ABSTRACT

PURPOSE: To assess the efficacy, predictability, and safety of LASIK for the surgical correction of low to moderate myopia with astigmatism using the SCHWIND AMARIS excimer laser.

METHODS: Six international study sites enrolled 358 eyes with a manifest refraction spherical equivalent (MRSE) from −0.50 to −7.38 diopters (D) (mean sphere: −3.13±1.58 D) with up to −5.00 D of astigmatism (mean: −0.69±0.67 D). All eyes underwent treatment with the nonwavefront-guided aspheric algorithm of the SCHWIND AMARIS excimer laser. All eyes were targeted for emmetropia. Refractive outcomes and corneal higher order aberrations were analyzed pre- and postoperatively. Visual quality was assessed using photopic and mesopic contrast sensitivity. Six-month postoperative outcomes are reported.

RESULTS: At 6 months postoperative, the MRSE for all eyes was −0.21±0.20 D, and 96% (343/358) of eyes had MRSE within ±0.50 D. Uncorrected visual acuity was 20/20 or better in 98% (351/358) of eyes, and no eyes lost 2 or more lines of best spectacle-corrected visual acuity. The total corneal higher order aberrations root-mean-square increased by 0.09 µm, spherical aberration increased by 0.08 µm, and coma increased by 0.04 µm postoperatively. Photopic and mesopic contrast sensitivity did not change 6 months postoperatively.


Wavefront, aspheric, and conventional LASIK for the treatment of myopia and myopic astigmatism is safe and effective.1,2 Recent advances in excimer laser technology, such as the use of aspheric ablation profiles, incorporation of higher order aberration treatment, and eye trackers, have presumably led to better refractive outcomes and reduced higher order aberration induction postoperatively.3,4 Although most laser manufacturers incorporate the suite of products mentioned above,1 the use of high repetition rates (500 Hz or higher) to reduce treatment times has not been widely adopted. This is likely due to technological constraints and the increased thermal effect concomitant with the use of higher repetition rates.5,6 If left unaddressed, the thermal effect can cause tissue damage5,6 and potentially reduce refractive outcomes.7 The reduction of treatment times may be beneficial for the following reasons: 1) shorter treatment times may result in less stromal dehydration, and 2) patients are less likely to lose fixation during the ablation.8,9

The SCHWIND AMARIS (SCHWIND eye-tech-solutions GmbH & Co KG, Kleinostheim, Germany) is a commercially available flying spot excimer laser that utilizes a 500-Hz repetition rate with an aspheric ablation algorithm for refractive treatments. One ablation algorithm, the “Aberration-Free™” algorithm, available in this platform, aims at maintaining the preoperative levels of higher order aberrations.10

Reasonable reductions in higher order aberrations after wavefront-guided treatments on aberrated eyes and reason-
able changes in higher order aberrations after wavefront-optimized treatments have been reported.\textsuperscript{11,12} However, ocular wavefront-guided and conventional treatments can increase higher order aberrations by 100% postoperatively.\textsuperscript{3} A significant number of refractive surgery patients may not benefit from ocular wavefront-guided treatment as the induction of higher order aberrations is related to baseline levels of higher order aberrations.\textsuperscript{3,13} For example, higher order aberrations tend to be induced in patients with $<0.30 \mu m$ and reduced in patients with $>0.30 \mu m$ of higher order aberrations.\textsuperscript{3,13} Physiologic optical aberrations may be required to maintain the optical quality of the eye.\textsuperscript{14,15} Based on these studies\textsuperscript{3,13-15} it seems that customized ablation algorithms in any form (ocular wavefront-guided, corneal wavefront-guided, topography-guided, etc) may not be appropriate for the entire refractive surgery population (ie, specific population groups have specific demands and deserve specific treatment solutions). No one-size-fits-all concept can be applied.

Our definition of “customization” is conceptually different and can be stated as: “The planning of the most optimum ablation pattern specifically for each individual eye is based on its diagnosis and visual demands.” It is often the case that the best approach for planning an ablation is a sophisticated pattern, which can still be simply described in terms of sphere, cylinder, and orientation (axis).

The present study evaluated the safety, predictability, efficacy, aberrations, and contrast sensitivity of LASIK to correct low to moderate myopia with astigmatism using the aspheric algorithm of the SCHWIND AMARIS excimer laser.

**PATIENTS AND METHODS**

**PATIENT POPULATION AND EXAMINATIONS**

Six investigative sites were involved in this prospective, international multicenter study of the treatment of myopia with astigmatism using the SCHWIND AMARIS excimer laser. The first three AMARIS laser machines fabricated by SCHWIND were used in this study and moved between the investigative sites to perform the treatments. This study followed the tenets of the Declaration of Helsinki.

Three hundred fifty-eight eyes of 179 patients undergoing bilateral LASIK for myopia with astigmatism were enrolled. Mean patient age was 28±7 years (range: 18 to 60 years). All patients included in the study were aged ≥18 years and had a manifest refraction spherical equivalent (MRSE) ranging from $-0.50 \text{D}$ to $-7.38 \text{diopters}$ (D) with up to $-5.00 \text{D}$ of astigmatism. Patients were enrolled in the study if they had best spectacle-corrected visual acuity (BSCVA) of 20/40 or better using the Early Treatment of Diabetic Retinopathy Study (ETDRS) chart, stable refraction for 1 year prior to the study, and discontinued contact lens wear for at least 1 week to 4 weeks (depending on contact lens type) prior to the preoperative evaluation. Patients were required to have normal keratometry and topography with $<0.50 \text{equivalent defocus}$\textsuperscript{16} of corneal wavefront aberration in root-mean-square (RMS) analyzed at a 6-mm analysis diameter or the maximum possible analysis diameter minus 0.5 mm for each topography if it was smaller than 6 mm measured with the SCHWIND Corneal Wavefront Analyzer (SCHWIND eye-tech-solutions GmbH & Co KG). For comparative analyses, all aberrations were analyzed for a 6-mm diameter.

For our analysis, the concept of equivalent defocus has been used as a metric to minimize the differences in the Zernike coefficients due to different pupil sizes. Equivalent defocus is “the amount of defocus required to produce the same wavefront variance as found in one or more high order aberrations.”\textsuperscript{16} A simple formula computes equivalent defocus in diopters from the wavefront variance in the Zernike modes in question:

$$M_e = 16\sqrt[3]{RMS \over PD^2}$$  \hspace{1cm} (1)

where $M_e$ is the equivalent defocus in diopters, RMS is the wavefront variance in the Zernike modes in question, and PD is the diameter considered for the wavefront aberration analysis.

On virgin eyes, equivalent defocus as proposed by Thibos et al\textsuperscript{16} seems to be relatively insensitive to different analysis diameters.\textsuperscript{17} Patients who suffered from an acute illness or who had a calculated postoperative corneal bed thickness $<250 \text{µm}$ after ablation, preoperative central corneal thickness $<475 \text{µm}$, previous ocular surgery, or abnormal corneal topography were excluded from the study.

Baseline examinations included measurement of uncorrected visual acuity (UCVA), BSCVA, MRSE, contrast sensitivity, corneal topography, corneal wavefront, ultrasound corneal pachymetry, pupillometry, slit-lamp examination of the anterior segment, and a dilated fundus examination. Pre- and postoperative refraction were based on obtaining patient subjective manifest refraction under photopic conditions and crosschecked with the objective refraction analyzed at 4 mm measured by the SCHWIND Ocular Wavefront Analyzer (SCHWIND eye-tech-solutions GmbH & Co KG).\textsuperscript{18}
For crosschecking refraction with ocular wavefront, patients were asked to see-through-the-target (forcing a disaccommodated state) instead of focusing-at-the-target (which is, however, fogged with +1.50 D) when performing aberrometry. Ocular wavefront was analyzed for a 4-mm diameter, and the Zernike refraction based on second order parabolic terms was recorded as the objective refraction value. This objective refraction value (rounded to a quarter of a diopter for sphere and cylinder, and to 5° for the astigmatism axis) was used as the initial refraction to be tested at the phoropter.

Pre- and postoperative contrast sensitivity using the CST 1800 D (Vision Sciences Research Corp, San Ramon, Calif) was measured at 3, 6, 12, and 18 cycles per degree (cpd) after correcting the refractive error with spectacles. Photopic contrast sensitivity measurement was done with illumination of 85 cd/m² without any glare and mesopic contrast sensitivity with an illumination of 6 cd/m² with 35 lux glare. Log values of the contrast sensitivity scores were used for statistical analysis.

At 1 day postoperatively, UCVA was measured and the patient underwent slit-lamp examination of the anterior segment. The same measurements as the baseline examination (with the exception of dilated fundoscopy and pupillometry unless warranted and contrast sensitivity at 6 months only) were performed at 1 week and 1, 3, and 6 months postoperatively.

TREATMENT PLAN

All aspheric treatments were planned using the SCHWIND CAM (Customized Ablation Manager, SCHWIND eye-tech-solutions GmbH & Co KG) treatment planning software. The SCHWIND CAM software integrates aspheric ablation profiles that compensate for the peripheral loss of energy due to an increased angle of incidence on the cornea and for biomechanical changes induced during LASIK. The treatment of ocular or corneal wavefront aberrations was not intended in this study.

The sphere and cylinder values entered into the laser were based on the manifest refraction without nomogram adjustment. Further, the flat and steep keratometry readings at 3-mm diameter as measured by the topographer were used for the compensation of the loss of ablation efficiency when the laser hits the cornea in non-normal incidence. All eyes underwent the refractive treatment using 6.00- to 7.00-mm diameter optical zones based on the preoperative scotopic pupil diameter. For each treatment, the SCHWIND CAM calculated the size of the optimal transition zone, depending on the preoperative refraction and optical zone. The total ablation zone ranged from 6.90 to 8.51 mm. All eyes were targeted for emmetropia.

Maintenance of the preoperative corneal higher order aberrations required a change in the corneal curvature postoperatively based on proprietary ablation algorithms considering astigmatic condition, spot overlapping, tissue removal, and tissue remodeling, which are calculated by the SCHWIND CAM. Retreatments were not permitted during the course of this study. Once finalized, the treatment plan was directly entered or transferred via secure digital memory card to the SCHWIND AMARIS excimer laser.

SURGERY

Eyes undergoing surgery were prepared as customary for each center. One or two drops of topical anesthetic were instilled and a sterile drape was used to isolate the surgical field. A lid speculum was inserted to allow maximum exposure of the globe. Two additional drops of topical anesthetic were instilled in the upper and lower fornices. Flaps with a superior hinge were made using the Carriazo-Pendular microkeratome (SCHWIND eye-tech-solutions GmbH & Co KG) using 110- or 130-µm heads (336 eyes) and flaps with a nasal hinge were made using the Amadeus (Ziemer Ophthalmic Systems, Port, Switzerland) using 120-µm heads (22 eyes).

Proper alignment of the eye with the laser was achieved with a 1050-Hz infrared eye tracker with simultaneous limbus, pupil, and torsion20 tracking integrated into the laser system and centered on the pupil. The eye tracker had an average response time of 2.9 milliseconds. The flap was lifted and the excimer laser ablation was delivered to the stroma. Patients were requested to fixate on a fixation light throughout the ablation. The flap was repositioned and the interface was irrigated with balanced salt solution, removing any debris. Patients received topical fluoroquinolone antibiotic, corticosteroid drops four times per day for 5 days, and ocular lubricants as needed.

EXCIKER LASER

The laser ablation algorithm used a flying spot laser delivery system that operates at 500 Hz with a super-Gaussian beam profile (Fig 1) of 0.54 mm Full Width Half Maximum. Depending on the planned refractive correction, approximately 80% of the corneal ablation is performed with a high fluence level (>400 mJ/cm²), thus decreasing treatment times. Fine correction is performed for the remaining ~20% of the treatment using a low fluence level (<200 mJ/cm²), which reduces the ablation volume per pulse delivered to smooth out the ablated area. Spot placement is randomized to prevent heat buildup between laser pulses. Additionally, an aspiration system with laminar flow dynamics is incorporated to reduce debris and heat buildup.
DATA ANALYSIS

Refractive outcomes, changes in higher order aberrations, and contrast sensitivity were analyzed using Microsoft Excel software (Microsoft Corp, Redmond, Wash) and Datagraph (Datagraph-Med GmbH, Wendelstein, Germany) refractive outcomes analysis software. LogMAR visual acuity was converted to Snellen acuity for data reporting purposes only. The paired single-sided t test and unpaired t test were used to determine statistically significant changes in corneal wavefront aberrations and contrast sensitivity, respectively. A P value <.05 was considered statistically significant. Data for 1 day, 1 week, and 1, 3, and 6 months after LASIK are reported.

RESULTS

PREOPERATIVE

Mean preoperative MRSE was −3.47±1.56 D (range: −0.50 to −7.38 D), mean sphere was −3.13±1.58 D (range: −7.25 to 0.00 D), and mean cylinder was −0.69±0.67 D (range: −5.00 to 0.00 D).

All 358 eyes underwent corneal wavefront measurements; however, only 223 eyes showed a topographical map free of artifacts in the central 6.5-mm region. Thus, a reliable corneal wavefront map of 6-mm analysis diameter was only obtained in these 223 eyes.

POSTOPERATIVE

Predictability and Refractive Stability. The attempted versus achieved MRSE for all eyes is plotted in Figure 2. At 6 months postoperatively, the mean MRSE for the entire study population was −0.21±0.20 D (range: −0.88 to +0.50 D). Mean postoperative sphere was −0.12±0.20 D (range: −0.75 to +1.00 D) and mean postoperative cylinder was −0.17±0.21 D (range: −1.25 to 0.00 D) at 6 months. For the entire cohort, 73% (261/358) of eyes had MRSE within ±0.25 D (Fig 3). Refractive stability postoperatively was evaluated by assessing the mean rate of change in MRSE over time (0.04 D/month). The mean MRSE did not change from 1 week to 1 month postoperatively (Fig 4). The mean rate of change in MRSE between 1 week and 3 months was −0.02 D/month, and the rate of change between 3 and 6 months was −0.01 D/month (see Fig 4).

Mean residual astigmatism magnitude did not change significantly from 1 to 6 months postoperatively. Figure 5 plots the change in astigmatism 6 months postoperatively.

Visual Acuity. Six months after surgery, 98% (351/358) of eyes had UCVA of 20/20 or better and
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65% (233/358) had UCVA of 20/16 or better (Fig 6). At 6 months postoperatively, there was a higher percentage of eyes with better UCVA than preoperative BSCVA at the 20/20 or better level of acuity (Fig 7). Clinically significant loss of BSCVA is considered a loss of 2 or more Snellen lines. Six months after surgery, no eye lost 2 or more lines of BSCVA (Fig 8). Best spectacle-corrected visual acuity increased by 2 or more lines in 8.4% (30/358) of eyes 6 months after surgery (see Fig 8).

Figure 2. Scattergram of attempted versus achieved manifest refraction spherical equivalent (SEQ) of 358 eyes 6 months after LASIK for myopia and myopic astigmatism using the SCHWIND AMARIS excimer laser.

Figure 3. Refractive outcome within attempted correction (D).

This discrepancy means that higher order aberrations may not have been measured in the same eyes pre- and postoperatively.

To ensure inductions of corneal wavefront aberrations were not masked due to the differences in the number of eyes preoperatively (223 eyes) and 6 months postoperatively (259 eyes), all eyes with corresponding preoperative and 6-month postoperative corneal wavefront were analyzed (162 eyes) (Fig 9). Mean change in total corneal higher order aberrations increased by 0.09 μm 6 months postoperatively ($P<.01$). The mean change in coma 0.04 μm ($P=.02$) and spherical aberration 0.08 μm ($P<.01$) was also statistically significant (see Fig 9).

Figure 10 plots the change in the attempted spherical equivalent correction compared to the change in various corneal higher order aberrations for all eyes that completed preoperative and 6-month postoperative corneal wavefront measurements. A statistically significant increase was noted in spheral aberration, coma, and total higher order aberrations as the attempted spherical equivalent correction increased (Fig 10). The change in BSCVA compared to the change in various corneal higher order aberrations is shown in Figure 11.

In addition, predictability, refractive stability, visual acuity, and safety analyses did not show different results when analyzed for the complete sample of treatments (358 eyes) compared with the analysis restricted for the group with corresponding preoperative and 6-month postoperative corneal wavefront (162 eyes).

Contrast Sensitivity. Six months postoperatively, no statistically significant change was noted in photopic or mesopic contrast sensitivity ($P>.05$) (Fig 12).

Complications. Intraoperatively, in one eye, a par-
tial flap was created; however, the surgeon elected to continue the treatment including laser ablation. Two eyes of two patients developed grade 1 diffuse lamellar keratitis (DLK) at day 1 postoperatively. Both eyes were treated with topical steroids and antibiotics four times daily on a tapering schedule over 1 month. The DLK resolved by 1 month postoperatively without adversely affecting BSCVA.

**DISCUSSION**

The present investigation of LASIK using the SCHWIND AMARIS excimer laser with a 500-Hz repetition rate found this laser platform to be safe and predictable and to provide stable results for the treatment of low to moderate myopia with up to $-5.00$ D of astigmatism. For example, 73% of eyes were within $\pm0.25$ D of intended correction (see Fig 3). Safety was demonstrated with no eyes losing more than one line of BSCVA 6 months after surgery (see Fig 7). Stability was achieved quickly, with a mean rate of change of $<0.02$ D/month from 1 week to 3 months postoperatively (see Fig 4).

Compared to other studies using nonwavefront-guided profiles, we found less amounts of induced higher order aberrations in our sample.

Kohnen et al. measured induced corneal higher order aberrations after conventional treatments. Using a 6-mm analysis diameter, they found an increase of $0.09$ µm for coma, $+0.13$ µm for spherical aberration, and $0.17$ µm RMS for higher order aberrations. Lombardo et al. in a study analyzing corneal wavefront for a 6-mm diameter after conventional PRK, reported an increase of $0.08$ µm and $0.11$ µm for coma and spherical aberration, respectively, for low myopic corrections, and an increase of $0.14$ µm and $0.37$ µm for coma and spherical aberration, respectively, for high myopic corrections. After conventional LASIK, de Ortueta et al. found an increase of $0.10$ µm for coma, $+0.17$ µm for spherical aberration, and $0.20$ µm RMS for higher order aberrations for a 6-mm diameter.

Marcos et al. found that ocular and corneal aberrations increased statistically significantly after myopic LASIK surgery by a factor of 1.92 (ocular) and 3.72 (corneal), on average. They found a good correlation ($P<0.0001$) between the aberrations induced in the entire optical system and those induced in the anterior corneal surface. However, anterior corneal aberrations increased more than ocular aberrations, suggesting changes in the posterior corneal surface as well.

Lee et al. found that after laser refractive surgery, anterior corneal aberration and ocular aberration increased equally and showed statistically significant correlations. They found no statistically significant differences of internal optics aberration values in coma, spherical aberration, and RMS for higher order aberrations.

Arbelaez et al. found that when comparing corneal...
and ocular aberrations, the amount of induced aberrations was similar for spherical aberration and coma. For the RMS for higher order aberrations, corneal induced aberrations were moderately higher, although not statistically significant, than ocular induced aberrations.

In our study of 716 analyzed topographies, 482 (67%) showed a 6.5-mm diameter disk available for corneal wavefront analyses. The reason why not all topographies showed reliable corneal wavefront aberrations of at least 6-mm diameter is attributable to the fact that we do not allow the videokeratoscope to extrapolate corneal topography to areas with no real data, which are affected by potential artifacts (eg, shadows from eyelashes, etc), during the measurements. Such artifacts may be due to disruption of the tear film, interference of the eyelashes or eyelids within the corneal area, or difficult recognition of the pupil contour (especially in dark colored eyes). Finally, 223 preoperative topographies (62%) and 259 postoperative topographies (72%) provided reliable corneal wavefront aberration information of at least 6 mm in size. This discrepancy means that corneal aberrations may not have been analyzed in the same eyes pre- and postoperatively. To ensure inductions of corneal wavefront aberrations were not masked due to the differences in the number of eyes preoperatively (223 eyes) and 6 months postoperatively (259 eyes), only eyes with corresponding...
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reliable preoperative and 6-month postoperative corneal wavefront (162 eyes) were reported in the analysis (see Fig 9).

Compared with other studies of ocular wavefront-guided LASIK treatment for myopia with astigmatism that found wavefront-guided LASIK to be safe and effective,2,4 the outcomes of the present study are better. Previous studies of myopic corneal wavefront-guided treatments using the ESIRIS laser (SCHWIND eye-tech-solutions GmbH & Co KG) with smaller sample sizes and lower preoperative astigmatism than our study found that there was no clinically significant loss of BSCVA.2,26 In the present study, Figure 2 demonstrates little scatter, indicating excellent accuracy despite the lack of nomogram refinement. Perhaps the incorporation of center-specific nomograms would further refine accuracy.

The outcomes of the present study confirm that aspheric LASIK with a 500-Hz excimer laser is clinically viable for the treatment of primary myopia and astigmatism. The efficacy reflects the predictability and accuracy reported herein. For example, within 6 months after surgery, 98% of eyes had UCVA of 20/20 or better without correction (see Fig 7). Six months postoperatively, UCVA exceeded preoperative BSCVA in more than 46% of eyes at the 20/16 or better levels. Best spectacle-corrected visual acuity was preserved in 99.4% (356/358) of eyes (see Fig 8). A contralateral eye study comparing aspheric and wavefront-guided treatments using the WaveLight laser (WaveLight AG, Erlangen, Germany) reported BSCVA was preserved in 83% of eyes.27

A prospective, randomized comparison of the WaveLight and CustomCornea (Alcon Laboratories Inc, Ft Worth, Tex) platforms reported 80% of eyes achieved UCVA of 20/20.28 A study by Binder and Rosenshein3 comparing three wavefront platforms found approximately 5% of eyes that underwent sphero-cylindrical treatments gained clinically significant BSCVA, which is less than our result of 8.5%.3 Comparing the outcomes in the present study with the aforementioned studies indicates the outcomes with the SCHWIND AMARIS are equivalent to or exceed those reported for wavefront-guided treatments and aspheric treatments despite treating higher levels of preoperative astigmatism. In our study, 0.5% (two eyes) lost one line of BSCVA. Because one line is the day-to-day variability in measuring visual acuity, clinically relevant loss of visual acuity is reported for two or more lines. Moreover, the two eyes losing one line of BSCVA were eyes with preoperative super vision (20/16) that resulted in normal vision (20/20) postoperatively.

On a more conceptual basis, our study population is relatively young, with a mean age of 28 years, so most of the patients can accommodate, thus, a hyperopic...
overcorrection of +0.50 D would still produce excellent UCVA despite a non-plano outcome. However, because the pre- and postoperative determined subjective manifest refraction of the patient was crosschecked with the objective refraction analyzed at 4 mm, the influence of accommodation is minimal.

Our study used an aspheric ablation algorithm independent of wavefront customization that aimed to maintain the preoperative levels of higher order aberrations (Aberration-Free™ algorithm). McLellan et al reported a beneficial effect on visual quality due to pre-existing higher order aberrations. Evidence of neural adaption to the baseline wavefront profile exists. The interaction between higher order aberrations can be beneficial to visual quality regardless of the magnitude of higher order aberrations. To date, the induction of wavefront aberrations postoperatively is random and the wavefront profile postoperatively cannot be predicted. Based on the random nature of higher order aberration induction and current research, it may be beneficial to maintain the preoperative wavefront profile for a significant number of refractive surgery candidates.

Using aspheric treatments, we found mild increases in corneal higher order aberration RMS (see Fig 9) and a statistically significant increase in spherical aberration and coma based on attempted correction (see Fig 10). Ocular wavefront measurements were only used to crosscheck manifest refraction measurements, and not for assessing higher order aberration at this time, which is why the higher order aberrations are reported in terms of induced corneal wavefront. Most studies report results in terms of induced or postoperative ocular aberrations, hence direct comparisons to the induced corneal aberrations in our study are not possible. Because we used the ocular wavefront measurement to objectively assess the refraction, we did not pay special care to pupil dilation beyond 6.00 mm or at least 5.50 mm. In addition, illumination conditions provided for ocular wavefront were not identical in the six centers, therefore, different maximum analysis diameters were available across the sample. Comparing different pupil sizes is not the standard method for comparison, and comparison of aberrations in diameters <5.50 mm has low clinical relevance. However, other studies in which direct comparison of induced aberrations in terms of corneal wavefront and ocular wavefront over the same sample was studied, showed that the induction of anterior corneal aberrations was always, at least, as high as the induction of ocular wavefront aberrations for the entire eye.

The increase in spherical aberration can be partially explained by the biomechanical response and corneal epithelial remodeling. The mild induction of higher order aberrations, spherical aberration, and coma may explain the maintenance of visual quality postoperatively found in the current study. For example, at 6 months postoperatively, there was negligible change in photopic and mesopic contrast sensitivity. This outcome may indicate that the induction of higher order aberrations reported here may require less neural adaption (if any at all). Although not statistically significant, a trend in Figure 10 indicated the lower the change in spherical aberration, the greater the increase in visual acuity postoperatively. However, the results of our study show no significant improvement of contrast sensitivity but improved postoperative visual outcomes. However, a separate study specifically designed to address neural adaption with nonwavefront-guided aspheric treatments is warranted to address this topic.

Based on the results presented, we are not postulating that customized ablation algorithms in any form (ocular wavefront-guided, corneal wavefront-guided, topography-guided, etc) are not useful. Rather, specific populations with specific demands deserve specific treatment solutions. Aspheric treatments aiming for preservation of the preoperative higher order aberrations show their strengths in patients with preoperative BSCVA of 20/20 or better, or in patients in whom the visual degradation cannot be attributed to the presence of clinically relevant higher order aberrations.

The use of a 500-Hz repetition rate did not create any postoperative complications. Thermal effects due
to excimer laser ablation and associated plume debris have been reported previously.\textsuperscript{5,6,33,34} One study reported better refractive outcomes after cooling the cornea prior to the ablation, which likely reduced the thermal buildup.\textsuperscript{7} The use of a particle aspirator coupled with random placement of the laser spots in this study seems to efficiently speed up the treatment without increasing the thermal load in the cornea.

The 6-month results presented in this study indicate that Aberration-Free\textsuperscript{TM} treatment of myopia with and without astigmatism using the SCHWIND AMARIS excimer laser is safe, provides excellent refractive and visual acuity results, and maintains preoperative contrast sensitivity.

**AUTHOR CONTRIBUTIONS**

Study concept and design (F.C.); data collection (M.C.A., I.A., C.B., A.F., T.N., P.R.); analysis and interpretation of data (F.C.); drafting of the manuscript (M.C.A.); critical revision of the manuscript (M.C.A., I.A., C.B., A.F., T.N., P.R.); administrative, technical, or material support (M.C.A., I.A., C.B., A.F., T.N., P.R.)

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