Visual quality improvement in refractive surgery
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Citation for published version (APA):
STRAYLIGHT MEASUREMENTS IN LASER IN SITU KERATOMILEUSIS AND LASER-ASSISTED SUBEPITHELIAL KERATECTOMY FOR MYOPIA
PURPOSE: To compare straylight values before and 3 months after laser in situ keratomileusis (LASIK) and laser-assisted subepithelial keratectomy (LASEK) and to analyze the causes of any change.


METHODS: Straylight was measured before and after LASIK or LASEK with a C-Quant straylight meter; values were recorded as the straylight parameter log(s). Main outcome measures were the difference between postoperative and preoperative straylight values and factors causing a difference between the values.

RESULTS: The study evaluated 102 eyes having LASIK and 137 eyes having LASEK. On average, there was significant improvement in straylight values postoperatively in both groups. The mean decrease was 0.016 log(s) in the LASIK group and 0.026 log(s) in the LASEK group. Nonparametric testing (sign test) showed that the improvement in straylight was statistically significant in more than 50% of eyes in both groups. Straylight improved in 62 eyes in the LASIK group (P<.001) and 78 eyes in the LASEK group (P<.02) and deteriorated in 35 eyes and 58 eyes, respectively. There was an increase in straylight in 17 eyes (7.1%). Clinical correlations were found in some eyes that had increased postoperative straylight values.

CONCLUSION: On average, straylight values 3 months after LASIK and LASEK were slightly decreased from baseline values. Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned. Additional disclosures are found in the footnotes.

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Refractive surgery is an accepted method of correcting refractive errors such as myopia. The accepted outcome measures of excimer laser refractive surgery are uncorrected distance visual acuity (UDVA), efficacy, safety, and stability of the refraction after the procedure.\textsuperscript{1,2}

Quality of vision is difficult to define by a single parameter. Some patients are dissatisfied with the quality of vision after excimer laser refractive surgery even though their Snellen acuity is 20/20 (1.0) or better. Higher-order aberrations, image degradation, and contrast acuity have been implicated as reasons for patient dissatisfaction.\textsuperscript{3} Glare disability is another parameter that correlates with visual complaints after refractive surgery.\textsuperscript{4}

All light reaching the eye is scattered to some extent when passing through the structures of the eye. This causes a veil of light over the visual image, resulting in degraded vision. This veil of light is called straylight. Straylight defines the functional effect of scatter and is a means of objective quantification.\textsuperscript{5,6} Straylight is a functional measure of the effect of light spreading over the retina; the term is used by the Commission Internationale d’Eclairage (CIE) to define disability glare. The amount of straylight is expressed as the straylight parameter; that is, as log(s). Glare disability, which is the reduction in visual performance caused by a glare source, causes retinal contrast degradation secondary to intraocular straylight.\textsuperscript{5–7} The most common example of a glare source is an oncoming headlight, resulting in a loss of contrast that degrades vision to a degree that the patient cannot see an object (eg, a car) that is right in front of her or him.\textsuperscript{5–8}

We prospectively measured straylight preoperatively and postoperatively with a straylight meter to study the behavior of the straylight parameter in patients having myopic excimer laser surgery. Intrastromal ablations (laser in situ keratomileusis [LASIK]) and surface ablations (laser-assisted subepithelial keratectomy [LASEK]) were included. The excimer laser used in refractive surgery disrupts the normal structure of the cornea; the collagen fibers of the cornea are lined up at specific intervals so that light rays pass undisturbed through the cornea and arrive at the media of the eye.\textsuperscript{9–13} Disruption of the corneal structure can occur in LASIK because the edges of the cut stroma return to a new position of apposition. In LASEK, the corneal tissue responds to the treatment with changes in the cellular structure and fibrillar organization, which can increase straylight; this may be an additional effect in LASIK as well. In both types of treatment, keratocytes undergo ultrastructural changes that may contribute to a change in straylight.\textsuperscript{9–12,14} Based on this assumption, we expected an increase in straylight after excimer laser refractive surgery.

**PATIENTS AND METHODS**

This consecutive prospective case series comprised eyes having refractive excimer laser surgery for myopia. Enrollment in the study occurred with informed consent. The tenets of the Declaration of Helsinki were followed. Assignment to LASIK or LASEK
was performed according to the consensus of the Netherland Society for Refractive Surgery (2006) and patient preference.

All eyes had a full ophthalmologic examination preoperatively. The evaluation included UDVA, corrected distance visual acuity (CDVA), manifest and cycloplegic refractions, slitlamp examination, dilated fundoscopy, topography, noncontact pachymetry, wavefront aberrometry, tonometry, and straylight measurement. Visual acuity was tested in 3m condensed lanes using the Early Treatment Diabetic Retinopathy Study chart in metric units. The 3-month postoperative examination included UDVA, CDVA, keratometry, tonometry, biomicroscopy, and straylight measurement.

Laser in situ keratomileusis was performed using an XP 120 microkeratome and a 100z excimer laser (both Bausch & Lomb). Laser-assisted subepithelial keratectomy was performed with a 20% ethanol solution, 30-second exposure time, and the same laser equipment used in LASIK cases. In LASeK cases in which the ablation was deeper than 100 µm, mitomycin-C (MMC) 0.02% was applied for 12 seconds and then rinsed with 30 cc of a balanced salt solution; additional appropriate informed consent was obtained in these cases.

Postoperatively, LASIK patients were treated with nonpreserved hourly sodium hyaluronic acid 0.1% eyedrops and tobramycin 0.3%–dexamethasone 0.1% given 3 times a day. The combination drops were stopped after 3 days. The artificial tears were continued for at least 3 months, during which time they were tapered. In LASeK patients, the postoperative treatment consisted of a bandage contact lens for 3 days with concomitant unpreserved artificial tears, tobramycin 0.3% eyedrops 3 times a day, and oral analgesic agents as needed. After the contact lens was removed 3 days postoperatively, the antibiotic agent was changed to chloramphenicol 0.4% ointment 4 times daily for 4 additional days. Flurometholone 0.1% eyedrops were started 8 days postoperatively and taken daily until 21 days. Artificial tears were used hourly and tapered until 3 months.

Undilated straylight measurements were performed twice preoperatively and twice 3 months postoperatively using a C-Quant straylight meter (Oculus Optikgeraete GmbH). The system and its parameters have been described.13,15 The straylight meter measures forward light scatter in the eye. It provides direct information about optical imperfections causing glare disability and determines straylight values according to the internationally accepted definition by CIE.5 An expected standard deviation (ESD) was developed to control and enhance the internal reliability of the test.15 Only reliable test results with an ESD less than 0.08 log units were accepted. Each measurement was repeated to arrive at an independent measure of reliability. Measurements were performed under ambient light by the same technician with corrective refraction performed with a meticulously kept set of trial lenses according to the manufacturer’s instructions. The straylight results of the meter were recorded on a logarithmic scale as log(s).15 A difference of 0.3 in log(s) corresponds to a difference in straylight intensity of a factor of 2.

Repeatability of the measurements was tested. Although the test used in the straylight meter (compensation comparison paradigm) is designed to eliminate bias, evaluation was performed to determine whether there was a learning effect. Thus, the
first measurements were repeated and the second measurement and first measurement compared. These data also provided an independent measure of repeatability to be compared with the ESD values given by the straylight meter.

Outcome measures were straylight values and whether there was a correlation between the values and factors such as slitlamp findings, ablation depth, and the use of MMC. Patient records were reviewed to find indications for changes between preoperatively and postoperatively. Efficacy (postoperative UDVA divided by preoperative CDVA) and safety (postoperative CDVA divided by preoperative UDVA) were other outcome measures.

Statistical analysis was performed using SPSS software (version 16, SPSS, Inc.). Results were analyzed by t tests and 1-sided nonparametric sign and Mann-Whitney tests. The significance level was 5%.

RESULTS

Two hundred thirty-nine eyes of 145 patients were tested; 102 eyes had LASIK and 137 eyes, LASEK. The mean age of the patients was 38.6 years (range 20 to 60 years). The mean preoperative spherical equivalent (SE) was -3.11 diopters (D) (range -0.75 to -7.00 D) in the LASIK group and -3.88 D (range -0.75 to -9.50 D) in the LASEK group. Mitomycin-C was used in 31 eyes in the LASEK group. These eyes had a mean preoperative SE refraction of -5.70 D (range -1.62 to -9.50 D).

Table 1 shows the postoperative outcomes in all eyes and by group. One eye (1%) in the LASIK group and 5 eyes (3.6%) in the LASEK group lost 2 or more lines of CDVA from the preoperative value.

Figure 1 shows the preoperative versus postoperative straylight values in the LASIK group. The mean decrease was 0.016 log(s) + 0.172 (SD), which was not statistically significant (P<.05, paired t test). Twelve eyes had an increase in straylight of more than 0.2 log units. A clinical correlation (microstriae in the LASIK flap in 5 eyes and interface debris in 2 eyes) was found in 7 eyes. In the remaining 5 eyes, the cornea did not show changes on biomicroscopy. The straylight was decreased by more than 0.2 log units in 11 eyes the LASIK group, all of which had a normal biomicroscopic examination.

Table 1: Postoperative outcomes.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean UCVA (Snellen)</th>
<th>Efficacy</th>
<th>Safety</th>
<th>Within ±0.50 D* (%)</th>
<th>SE Refraction (D) Mean</th>
<th>± SD Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cases</td>
<td>1.23 (20/15)</td>
<td>1.16</td>
<td>1.19</td>
<td>96.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LASIK</td>
<td>1.18 (20/16)</td>
<td>1.13</td>
<td>1.18</td>
<td>95.1</td>
<td>+0.17 ± 0.27</td>
<td>-0.50 to +1.50</td>
</tr>
<tr>
<td>LASEK</td>
<td>1.25 (20/15)</td>
<td>1.18</td>
<td>1.20</td>
<td>97.8</td>
<td>+0.03 ± 0.22</td>
<td>-0.50 to +1.00</td>
</tr>
<tr>
<td>LASEK + MMC</td>
<td>1.15 (20/17)</td>
<td>1.16</td>
<td>1.12</td>
<td>-</td>
<td>-0.01 ± 0.49</td>
<td>-0.75 to +1.25</td>
</tr>
</tbody>
</table>

LASEK = laser-assisted subepithelial keratectomy; LASIK = laser in situ keratomileusis; MMC = mitomycin-C; UDVA = uncorrected visual acuity
One patient in the LASIK group had grade II diffuse lamellar keratitis (DLK); however, the patient had a complete recovery and a low postoperative log(s) value. Preoperatively, mean log(s) straylight value was 1.02 log(s) in the right eye and 1.16 log(s) in the left eye. The postoperative values were to 0.85 log(s) and 0.86 log(s), respectively.

Figure 2 shows the preoperative versus postoperative straylight values in the LASEK group. The mean decrease of 0.026 ± 0.141 log(s) was statistically significant (P<.02, paired t test). Five eyes had an increase in straylight of more than 0.2 log units. In 4 eyes, trace haze was noted in the charts postoperatively. One eye had a scar from a postoperative corneal foreign-body injury that occurred 6 days postoperatively. In the 14 eyes with a decrease in straylight of more than 0.2 log(s), slitlamp examination did show abnormalities.

Figure 3 shows the preoperative versus postoperative straylight values in the 31 LASEK eyes treated with MMC. The mean decrease was 0.056 ± 0.164 log(s), which was significantly greater than in the LASEK group as a whole (P<.05, paired t test).

Compared with values in a normal population, the baseline measurement in the LASIK and LASEK eyes was increased by a mean of 0.06 log(s) (P<.001). Evaluation of postoperative results versus preoperative results showed that this increase did not influence the comparative results.
The repeatability evaluation showed a mean difference between the first and second straylight measurement of 0.009 ± 0.079 log(s) preoperatively and 0.007 ± 0.078 log(s) postoperatively (Figure 4). Neither difference was statistically significant; thus, there was no learning effect.

Figures 1 to 3 suggest that the distribution of the postoperative and preoperative differences between measurements did not conform to a normal Gaussian distribution. Thus, nonparametric testing was performed and showed that the straylight value was statically significantly better in more than 50% of eyes in both groups. The straylight value improved in 62 eyes in the LASIK group (P<.001) and in 78 eyes in the LASEK group (P<.02) and decreased in 35 eyes and 58 eyes, respectively.

Figure 5 and Figure 6 show straylight changes as a function of ablation depth in the LASIK group and LASEK group, respectively. Ablation depth correlated positively with a decrease in straylight in groups. However, the correlations were not statistically significant. In the LASEK group, comparison of eyes with MMC and eyes without MMC with and without ablation depth as covariate showed no significant differences.

**DISCUSSION**

Excimer laser refractive surgery is an accepted method of treating refractive errors. In general, postoperative UDVA, predictability, and safety results have been good. However, postoperative quality of vision remains a subject of ongoing discussion, and its parameters are not standardized. Different tests yield different results and are usually performed under nonstandardized conditions. The straylight meter used in the present study is reported to give reliable and repeatable measurements of forward scatter in the eye. This scatter is a measure of glare disability, which is becoming an important parameter of quality of vision not only in refractive surgery but also in other situations (eg, night driving, cataract surgery, contact lens wear).

In our study, we surprisingly found that on average, straylight (ie, glare disability) was reduced after LASIK and LASEK. Nonparametric testing showed that the decrease was statistically significant in more than 50% of cases. The finding is even more striking
The repeatability evaluation showed a mean difference between the first and second measurements in LASIK and LASEK for Myopia straylight measurement of 0.009 ± 0.079 log(s) preoperatively and 0.007 ± 0.078 log(s) postoperatively (Figure 4). Neither difference was statistically significant; thus, there was no learning effect.

Figures 1 to 3 suggest that the distribution of the postoperative and preoperative differences did not conform to a normal Gaussian distribution. Thus, nonparametric testing was performed and showed that the straylight value was statistically reduced after LASIK and LASEK. Nonparametric testing showed that the decrease was not significant. In the LASEK group, comparison of eyes with MMC and eyes without MMC with and without ablation showed no significant differences.

Ablation depth correlated positively with a decrease in straylight values and ablation depth in the LASIK and LASEK groups. However, the correlations were not statistically significant. In the LASEK group, a significant decrease occurred in 62 eyes (P<.001) and in 78 eyes (P<.02) in the LASIK group.


delta log straylight parameter
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6

max ablation depth (μm)

0 20 40 60 80 100 120 140 160 180 200

Figure 5. Relationship between straylight values and ablation depth in the LASIK group (r = -0.093, not significant).

Figure 6. Relationship between straylight values and ablation depth in the LASEK group (r = -0.085, not significant).

In a 1996 study, Schallhorn et al. evaluated 30 eyes that had photorefractive keratectomy (PRK) but no change in straylight, a finding the authors found surprising. Other studies in the 1990s found no increase in straylight after laser refractive surgery in general; as in our study, increased straylight values were found on an individual basis. In a study of PRK and LASIK, Beerthuizen et al. found that there was generally no significant change in straylight values 1 month postoperatively; however, several patients with increased straylight measurements had microstriae, interface debris, or haze. We also found a clinical correlation between increased straylight measurements and flap-related issues and haze. On the other hand, Beerthuizen et al. found increased straylight values in cases without clinical signs or symptoms to explain the increase; this also occurred in our study. Results in a study by Vignal et al. suggest that this can occur. Although they found no definite effect of straylight on clinical parameters, they found a correlation between postoperative glare complaints and increased straylight measurements. Vignal et al. also found that patients with improved contrast sensitivity had no increase in straylight values. Furthermore, patients with no visual complaints had lower straylight values than patients with night-vision complaints. We did not correlate straylight measurements with patient complaints. At our clinic, patients complete a voluntary questionnaire 3 months after surgery; however, the questionnaire does not include glare symptoms. We did not specifically evaluate night-vision disturbances preoperatively or postoperatively; therefore, we cannot correlate straylight outcomes...
with patient-reported clinical symptoms (ie, whether patients were aware of changes in straylight).

In some cases of increased straylight, we saw a physical finding on biomicroscopy (eg, microstriae of the flap, haze, interface debris) that might explain the increase.

Microstriae can reduce contrast sensitivity\(^{20}\) and have been implicated in the increase in straylight after LASIK.\(^{19}\) A 1995 study of PRK by Veraart et al.\(^{12}\) found increased straylight values after reepithelialization in the early postoperative period; the straylight measurements slowly return to baseline within months except in cases of severe haze. There are several reports of haze as a cause for increased straylight values,\(^{12,19}\) and we found this to be true in several cases. The use of MMC reduces the incidence of severe haze and results in lower straylight values because straylight is a parameter of corneal clarity, and it may correlate well with cellular responses to MMC.\(^{11}\)

Other factors that might increase straylight measurements were excluded in our study. The trial lenses we used were kept meticulously clean according to the operator's manual. Pachymetry and tonometry were performed with noncontact instruments; thus, direct physical contact and disturbance of the corneal epithelium are excluded causes of the relatively increased preoperative straylight values compared with those in the normal population.

Studies of backscatter\(^{9,10}\) report increased light scattering from the cornea after laser refractive surgery. However, backscatter is not equivalent to forward scatter as measured by the straylight meter we used. Backscatter correlates well with haze. In LASIK, backscatter is related to the edges of the LASIK flap. Backscatter is significantly lower in LASIK than in LASEK.\(^{9,10}\) Increased straylight after radial keratotomy has been reported,\(^{21}\) which is not surprising because the technique intentionally induces corneal scarring to reshape the prolate cornea.

The reason for our finding of a potential decrease in straylight as a result of laser refractive surgery is puzzling. First, measurements were taken 3 months postoperatively; it is generally accepted that by this time, healing is almost complete and refraction has stabilized.

We expected an increase in straylight as a result of disruption of the fibers and cells of the cornea.\(^{9-11}\) One consideration is whether the preoperative straylight values in our patients were relatively high. Most patients were wearing contact lenses up to a few days before preoperative testing. Contact lens wear can cause increased straylight measurements, even after the lenses have not been worn for a while (I.J.E. van der Meulen, personal communication, December 2008). Thus, the history of contact lens wear may be why our patients had a 0.06 log(s) increase over values in the normal population.

Another consideration is that the reduction in straylight reflects an effect in the cornea itself. In the young normal eye, a substantial part of straylight originates from the cornea.\(^{6}\) Perhaps removing part of the cornea decreases its influence as a source of straylight. We studied the relationship between straylight and ablation depth. Roughly one third of ocular straylight can be attributed to corneal sources. If a maximum of 20% of the cornea were ablated, the total contribution to straylight decrease would be
STRAYLIGHT IN MYOPIC LASIK AND LASEK

on the order of one fifteenth of the total ocular straylight. On a logarithmic scale, this amounts to 0.03 log units. Although this is a small number, it may be significant (mean value 0.016 in LASIK group and 0.026 in LASEK group). On an individual basis, such a change is hard to detect. We also found that deeper ablations were correlated with a greater decrease in straylight values in both groups. Although the finding was not statistically significant, it may indicate that ablation depth is the most important factor in reducing straylight. The use of MMC may mitigate the effect of ablation depth on straylight reduction because of the tissue response it evokes.

Another potential cause for the unexpected finding of decreased straylight after LASIK and LASEK may be that corneal hydration can change in vitro and in vivo, as reported by Patel et al. Corneal hydration is related to corneal transparency and thus to visual function. Perhaps the workload of the endothelium decreases based on ablation of tissue that otherwise must be kept dehydrated and, therefore, the stromal tissue becomes less hydrated, decreasing straylight.

Other factors that might have affected our results are pupil size, a change in the refractive index, and tear-film changes. Straylight is weakly dependent on pupil sizes between 2.0 mm and 8.0 mm in the normal population. In our study, the expected difference would be on the order of 0.01 log(s) assuming a change of 0.5 mm. We did not assess the influence of tear-film, although it is related to preoperative contact lens wear. Moreover, the tear-film would have likely recovered by the time the postoperative measurements were taken in our study.

The repeatability evaluation showed that the learning curve of the testing was not a source of bias. The mean difference between the first and second straylight measurement was 0.009 ± 0.079 log(s) preoperatively and 0.007 ± 0.078 log(s) postoperatively.

In conclusion, on average, 3 months after myopic laser refractive surgery, straylight was reduced. Most cases of increased straylight were related to clinical findings such as microstriae, debris, or haze. Additional studies are needed to corroborate the positive finding and correlate it with physical phenomena in the cornea. Although straylight has a role as an objective parameter of quality of vision in laser refractive surgery, the correlation between the findings and patients’ subjective quality of vision must be evaluated.

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