

Clinical Photoablation With a 500-Hz Scanning Spot Excimer Laser

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ABSTRACT

PURPOSE: The aim of this study was to use a 500-Hz scanning spot laser (Concept500, WaveLight Laser Technologie AG, Erlangen, Germany) to investigate potential side effects that might be associated with the use of a high repetition rate laser platform.

METHODS: Seven eyes were treated using a 500-Hz scanning spot laser for laser in situ keratomileusis (LASIK). The local frequency of the ablation was kept below 40 Hz to avoid local heating of corneal tissue. With the exception of the high repetition rate (500 Hz), all other laser parameters such as fluence, algorithm, ablation profile, and spot diameter were identical to a standard WaveLight Allegretto laser system. Patients were examined at 1 month and 1 year after initial treatment. Preoperative and postoperative examination included manifest sphere and cylinder, uncorrected and best spectacle-corrected visual acuity (BSCVA).

RESULTS: All eyes were treated for myopia or myopic astigmatism. Five eyes received spherocylindrical and two eyes spherical ablation only. No adverse events correlated with the use of a high repetition rate laser system were observed during surgery or at any point during follow-up. All eyes maintained or had improved BSCVA at 12 months after treatment when compared to preoperative values.

CONCLUSION: The use of an excimer laser with a maximal repetition rate of 500 Hz and a local repetition rate of less than 40 Hz was free of any specific side effect that might be associated with the use of such a high repetition rate. [*J Refract Surg* 2004;20:831-834]

Customized laser surgery with scanning spot lasers allows adjustment of spheric or cylindrical aberrations, but also aberrations of higher order and in detail, irregular astigmatism. Data obtained from wavefront analysis or corneal topography may be used to establish more complex ablation profiles compared to the simple ablation profiles used in spherocylindrical corrections.¹⁻⁸

Besides precise measurement of the wavefront, the success of such a procedure depends on the way in which the ablation profile is transferred onto the cornea. Here, two additional parameters play a vital role—beam diameter and speed of treatment.

The beam diameter⁹⁻¹¹ is a key parameter to provide correction of higher order aberrations. A small diameter enables the surgeon to reshape the cornea by applying a complex ablation profile. However, the use of such a small laser spot demands fast eye tracking, accurate scanning mirrors, and highly stable excimer lasers. In addition, laser treatment should be performed within 30 to 60 seconds because the cornea might dry and the fixation ability of the patient might decrease when treatment time is too long. Therefore, smaller laser spots need higher repetition rates to avoid these effects. On the other hand, a high repetition rate might induce an increased temperature load to the tissue.

The aim of this pilot study was to investigate potential clinical side effects related to the use of a high repetition rate. Such thermal side effects could manifest as increased inflammation in the early postoperative period, opacities in the interface, and irregularities as detected in corneal topography.

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PATIENTS AND METHODS

Patients

A prospective study of LASIK with a high repetition rate laser system for myopia and astigmatism was initiated. There were seven males (three right eyes, four left eyes) who ranged in age from 30 to 40 years (mean age 35 years). Inclusion criteria were patient age >21 years, manifest refraction less than -12.00 diopters (D) in sphere and less than 4.00 D in cylinder, stable manifest refraction over the previous 2 years, the pupil of the eye treated was not deformed, the patient agreed to participate in the study, and to attend follow-up examinations for up to 1 year after surgery. Informed consent was obtained from all patients after a thorough explanation of the procedure and its potential risks. The institutional review board of the University eye clinic approved this pilot study.

Patients were excluded from the study if they had a systemic or ocular disease likely to influence corneal healing, a history of glaucoma, retinal disorders that might limit visual acuity (eg, myopic maculopathy) or complicate the LASIK procedure (eg, equatorial degenerations), previous ocular surgery, or suffered from dry eyes substantiated by a pathologic Schirmer test. One eye with amblyopia (the first eye in this pilot study) and a best spectacle-corrected visual acuity (BSCVA) of 20/30 was included in the series. Contact lens use was ceased 2 weeks before preoperative examination.

Clinical Examinations

The following examinations were performed: uncorrected (UCVA) and best spectacle-corrected (BSCVA) visual acuity (Snellen visual acuity chart), corneal topography (Topolyzer, WaveLight Laser Technologie AG, Erlangen, Germany), applanation tonometry, pachymetry, slit-lamp microscopy of the anterior segment, and contact lens ophthalmoscopy of the posterior segments. Patients were examined at 1 day, 1 month, and 12 months after surgery. At the day 1 postoperative examination only, UCVA, BSCVA, and slit-lamp microscopy were performed (data not shown). Preoperative spherical equivalent refraction ranged from -0.35 to -9.75 D, and astigmatism ranged from 0 to 3.50 D: between 0 and -0.99 D in two eyes, -3.00 to -3.99 D in two eyes, -4.00 to -4.99 D in two eyes, and -5.00 to -5.99 D in one eye; cylinder was between 0 and 1.00 D in three eyes, 1.00 to 2.00 D in three eyes, and 3.00 to 4.00 D in one eye.

Surgery

All LASIK procedures were performed between September and December 2001 under topical anesthesia (proparacaine 0.5%). First, a flap with a diameter of 9.0 mm and a thickness of approximately 130 μ m was created with a superior hinge, using a Supratome microkeratome (Schwind Eye-Tech-Solution, Kleinostheim, Germany).

Ablation

Laser treatments were performed using a 500-Hz scanning spot laser system (Concept500, WaveLight Laser Technologie AG, Erlangen, Germany). A Gaussian beam profile with truncated wings was used to reduce thermal load of the surrounding tissue by sub-threshold laser energy. The ablation diameter of a single spot at the cornea was 0.9 mm. The mean radiant exposure was 0.2 J/cm². The scanning program was adjusted to provide a local repetition rate of 40 Hz or less. The sampling rate of the video-based eye tracker was 500 Hz, thus reducing the latency between registration of the eye position and mirror alignment to approximately 4 ms. (The eye tracking frequency and the repetition rate of the laser were both 500 Hz; each treatment point on the cornea was treated at a maximum 40 times per second.) Automatic pupil detection allowed accurate centering of the treatment zone. During treatment, the patient was advised to concentrate on a fixation target mounted coaxially to the optical axis of the laser system. In all treatments, the ablation zone was 6.5 mm and the overall treatment zone was 7.2 mm in diameter. Treatment time was less than 5 seconds per diopter of myopia. After photoablation, the flap was repositioned and the interface was rinsed with balanced salt solution. A bandage lens soaked in ofloxacin 0.5% solution was applied for the first night after surgery. Fluorometholone drops 0.1% were used twice daily for 1 week.

All treatments were based on manifest refraction with a target refraction in all eyes of plano, except one eye for which the target refraction was -0.75 D. Nomogram adjustments were not applied in this study. Preoperative calibration tests of the laser system included energy measurements, laser beam profiling, ablation of test target, scanning mirror alignment check (checkerboard pattern ablation on test target), and testing of the optical alignment of the fixation light and the video eye tracker.

Clinical results were analyzed regarding safety, efficacy, and predictability after follow-up at 1 and 12 months.

Table 1
Safety After LASIK With a 500-Hz Scanning Spot Laser

Variable	Time After LASIK	
	1 mo (N=7)	12 mo (N=7)
Loss of lines of BSCVA	0	0
BSCVA worse than 20/40	1	0
BSCVA worse than 20/25 if 20/20 or better at baseline	0	0
Irregular corneal topography	0	0

RESULTS

All operations were uneventful. All corneas remained clear during and after photoablation. Slit-lamp microscopy revealed no signs of corneal opacities and/or thermal damage in the interface immediately after surgery or at any postoperative examination. On the first postoperative day, UCVA was 20/40 or better in all eyes. Follow-up examinations were performed at 1 and 12 months after surgery.

Safety was evaluated by maintenance of BSCVA. All eyes had stable or better BSCVA 12 months after surgery when compared to preoperative values (Table 1). The first eye of the cohort was amblyopic with a BSCVA of 20/40 before surgery; at 1 month after surgery, BSCVA was 20/50, and at 12 months after surgery, 20/30. No irregularities were detected in corneal topography at any examination beyond the first postoperative day.

At 12 months, all eyes achieved UCVA of 20/40 or better. Four of seven eyes had 20/20 or better, with one eye intentionally undercorrected to -0.75 D and one eye amblyopic.

At 12 months after surgery, mean spherical equivalent refraction in all eyes did not exceed ± 1.00 D (Table 2); five of seven eyes (71.4%) were within ± 0.50 D. Cylinder was reduced to less than -1.00 D in all eyes.

DISCUSSION

The purpose of this study was to investigate possible clinical side effects that might be associated with use of a high repetition rate excimer laser for laser vision correction. Our results demonstrate that the use of repetition rates as high as 500 Hz did not affect the clinical outcomes of LASIK procedures. None of the operated eyes showed an adverse reaction that could be related to the higher repetition rate of the laser.

Although ultraviolet photoablation with the ArF excimer laser is a "cold ablation," the temperature

Table 2
Efficacy After LASIK With a 500-Hz Scanning Spot Laser

Variable	Time After LASIK	
	1 mo (N=7)	12 mo (N=7)
UCVA 20/20 or better	5	4
UCVA 20/40 or better	6	7
Manifest spherical equivalent refraction ± 0.50 D	6	5
± 1.00 D	7	7

risks above 200°C within several nanoseconds.¹² Bende and coworkers found a mean in situ temperature increase in tissue surrounding the ablation area of approximately 8°C.¹³ Similar results have been published by Maldonado-Codina and colleagues¹⁴ and by Betney and colleagues.¹⁵ Excimer laser platforms usually work with a repetition rate of 10 to 50 Hz and a radiant exposure (fluence) of approximately 0.2 J/cm²; this results in an average power on the corneal surface of approximately 0.8 to 3.8 W, assuming a typical treatment zone of 6.0 to 7.0 mm in diameter. In principle, the total energy (sum of all laser spots applied) needed to remove the same amount of tissue with smaller scanning spots should be the same as when using larger spots. The energy of a single laser pulse used in our study was approximately 2 mJ at a mean radiant exposure of 0.2 mJ/cm². The scanning algorithm of the Concept500 laser takes into consideration that the local frequency should be below 40 Hz. Thus, the laser spots (0.9-mm diameter) are distributed systematically within the 6.0- to 7.0-mm-diameter treatment zone. The resulting average power distributed within the treatment zone is almost identical to the power distribution in standard laser systems. Consequently, one might not expect a significantly higher thermal load during corneal laser surgery with a high repetition rate laser system.¹⁶

Laser in situ keratomileusis is widely accepted as a safe procedure for correction of refractive errors. Remarkable improvements have been made by the introduction of customized laser ablation—superior to conventional photoablation—by including correction of higher order optical aberrations.

A recent study by Huang and Arif¹⁰ showed that, based on fundamental considerations with currently used beam diameters of 1.0 mm and less, it should be possible to eliminate most higher order optical aberrations in a normal eye. Thus, current laser technology should be adequate for corneal reshaping in the majority of cases. However, the

quality of the correction declines steadily as beam size increases.¹¹ Therefore, customized photoablation may require additional reduction in laser spot size to enable finer and more complex ablation profiles in highly aberrated eyes or in eyes with local irregularities such as central steep islands.¹⁰

In contrast, reducing the spot size for customized ablation has a distinct effect on other technical parameters, such as the eye tracking system. Bueeler and colleagues¹¹ studied the effect of various laser parameters on the optical outcome of photorefractive procedures. Numerical simulations of the entire ablation process were performed on a schematic model eye by varying ablation depth per pulse, laser spot size, eye tracker latency, and magnitude of refractive correction. They showed unambiguously that contrast transfer decreased significantly with increased latency of the eye tracker. For constant laser and tracking parameters, this decrease was more significant for higher myopic corrections. Treatments performed with smaller spot sizes and smaller ablation depths per pulse were more sensitive to tracking latency. Assuming defined eye tracker latency, the most stable results were obtained for large beam diameters and high central ablation depths per pulse. However, a tracking latency below 10 ms would allow for a reduction of the beam diameter to 0.50 mm. In our study, treatments were performed with a 500-Hz scanning spot laser with a spot size of 0.9 mm. Latency was on the order of 4 ms, ensuring an optimized balance between spot size and eye tracker performance.

In addition to its influence on the aforementioned technical parameters, reducing the spot diameter systematically increases the number of laser pulses. In brief, the number of laser pulses that must be applied for a myopic correction increases with the decrease of the square of the spot diameter. Ablation time should not exceed 60 seconds because of possible corneal drying or decrease in the patient's concentration during the treatment. A minimal ablation zone of 6.0 mm, small spot size <0.5 mm, and a limited treatment time might require a much faster scanning spot laser, superior to current commercially available systems.

In our pilot series of seven eyes, the use of the 500-Hz excimer laser did not reveal any specific clinical side effects potentially associated with the

use of a high repetition rate. New laser systems equipped with high repetition rates may facilitate customized treatments with smaller laser spots (diameter <0.9 mm) for highly aberrated eyes that cannot be treated with currently available systems.

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