the peripheral cornea. Compensation for the loss in energy with increasing angle of incidence decreases induced spherical aberration, creating a larger effective optical zone and the potential for better visual quality compared to conventional spherical ablations. A recent comparison of aspheric algorithms compared to conventional ablation using NAVEX reported larger effective optical zones and better visual quality using an aspheric algorithm.

However, the question remains whether corneal-based ablation or ocular wavefront-based ablation...
Figure 3. Stability curves for eyes that underwent A) optimized path difference custom aspheric treatments (OPDCAT) or B) customized aspheric treatment zone (CATz) ablation using the NIDEK Advanced Vision Excimer Laser platform.

Figure 4. Refractive outcomes for eyes that underwent A) optimized path difference custom aspheric treatment (OPDCAT) or B) customized aspheric treatment zone (CATz) ablation using the NIDEK Advanced Vision Excimer Laser platform.

Figure 5. Efficacy of eyes that underwent A) optimized path difference custom aspheric treatment (OPDCAT) or B) customized aspheric treatment zone (CATz) ablation using the NIDEK Advanced Vision Excimer Laser platform.
presents a better option for primary treatments. There are two fundamental differences between OPDCAT and CATz. First, OPDCAT delivers an aspheric ablation to both the programmed optical and transition zones, and second, OPDCAT treats the ocular higher order aberrations whereas CATz treats corneal front surface irregularities. Based on the current study, little difference was found between CATz and OPDCAT. The OPDCAT group had lower postoperative higher order aberration and spherical aberration.

Our observations differ from a contralateral eye study conducted by Pop and Bains who reported better visual outcomes and less induction of aberrations using CATz compared to OPDCAT. Pop and Bains attribute the difference to the use of Zernike polynomials in the OPDCAT algorithm, which smoothes raw data making the treatment less predictable. One explanation of the difference from the current study may be that the study by Pop and Bains was conducted with an earlier version of the excimer laser and Final Fit software that may have used different ablation algorithms and treatment parameters. Using a different excimer laser platform, Koller et al. found aspheric and ocular wavefront-guided treatments were equivalent in refractive and optical outcomes, similar to our results.

Both aspheric ablation algorithms require meticulous treatment planning to account for any unmasked astigmatism and to determine the source of astigmatism. For example, it must be ensured that higher order aberrations are not the source of the astigmatism (see Fig 2). If such factors remain unaccounted for, the result can be pseudodecentration, residual astigmatism or refractive error, and the induction of higher order aberrations, all of which can degrade visual acuity. Final Fit software allows the surgeon to simulate the postoperative topography or wavefront maps to...
determine whether residual astigmatism remains and further treatment is warranted. By simulating the effect of treatment on both corneal topography and wavefront, the trial and error learning curve is significantly reduced.

To deliver the planned treatment onto the cornea, we believe compensation for cyclotorsion is fundamental. An axis error of 3° can cause a diminution in visual quality. Cyclotorsion can cause an undercorrection of astigmatism and a change in axis postoperatively.1 Cyclotorsion of negative cylinder can induce positive spherical error whereas positive cylinder can induce negative sphere. Higher order aberrations are much more sensitive to axis errors. For example, a 5° rotation results in the induction of 0.10 µm of higher order aberrations and a 10° rotation can result in an approximate 50% loss of modulation transfer function.14

Although both algorithms were found to be equivalent, subjectively we prefer to use OPDCAT treatments for primary cases and CATz for secondary treatments. The advantages of the OPDCAT ablation include the ability to treat any aberration or combination of aberrations that include internal aberrations and there is less tissue consumption for the same refractive error compared to CATz. In retreatment cases where treatment planning is more involved and a variety of parameters need to be modified in Final Fit to determine a given corneal curvature and diameter centrally, CATz presents the better option.

REFERENCES

Figure 8. Spherical aberration 3 months postoperatively of eyes that underwent optimixed path difference custom aspheric treatment (OPDCAT) or customized aspheric treatment zone (CATz) ablation using the NIDEK Advanced Vision Excimer Laser platform. The numbers 12, 24, and 40 denote the Zernike coefficient.