

# Straylight before and after LASEK in Myopia: Changes in Retinal Straylight

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**PURPOSE.** To quantify the changes in retinal straylight that occur after laser-assisted subepithelial keratectomy (LASEK).

**METHODS.** This prospective study included 86 eyes of 49 patients who were scheduled for LASEK surgery. Patients were divided into groups based on their preoperative contact lens wear habits: rigid lenses (RCL), soft lenses (SCL), spectacles after a period of contact lenses (SaC), and spectacles only (Specs). Retinal straylight was tested before surgery and 6 months after surgery with the compensation comparison method. Straylight was also compared to a normal reference database. The difference with the average straylight increase with age, called base- and age-corrected (BAC) straylight, was also studied.

**RESULTS.** Before surgery, BAC straylight was found to be strongly elevated, with a value of  $0.15 \pm 0.14$  log units. After LASEK, this decreased to  $0.00 \pm 0.14$  log units. The reduction was significant (paired *t*-test,  $P \ll 0.01$ ) and correlated with preoperative BAC straylight levels ( $r^2 = 0.332$ ;  $P \ll 0.01$ ). There was no correlation between the straylight change and the spherical equivalent of the laser refractive correction ( $r^2 = 0.042$ ;  $P = 0.059$ ). Preoperative wear of soft contact lenses increased the BAC straylight by approximately 0.06 log units, with respect to the spectacles groups ( $P < 0.05$ , unpaired *t*-test), but after surgery, this difference was no longer found ( $P > 0.05$ ).

**CONCLUSIONS.** Higher than normal preoperative BAC straylight was found to normalize after LASEK refractive surgery. Wearing soft contact lenses causes an additional increase in preoperative BAC straylight that is eliminated after LASEK. (*Invest Ophthalmol Vis Sci.* 2010;51:2800–2804) DOI:10.1167/iovs.09-4679

Many postrefractive patients complain about increased glare and halos, especially at night.<sup>1</sup> Such complaints are caused by light scattered in the eye, superimposed on the retinal image normally present in healthy eyes. This light-spreading can have two origins<sup>2</sup>: a refractive one, caused by wavefront aberrations spreading light over small angular distances, and a diffractive one, due to small irregularities in the

ocular media scattering light over large angular distances. Many conditions can cause this diffractive process, such as the corneal epithelial healing process, corneal haze, superficial scars, and postoperative flap positioning.

In older studies in the literature, investigators attempted to objectify glare-related complaints after photorefractive keratectomy (PRK) by performing pre- and postoperative straylight measurements, but found varied results. In one, there was an average increase in straylight<sup>3</sup>; in another, there was no change after a transient increase<sup>4</sup>; and two others, there was no change after a follow-up of 1 month.<sup>5,6</sup> For laser-assisted in situ keratomileusis (LASIK), similar results were found after a 1-month follow-up.<sup>6</sup> It must be pointed out that these results were the average of their respective populations and that in each of these studies a number of individual eyes presented clear straylight increases.<sup>6</sup>

As the sample sizes in these earlier studies were limited, the present work was undertaken to study the straylight changes that occur after laser-assisted subepithelial keratectomy (LASEK) in a larger population and using more recent straylight measurement technology. LASEK is a modification of the PRK technique,<sup>7</sup> in which a flap of epithelial cells is detached from the stroma before the laser treatment and replaced over the treatment zone afterward to act as a bandage. It is known from the literature that postoperative haze formation in the cornea is similar in LASEK and PRK<sup>8</sup> and that it is more pronounced in PRK than in LASIK.<sup>9</sup> To reduce this haze, mitomycin-C has been applied to the stroma and has been shown to reduce haze.<sup>10,11</sup> As this postoperative haze would interfere with our straylight measurements we chose a follow-up period of six months, corresponding with the time necessary for total corneal healing.

## METHODS

### Patients

This prospective work includes 86 eyes of 49 myopic patients who were scheduled for a LASEK procedure. Exclusion criteria were a history of previous ocular surgery, amblyopia, cataract, corneal scars, preoperative corneal haze, or macular diseases of systemic origin. Patients were tested before surgery and 6 months after surgery and their eyes were not dilated for the examinations. They received instructions to remove any rigid gas permeable contact lenses for 1 month before the measurements. For soft contact lenses, this period was reduced to 1 week.

This study adhered to the tenets of the Declaration of Helsinki and received ethics committee approval (Ref. nr. 7/6/24). Signed informed consent was obtained from the participating subjects.

### Straylight

The retinal straylight measurements in this study were performed with a commercial version of the compensation-comparison technique proposed by Van den Berg (C-Quant; Oculus Optikgeräte, Wetzlar, Ger-

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many). This method has been described in full detail in the literature<sup>12,13</sup> and has been thoroughly validated.<sup>14,15</sup> It provides a measure for the straylight parameter *s*, usually given in logarithmic form log(*s*), as well as an estimation of the fit quality *Q* of the psychometric function and an estimated repeated measures SD *Esd*.<sup>16</sup> Each measurement was performed under spherical equivalent correction of the patient's refraction with the coated trial lenses included with the C-Quant device. Only a single trial lens was used at a time, and care was taken that the lenses were clean and scratch-free before every measurement.

In healthy eyes, retinal straylight has been shown<sup>17,18</sup> to increase with the fourth power of age after the age of 45 and can be modeled as follows<sup>19,20</sup>:

$$\log[s(\text{age})] = 0.931 + \log\left[1 + \left(\frac{\text{age}}{65}\right)^4\right] \quad (1)$$

Note that this population<sup>20</sup> showed a slightly higher base constant in this equation (0.931) in comparison with the constant derived from a large European study on which the C-Quant reference line is based (0.870).<sup>19</sup> By subtracting this reference model from the measured straylight it is possible to define a base- and age-corrected (BAC) straylight that compensates for the base constant and the effect of the age-related increase in straylight. The confidence interval around this model was chosen to be ±0.20 log units, the same value as used in the European study. Note, however, that this interval was based on averages over two repeated measurements for each eye. In the present study only one measurement per eye was taken.

In the same paper,<sup>20</sup> we reported that the spherical equivalent *SE* also plays a role in retinal straylight and that this can be modeled as follows:

$$\log[s(\text{age}, SE)] = 0.931 + \log\left[1 + \left(\frac{\text{age}}{65}\right)^4\right] + (0.0024 \cdot SE^2 - 0.0072 \cdot SE + 0.0125) \quad (2)$$

Another type of corrected straylight can be defined by subtracting model 2 from the measured straylight. This parameter will be referred to as "base-age-SE-corrected" straylight (BASEC straylight).

**Gaussian Broad-Beam LASEK**

All LASEK procedures were performed with a Gauss excimer laser (InPro GmbH, Norderstedt, Germany), with a 193-nm ArF laser beam. This system produces a broad laser beam with a Gaussian profile<sup>21</sup> to induce a spherical correction on the entire cornea at once, which is in contrast with the more popular flying spot laser system.<sup>22</sup> The main advantage of this broad beam delivery method is that the treatment times can be kept relatively short compared with that of other systems: for example, ±11 seconds for myopia of -4 D, compared with more than 1 minute with a flying-spot delivery system. It also produces a

TABLE 1. Subject Data

Subjects, <i>n</i>	49
Male/female	17/32
Subject ethnicity	
Caucasian	47
Non-Caucasian	2
Age, <i>y</i> *	35.3 ± 11.1 (18-62)
Eyes, <i>n</i>	86
Right/left eyes	43/43
Preop SE refraction, D*†	-5.11 ± 1.79 (-9.875 to -1.6250)
Preop cylinder, D*	-1.00 ± 0.98 (-5.50 to 0.00)

\* Respectively, mean value, SD (range).  
 † SE, spherical equivalent.

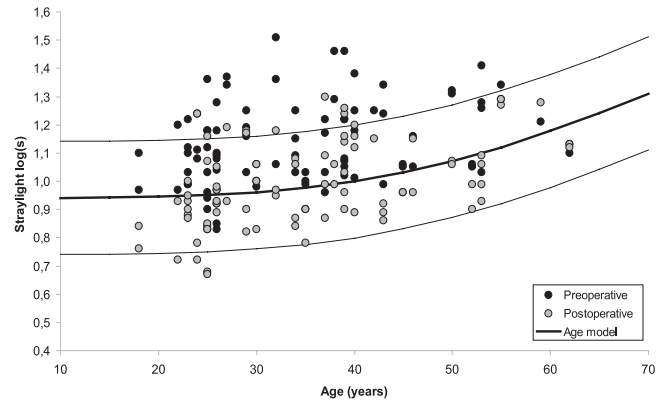


FIGURE 1. Retinal straylight as a function of age before and after LASEK, compared with the age model 1. Thin lines: the confidence interval of ± 0.2 log units.

smoother ablation surface, produces less corneal haze, and has a high reliability.<sup>23</sup>

**Statistical Methods**

All data were processed with commercial software (Excel 2003; Microsoft, Redmond, WA and SPSS, ver. 12; SPSS, Chicago, IL). Statistical power analysis indicated that a sample of 65 eyes is necessary to detect a significant change in retinal straylight of 0.025 log units with an α = 0.05.

**RESULTS**

**Patients**

In all 86 myopic eyes that were included in this work, the spherical equivalent refraction was recorded as well as a straylight measurement of acceptable quality (i.e., an *Esd* parameter below 0.08 and a measurement quality parameter *Q* > 0.5), both before and after surgery. In a subgroup of 54 of these eyes, axial length and anterior segment biometry measurements were obtained before and after surgery (Pentacam Scheimpflug system; Oculus Optikgeräte). The population data of the subjects study are given in Table 1.

**Comparison of Straylight before and after LASEK**

After the LASEK procedure, the BAC straylight decreased from 0.15 ± 0.14 log units (average ± SD) to 0.00 ± 0.14 log units, which was significant (paired *t*-test, *P* << 0.01).

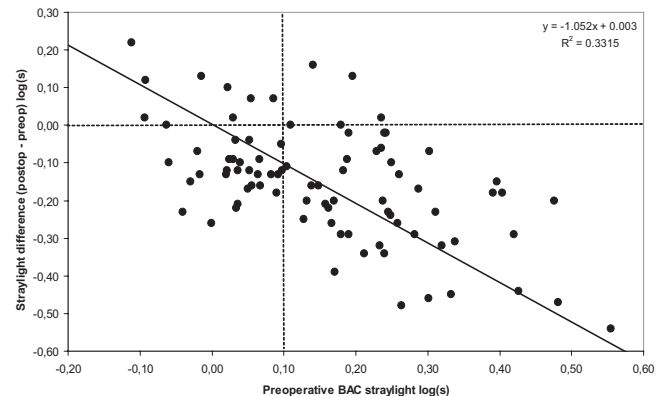


FIGURE 2. Change in retinal straylight after LASEK as a function of the pre-LASEK BAC straylight.

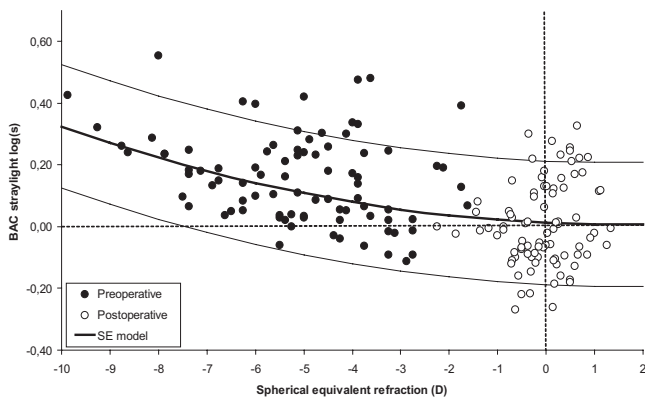


FIGURE 3. BAC straylight as a function of SE refraction before and after LASEK, compared with the SE model 2. *Thin lines*: the confidence interval of  $\pm 0.2$  log units.

Before surgery, the correlation between straylight and age was weak (linear fit,  $r^2 = 0.074$ ; Pearson  $P = 0.012$ ), partially due to the limited variation in age within the study population. For 36% of the eyes, the straylight level fell outside the confidence interval (CI) defined around model 1. After surgery, the straylight followed the age model 1 more closely (Fig. 1), with only 16% of the eyes outside the CI.

The individual postop-preop changes in straylight were clearly correlated to the preoperative BAC retinal straylight levels (linear regression,  $r^2 = 0.332$ ;  $P \ll 0.01$ ; Fig. 2).

### Comparison with SE Model

Comparing the BAC straylight as a function of the SE refraction with the SE model 2 showed that before surgery the data closely followed the model's increase with increasing myopia (Fig. 3). A number of individual eyes had BAC straylight levels that exceeded the CI around the model. After surgery, most of the BAC straylight values were within the CI.

When the BASEC data of this study was compared with that of the volunteers in Rozema et al.<sup>20</sup> no significant difference was seen ( $P = 0.341$ , unpaired  $t$ -test).

### Influence of Preoperative Contact Lens Wear

In the group of 86 eyes included in this study, 7 had rigid gas-permeable contact lenses (RCL), 29 had soft contact lenses (SCL), 11 had contact lenses of unknown type, 19 wore spectacles after a period of wearing contact lenses (SaC), and 20 had never had contact lenses (Specs). The eyes with an unknown contact lens type were excluded from further analysis.

In the other four groups, the decrease in uncorrected straylight after LASEK was significant (paired  $t$ -test,  $P < 0.01$ ) and was the same for all groups (one-way ANOVA after a Levene test to verify equality of the variances). This is shown in Table 2. As the change in retinal straylight and BAC straylight can be considered identical, provided not too much time has passed

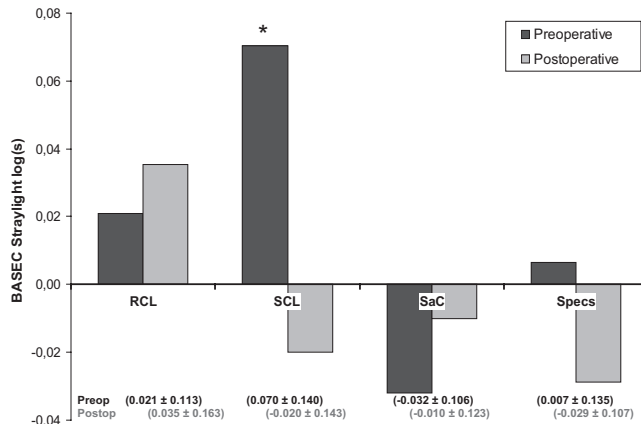


FIGURE 4. Pre- and postoperative BASEC straylight in the four contact lens groups. \*Statistically significant change (paired  $t$ -test).

between the pre- and postoperative measurements, the changes in BAC straylight were not considered separately.

Given the observation in Figure 3 that both before and after surgery the BAC straylight closely follows model 2, it is possible that some subtle differences in BASEC straylight can be found between the contact lens groups by subtracting model 2 from the straylight  $s$ .

Comparing the preoperative BASEC straylight of these four groups with each other by means of a one-way ANOVA, both spectacle groups (SaC and Specs) showed lower mean BASEC straylight values than those in the contact lens groups (RCL and SCL). The average preoperative BASEC straylight value for the RCL was lower than for the SCL, but no statistically significant differences were found ( $P > 0.05$ ; Fig. 4). Comparison of the two contact lens groups combined (RCL and SCL) with the two spectacles groups combined (SaC and Specs) showed the preoperative BASEC straylight of the former to be significantly higher than that of the latter (unpaired  $t$ -test;  $P \ll 0.01$ ).

A study of the BASEC straylight change after LASEK in the four contact lens groups showed a decrease in the SCL and Specs groups, whereas there was a slight increase in the RCL and SaC groups (Table 2, Fig. 4). In SCL, this decrease was statistically significant (paired  $t$ -test,  $P \ll 0.01$ ). The amplitudes of the postoperative BASEC changes were found to be inversely proportional to the preoperative BASEC straylight values ( $r^2 = 0.297$ ;  $P \ll 0.01$ ; data not shown).

After surgery, no significant differences in BASEC straylight were found between the four groups (one-way ANOVA).

### Straylight Change and Laser Correction

No correlation was found between the change in straylight and the amount of laser refractive correction (Fig. 5,  $r^2 = 0.042$ ;  $P = 0.059$ ) or the amount of ablated stromal tissue ( $r^2 = 0.026$ ;  $P = 0.144$ ). No correlations between these parameters were

TABLE 2. Straylight Changes Categorized According to Contact Lens Wear

	RCL	SCL	SaC	Specs	$P^*$	Significant Differences†
Eyes, $n$	7	29	19	20		
Straylight change‡	<b>-0.11 ± 0.06</b>	<b>-0.21 ± 0.14</b>	<b>-0.08 ± 0.13</b>	<b>-0.13 ± 0.14</b>	<b>0.017</b>	SCL < SaC
BASEC change‡	0.01 ± 0.06	<b>-0.09 ± 0.13</b>	0.02 ± 0.14	-0.04 ± 0.15	<b>0.041</b>	SCL < SaC

\* One-way ANOVA, where  $P < 0.05/2 = 0.025$  is considered significant (Bonferroni correction).

† Post hoc test: Tukey HSD if Levene test  $> 0.05$ , Tamhane T2 if Levene test  $< 0.05$ .

‡ Paired  $t$ -tests to detect BASEC straylight changes (indicated in bold), where  $P < 0.05/4 = 0.013$  is considered significant (Bonferroni correction).

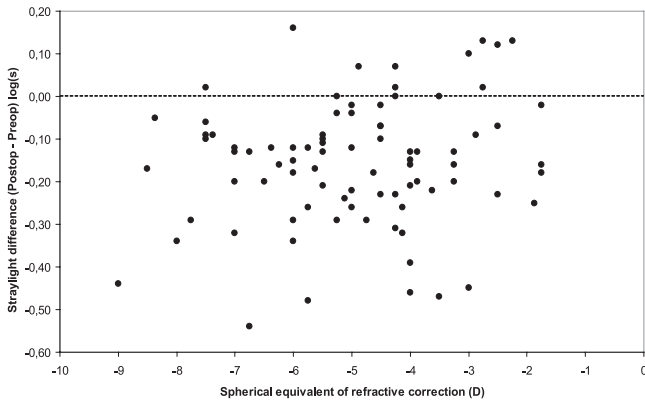


FIGURE 5. Change in uncorrected retinal straylight after LASEK as a function of the spherical equivalent of the refractive correction induced by LASEK.

found if the four contact lens subgroups were studied separately.

DISCUSSION

Contrary to expectations, these observations demonstrate that, after a LASEK procedure, retinal straylight decreased at a rate that correlated with preoperative BAC straylight (Figs. 1, 2) and that both before and after surgery the BAC straylight followed the SE model 2 (Fig. 3). In other words: the preoperative straylight values were elevated with respect to the reference values, but they normalized after surgery. This suggests that, regardless of what the underlying cause of the BAC straylight increase is, this cause is neutralized by the LASEK procedure. To identify this cause, factors should be considered that induce a preoperative straylight increase rather than those that induce a postoperative decrease.

There are several parameters that change after laser refractive surgery—most notably, the spherical equivalent refraction and the corneal thickness. However, changes in these parameters were not found to correlate significantly with the changes in straylight, both in the entire group of eyes and in the four contact lenses subgroups, perhaps because of an insufficient statistical power, resulting from a large SD on the postoperative straylight changes (Fig. 5).

All straylight measurements were performed under SE correction, which meant that before surgery all tests were performed with a trial lens, whereas after surgery this correction was no longer necessary for most eyes. The glass of the lenses may scatter a portion of the light; however, it has been shown in the literature<sup>24</sup> that this causes a straylight increase of approximately 0.01 log units only. The presence of trial lenses can therefore account for only a minute fraction of the preoperative straylight increase.

Another factor of importance is the wearing of contact lenses and any possible damage this may have caused to the various corneal layers in the form of haze or edema. As seen in Table 2 and Figure 4 the contact lens groups (RCL and SCL) had a significantly higher preoperative BASEC straylight than the spectacles groups (SaC and Specs). This result shows that wearing contact lenses increases retinal straylight, as was described in other studies.<sup>25</sup> The RCLs also showed nonsignificantly lower preoperative BASEC straylight values than the SCLs, which can be explained by the difference in contact between the different contact lens types and the cornea. The RCLs are mostly suspended over the cornea, whereas the SCLs are in close contact with the cornea.

After LASEK, however, the differences between these groups are no longer statistically significant, which suggests that the LASEK procedure may correct for this contact lens-related increase as well. This decrease in significance may be the result of the laser ablation of the upper stromal tissue during the procedure and the postoperative epithelial re-growth, both of which may have been damaged by the contact lenses.

Our results may be compared with those in the literature (Table 3), which shows that up until 2008 the straylight remained on average constant after laser refractive surgery, with some increases in individual eyes. In two studies<sup>3,4</sup> a transient straylight increase was found, that disappeared after a few months. As one of these studies<sup>3</sup> contained only four eyes and was performed in the early days of laser refractive surgery (1995), this result may not be valid for the current generation of laser systems.

Only in one recent study<sup>26</sup> was a decrease reported, albeit to a much lesser extent, whereas another study (Michael R, personal communication, November 20, 2008) found no significant change. However, in both studies, as well as in the present study, a larger percentage of eyes had a straylight

TABLE 3. Comparison with Undilated and Uncorrected Straylight Measurements

First Author	Year	Refractive Technique	Eyes (n)	Follow-up	SL Method	SL Change*	Decrease >0.1	Increase >0.1	Conclusion
Veraart <sup>3</sup>	1995	PRK	4	2 wk	DC	0.23 ± 0.12	0.0%	100%	Increase
			4	3.5 mo	DC	0.18 ± 0.25	25%	50%	2 increased, 2 same or less
Harrison <sup>5</sup>	1995	PRK	16	1 mo	SLM (DC)	Same			Average same
			14	1 mo	cSLM (DC)	Same			Average same
			6	1 mo	ITGP	Same			Average same
Schallhorn <sup>4</sup>	1996	PRK	30	1 mo	DC	5% increase			Increase (P < 0.01)
			30	3 mo	DC	Same as preop, some increases			Average same (P > 0.05)
Beerthuisen <sup>6</sup>	2007	PRK	12	1 mo	CC	0.036 ± 0.024	8.3%	16.6%	Average same (P > 0.05)
		LASIK	12	1 mo	CC	0.036 ± 0.024	8.3%	33.3%	Average same (P > 0.05)
Michael†	2009	LASIK	46	2 mo	C-Quant (CC)	-0.02 ± 0.17	32.6%	21.7%	Average same (P ≫ 0.05)
Lapid-Gortzak <sup>26</sup>	2009	LASIK	102	3 mo	C-Quant (CC)	-0.016 ± 0.172	29%	23%	Decrease (P ≪ 0.01)
		LASEK	137	3 mo	C-Quant (CC)	-0.026 ± 0.141	28%	15%	Decrease (P < 0.02)
Rozema	2009	LASEK	86	6 mo	C-Quant (CC)	-0.15 ± 0.15	64.0%	5.8%	Decrease (P ≪ 0.01)

SL, straylight; CC, compensation comparison method; DC, direct comparison method; (c)SLM, (computerized) straylight meter; ITGP, Increment Threshold-Glare Paradigm.

\* Log units.

† Personal communication, November 20, 2008.

decrease  $>0.1$  log units than had a straylight increase  $>0.1$  log units (Table 3).

Based on these observations we hypothesize that measured straylight decreases after a laser refractive procedure are common. However, these decreases may sometimes be masked by a wide range of minor complications, such as corneal haze, LASIK flap position, or geometry. As it may be assumed that a varying number of complications have taken place in these older studies, the fact that, on average, straylight did not change may signify that an underlying decrease was present. With the continuous improvements in the field of laser refractive surgery, the incident rates of such complications have steadily decreased over the years.

Both studies that showed a straylight decrease used the C-Quant for straylight measurement, which has been demonstrated to be a highly sensitive method. It is conceivable that due to the measurement methods and smaller population sizes used in the older studies the statistical power required for observing this decrease was not obtained. Most studies in the literature also had very short follow-up periods, typically 1 month, whereas it is known from the literature that the post-PRK corneal haze peaks after 1 month before it gradually decreases.<sup>27</sup> It is therefore possible that postoperative decreases were not observed because of follow-up periods that were too short.

For now, it therefore remains unclear what causes the preoperative SE dependency of the retinal straylight or its decrease after refractive surgery. Further research is needed to investigate these matters in more detail, especially the link with preoperative contact lens wear.

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