Wavefront-optimized Versus Wavefront-guided LASIK for Myopic Astigmatism With the ALLEGRETTO WAVE: Three-month Results of a Prospective FDA Trial

Karl G. Stonecipher, MD; Guy M. Kezirian, MD, FACS

ABSTRACT

PURPOSE: To compare visual outcomes using the WaveLight ALLEGRETTO WAVE to administer either wavefront-optimized (standard LASIK) or wavefront-guided (custom LASIK) treatments in myopic eyes.

METHODS: In this prospective, open-label, multicenter study conducted in the United States, 374 eyes were randomized by alternating enrollment to receive either wavefront-optimized or wavefront-guided LASIK treatments with this laser platform. Bilateral treatments were administered, with both eyes of each patient receiving the same treatment. Corneal flaps were created using the IntraLase femtosecond laser.

RESULTS: In this FDA clinical trial, results at 3 months postoperatively revealed that 93% of eyes in both cohorts receiving either wavefront-optimized or wavefront-guided treatments attained an uncorrected visual acuity (UCVA) of 20/20 or better. Seventy-six percent of eyes with the wavefront-optimized treatment and 64% of eyes with the wavefront-guided treatment achieved UCVA of 20/16 or better. None of the eyes that received either treatment lost two lines or more of best spectacle-corrected visual acuity (BSCVA). In addition, 58% of eyes with wavefront-optimized treatment and 62% of eyes with wavefront-guided treatment gained one line or more of BSCVA. None of the eyes in either treatment group underwent retreatment.

CONCLUSIONS: In the majority of eyes, no statistically significant differences were found between either treatment group in regard to visual acuity and refractive outcomes. Wavefront-guided treatments are not required in most cases with this laser, but may be considered if the magnitude of preoperative root-mean-square (RMS) higher order aberrations is >0.35 μm. In this study population, 83% of eyes had preoperative RMS higher order aberrations of <0.3 μm. [J Refract Surg, 2008;24: S424-S430.]

The study presented is a follow-up US Food and Drug Administration (FDA) comparative trial of standard or wavefront-optimized treatments versus wavefront-guided treatments with the WaveLight ALLEGRETTO WAVE Excimer Laser System (WaveLight AG, Erlangen, Germany). The initial FDA trial was approved in October 2003 for the reduction or elimination of myopia of up to 12.00 diopters (D) of sphere and up to −6.00 D of astigmatism at the spectacle plane in patients aged 18 years or older. The ALLEGRETTO WAVE features multiple programming modules including a wavefront-optimized or standard treatment and a wavefront-guided platform. The wavefront-optimized module is used for standard refractive treatments based on the prescription and preoperative conditions of the presenting patient. With the wavefront-guided module, the wavefront-guided treatment is completely reliant on wavefront examination data obtained using the WaveLight Allegro Wavefront Analyzer. This study compared wavefront-optimized versus wavefront-guided treatments with the WaveLight ALLEGRETTO WAVE excimer laser system for use in LASIK treatments for the reduction or elimination of up to −7.00 diopters (D) of spherical equivalent myopia or myopia with astigmatism, with up to −7.00 D of spherical component and up to 3.00 D of astigmatic component at the spectacle plane in patients aged 18 years or older, and in patients with documentation of a stable manifest refraction defined as

From The Laser Center, Greensboro, NC (Stonecipher); and SurgiVision® Consultants Inc, Scottsdale, Ariz (Kezirian).

Dr Stonecipher is a Global Ambassador/Consultant to WaveLight and is an Investigator in the FDA clinical trials for the ALLEGRETTO laser. Dr Kezirian is owner of SurgiVision® Consultants Inc, sponsor of the IDE study for the ALLEGRETTO WAVE Excimer Laser System referenced in this article.

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Correspondence: Karl G. Stonecipher, MD, 3312 Battleground Ave, Greensboro, NC 27410. Tel: 336.288.8823; Fax: 336.288.8493; E-mail: stonenc@aol.com
<0.50 D of preoperative spherical equivalent shift over 1 year prior to surgery.2

In the FDA clinical trial investigating the safety and effectiveness of wavefront-guided LASIK with the STAR S4 Excimer Laser System with variable spot scanning and WaveScan System (VISX Inc, Santa Clara, Calif).3 351 eyes were treated with wavefront-guided LASIK. This clinical trial in support of premarket approval reported that, for all treated eyes at 3 months postoperative (318 eyes), 88.4% of patients had an uncorrected visual acuity (UCVA) of 20/20 or better. Manifest refraction spherical equivalent (MRSE) was within ±0.50 D of the intended correction in 87.1% of patients, and 97.2% had an MRSE within ±1.00 D of the intended correction. One (0.3%) patient lost two or more lines of best spectacle-corrected visual acuity (BSCVA) at the 3-month interval. The study reported that “the average higher order aberration did not decrease after CustomVue treatment.”

In the FDA clinical trial assessing the safety and effectiveness of LASIK treatments with the Technolas 217z Zyoptix System (Bausch & Lomb, San Dimas, Calif).4 340 eyes were evaluated with the wavefront-guided ablation. In this study, postoperative UCVA of 20/20 or better was reported in ≥90% of eyes from the point of stability (3 months) forward. Approximately 70% of eyes had UCVA of 20/16 or better. For all treated eyes at 3 months, 76% of patients had an MRSE within ±0.50 D of the intended correction and 93.8% had an MRSE within ±1.00 D of the intended correction. At the 3-month interval, 1.2% of patients lost two or more lines of BSCVA.

This FDA clinical trial in support of premarket approval assessed the safety and effectiveness of the wavefront-optimized as compared to the wavefront-guided myopic LASIK treatment with the ALLEGRETTO WAVE. The clinical trial was designed to directly compare these two treatment approaches. The null hypothesis discussed in the study protocol was that both cohorts will perform similarly for vision and refractive outcomes; however, eyes with preoperative higher order aberrations root-mean-square (RMS) >0.2 should have better postoperative higher order aberration results in the wavefront-guided LASIK cohort. In addition, postoperative higher order aberrations will correlate with low contrast visual acuity, contrast sensitivity, and patient subjective complaints.

PATIENTS AND METHODS

The WaveLight ALLEGRETTO WAVE excimer laser system is a scanning spot excimer laser system, which includes an excimer laser with high pulse repetition rate (200 Hz), beam delivery optics, and a pair of galvonometer scanners for positioning the laser pulses. The integrated 200 Hz eye-tracker permits the system to track fast eye movements or to interrupt the treatment when the eye moves out of a predetermined range. An infrared high speed camera images the eye with a capture rate of 200 Hz. Each image is processed to determine the current position and size of the pupil. Pupil position information is then used to actively align mirrors for correct placement of the next laser pulse on the eye. The whole process takes <10 milliseconds. The specially shaped profile of the ablation area (6.5-mm optical zone with 9.0-mm ablation zone) and the small spot diameter (0.95±0.1 mm) provide the accuracy to achieve the desired contour of the treated surface. The ablation contours are based on sophisticated numerical algorithms. The small spot diameter allows for a lower pulse energy with fluence on average of 200 mJ/cm² and 400 mJ/cm² peak.

This study was a prospective, open-label, seven-investigator clinical trial conducted at 5 study sites in the United States. A total of 187 patients including 374 eyes were treated. The eyes studied included 188 in the study cohort and 186 in the control cohort between September 14, 2004 and September 7, 2005. All follow-up received by SurgiVision® Consultants Inc (Scottsdale, Ariz) prior to December 8, 2005, was included in the Pre-Market Approval (PMA) supplement.

Three hundred seventy-four eyes with myopic spherical equivalent refraction ranging up to −7.00 D and up to 3.00 D of cylinder were randomized to receive either a wavefront-optimized or wavefront-guided LASIK treatment with the WaveLight ALLEGRETTO WAVE excimer laser system. In this study, the wavefront-optimized cohort was considered the control group and the wavefront-guided cohort was considered the study group. The study or wavefront-guided cohort underwent bilateral LASIK treatments based on aberrometry measurements. The control or wavefront-optimized cohort underwent bilateral LASIK treatments based on clinical refractions without regard to measured aberrometry. Appropriate institutional review boards approved the project and informed consent was obtained from the patients after the nature of the procedure had been fully disclosed.

Because bilateral treatments were administered, with both eyes of each patient receiving the same treatment, patients were assigned to one of the two study cohorts based on alternating enrollment. All corneal flaps were created with the use of the IntraLase femtosecond laser (IntraLase Corp, Irvine, Calif) and optical treatment zones were matched to 6.5 mm for the LASIK ablation. Flap diameter varied between 9.0 and 9.5 mm based on surgeon discretion. Flap thickness varied between 100 and 130 µm based on surgeon discretion.
RESULTS

The alternating enrollment process resulted in comparable cohorts for all preoperative features including demographics, refractive errors, and preoperative wavefront characteristics. In the study cohort, more males than females were treated with 55.3% (104/188) of the cases being male and 44.7% (84/188) being female. Overall, 93.6% (176/188) of eyes treated were in Caucasians, 3.2% (6/188) in Blacks, 2.1% (4/188) in Asians, and 1.1% (2/188) in Hispanics. The mean age of the patients treated was 33.5±7.7 years (range: 21 to 52 years). In the control cohort, more females than males were treated with 53.8% (100/186) of the cases being female and 46.2% (86/186) being male. Overall, 92.5% (172/186) of eyes treated were in Caucasians, 4.3% (8/186) in Blacks, 2.1% (4/186) in Asians, and 1.1% (2/186) in Hispanics. The mean age of the patients treated was 34.2±8.3 years (range: 19 to 58 years).

Patients were evaluated preoperatively and postoperatively at 1 day and 1, 3, 6, and 12 months. Only the data collected for the PMA at 3-month follow-up are presented herein. Preoperative objective measurements included distance and near UCVA, manifest refraction, distance BSCVA, low contrast acuity, contrast sensitivity, cycloplegic refraction, applanation tonometry, slit-lamp examination, pupil size measurement in photopic and scotopic conditions, central keratometry, computerized corneal topography, aberrometry, pachymetry, dilated fundus examination, measurement of angle kappa, and patient questionnaire.

Postoperatively, objective measurements included distance and near UCVA, manifest refraction, distance BSCVA, low contrast acuity, contrast sensitivity, cycloplegic refraction, applanation tonometry, slit-lamp examination, central keratometry, computerized corneal topography, aberrometry, dilated fundus examination, and patient questionnaire.

The patient questionnaire consisted of a subjective assessment of visual quality before and after surgery: How would you rate the quality of your vision without glasses or contact lenses? Responses ranged between “Terrible” and “Excellent.”

All patients in this study were scheduled for bilateral treatments and all patients actually underwent bilateral treatment. Patients were eligible for retreatment no sooner than 3 months after surgery; however, no patient required retreatment in this study group. Patients were eligible for retreatment if the manifest refraction spherical equivalent (MRSE) was ≥0.50 D (myopic or hyperopic), the manifest astigmatism was ≥0.50 D, the distance visual acuity was 20/30 or less, or due to any subjective complaints by the patient with treatable cause as determined by the investigator. Effectiveness was evaluated based on improvement in UCVA and predictability of the MRSE. No significant differences were found between the two cohorts for UCVA, MRSE, or BSCVA changes. Differences between the cohorts were found for aberrometry results.

With regard to patient questionnaires, there were similar results (no statistically significant differences) for rating the quality of vision without glasses or contact lenses, glare with night driving, halos at night, or light sensitivity. Both groups showed improved vision from their preoperative levels. Neither group showed apparent correlation of subjective symptoms with postoperative higher order aberrations; however, with the small sample size these findings may not be of the magnitude to reveal statistical significance.
The 3-month key effectiveness variables for this clinical trial, which include the UCVA, MRSE, and data regarding BSCVA, are presented in Figure 1. Twenty-two percent of the wavefront-optimized group and 25% of the wavefront-guided cohort attained UCVA of 20/12.5. Seventy-six percent of the wavefront-optimized group and 64% of the wavefront-guided group achieved UCVA of 20/16. An equal percentage of each group (93%) had a post-procedure UCVA of 20/20. Of those patients who had an MRSE within ±0.50 D of the intended refraction, 94% were in the wavefront-optimized group and 93% were in the wavefront-guided group. Of the patients who achieved a postoperative UCVA better than their preoperative BSCVA, 89% were in the wavefront-optimized group and 86% were in the wavefront-guided group. With the exception of the 20/16 UCVA, the differences found between the control and study groups were not significant. For the 20/16 UCVA, the wavefront-optimized group demonstrated a small advantage over the wavefront-guided group, which was statistically significant at the 5% level (P=.02).

When comparing the BSCVA gain in visual acuity, 58% of eyes with wavefront-optimized treatment and 62% of eyes with wavefront-guided treatment gained one line or more of BSCVA. The P value comparing the wavefront-optimized and wavefront-guided groups was not statistically significant at the 5% level (Fig 2). No eyes in this study lost two or more lines of BSCVA.

Contrast sensitivity and low contrast visual acuity were measured using the Vector-Vision CSV-1000 (VectorVision, Greenville, Ohio). A change of greater than 0.2 log units is generally considered an indicator of a significant change,5,6 but neither group demonstrated a change of more than 0.1 log units at 3 months postoperative in comparison to their preoperative readings. In addition, neither group experienced a mean worsening of contrast sensitivity. When the results were stratified according to postoperative RMS of
higher order aberration, no difference between the two study cohorts was observed.

With regard to the wavefront characteristics (Fig 3), 83% of eyes had ≤0.3 µm of preoperative RMS higher order aberrations and 93% of eyes had ≤0.4 µm of preoperative RMS higher order aberrations. For eyes with preoperative RMS higher order aberration errors of <0.3 µm, the results showed similar wavefront outcomes for both cohorts (Fig 4). Eyes with 0.3 to 0.4 µm of preoperative RMS higher order aberrations and a preoperative MRSE < -4.00 D resulted in a better postoperative aberration profile with wavefront-guided LASIK. Eyes with >0.4 µm of preoperative RMS higher order aberrations, which received up to ~7.00 D of treatment, also demonstrated a better postoperative aberration profile with wavefront-guided LASIK. However, in cases with >0.4 µm of preoperative RMS higher order aberration errors, higher order aberrations were also reduced in the wavefront-optimized group. The outcomes seen in the wavefront-optimized eyes were not dependent on the magnitude of preoperative refractive error. An evaluation of the induced postoperative aberrations across the spherical equivalent refraction treatment range demonstrated a minimal induction of higher order aberrations with the wavefront-optimized treatment.

In patients who achieved a postoperative visual acuity of 20/12.5, lower postoperative aberrations appeared to contribute to this better acuity (Fig 5). This effect was only seen at the 20/12.5 level and weakly at the 20/16 level with no difference found at the 20/20 level. In the two cohorts, no correlation was found between higher order aberrations and contrast sensitivity. In regards to postoperative levels of spherical aberration, the levels were not affected in the wavefront-optimized group, which would be expected by definition, and were reduced in the wavefront-guided group (Fig 6).
DISCUSSION

This study confirmed the safety and efficacy of wavefront-optimized and demonstrated the safety and efficacy of wavefront-guided treatments with the ALLEGRETTO WAVE excimer laser. The results revealed similar wavefront outcomes in both groups. In eyes with <0.3 µm of preoperative higher order aberrations, accounting for 83% of eyes, the postoperative higher order aberrations were substantially equivalent in both cohorts. Eyes with 0.3 to 0.4 µm of preoperative higher order aberrations demonstrated slightly more improvement in postoperative higher order aberrations with wavefront-guided treatments than with wavefront-optimized treatments. In cases with >0.4 µm of preoperative higher order aberrations, postoperative higher order aberrations were significantly reduced in the wavefront-guided cohort. Contrast sensitivity was preserved by both treatment methods.

Preoperative features that can help identify patients who would benefit from wavefront-guided LASIK treatments include significant preoperative RMS higher order aberrations >0.35 µm (Table). However, the wavefront-optimized eyes experienced only minimal increases in postoperative higher order aberrations.

The ALLEGRETTO WAVE maintains a more natural corneal shape by adjusting for the asphericity of the cornea based on the anterior curvature readings. The system compensates for the slope in the cornea by delivering a larger number of pulses to the periphery. In the wavefront-optimized treatment, this enhanced uniform optical zone preserves a more normal corneal shape, thereby minimizing the amount of spherical aberration induced during surgery as compared to traditional laser systems. To produce similar results, wavefront-guided treatments may be required with other lasers that do not offer the option of wavefront-optimized ablation profiles.

With the use of this laser, it should be emphasized that wavefront optimization preserves asphericity while minimizing the induction of fourth order spheri-
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cal aberration C12. In addition, wavefront-guided treatments have no advantage over wavefront-optimized treatments in patients who have preoperative RMS higher order aberrations <0.3 µm. In this study population, 83% of eyes had preoperative RMS higher order aberrations <0.3 µm, which suggests that, in the majority of cases, the wavefront-guided treatment offers little advantage over wavefront-optimized treatments with this laser. With this laser system, wavefront-guided LASIK may provide an advantage in approximately 33% of eyes and this translates to approximately 20% to 25% of eyes in the overall general population.

REFERENCES