Straylight in anterior segment disorders of the eye

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Chapter 8
CONTRIBUTIONS OF THE CAPSULORRHEXIS TO STRAYLIGHT

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ABSTRACT

Objectives
To quantify the effect of the capsulorrhexis on straylight and to determine optimal capsulorrhexis size.

Methods
Fifty-six pseudophakic eyes with intact capsulorrhexis were included in the study. Straylight was measured with a straylight meter before and after pupil dilation. Capsulorrhexis and pupil diameter were measured and opacity of the anterior capsule was graded (on a scale of 0-5) with the slitlamp. Capsulorrhexis size and opacity were compared with the difference in straylight values between natural and dilated pupils.

Results
The mean capsulorrhexis diameter was 4.5 mm (range, 2.9 - 6.2 mm). Most anterior capsular rims were opaque in the area of contact with the intraocular lens (62.5% higher than grade 1). Mean straylight before pupil dilation was log(s) = 1.25 (range, 0.68 - 2.13), which increased to 1.46 (range, 0.88 - 2.22) after pupil dilation, which corresponds to a 62% increase (P < 0.0001). The effect of capsulorrhexis size and opacity on the increase in straylight in scotopic conditions can be quantified by the following formula: \( \Delta s = 19 \times \text{(grading of anterior capsular rim)} \times \text{(fraction of pupil area covered by rhexis)} \).

Conclusions
The influence of size and opacity of the capsulorrhexis via straylight is described in a quantitative model. Capsulorrhexis size must be greater than 4 mm to prevent functional problems at night.
INTRODUCTION

Cataracts can lead to reduced quality of vision via increased disability glare, which can be improved by cataract extraction. A cataract extraction should lessen glare and avoid iatrogenical induction of new causes of undesirable visual symptoms. Disability glare was found to be the direct result of straylight; thus, the International Standards Committee defines disability glare as straylight. Many pseudophakic eyes have improved straylight values compared with eyes with cataract and even healthy eyes of patients of the same age. Nevertheless, among patients with pseudophakia, disability glare may persist.

The concept of glare is not always clearly defined and may apply to many different conditions. Presence and intensity of glare are subjectively experienced and strongly dependent on the visual environment. Glare testers typically measure the effect of glare on perception, which is dependent on specific measurement conditions. This has made reliable glare testing in clinical use difficult and results of these tests often unreliable and hard to compare. With the introduction of an improved version of the straylight meter (C-Quant; Oculus GmbH, Wetzlar, Germany), a clinically useful instrument has become available to objectively document and quantify straylight values and thus disability glare. Results of straylight measurements taken via the straylight meter correlate well with the unfavorable effects of glare on perception.

Among patients with pseudophakia, increased straylight values compared with those found in healthy, young eyes are frequent. Because glare sensitivity after cataract surgery is infrequently studied, the causes of the continued increase in straylight in pseudophakic eyes are not well understood. Anterior and posterior capsule fibrosis are supposed to play a major role in postoperative quality of vision, as well as diameter and configuration of pupil and capsulorrhexis, type of intraocular lens (IOL), and opacities in other ocular media.

The capsulorrhexis and opacity of the remaining anterior capsule may contribute considerably to glare postoperatively. Numerous studies have been performed to determine the ideal capsulorrhexis diameter. A large capsulorrhexis may contribute to increased posterior capsule opacity and posterior capsule wrinkling. An eccentric or too-large capsulorrhexis that does not cover the peripheral IOL optic may also cause troublesome visual symptoms owing to light-scattering by the bare edge of the optic. However, a smaller capsulorrhexis makes cataract removal and proper IOL placement more difficult. Although patients with a small capsulorrhexis (4.5-5.0 mm) were shown to have better visual performance postoperatively than patients with a large capsulorrhexis (6.0-7.0 mm), a small capsulorrhexis may further contract and lead to increased glare. Visual acuity (VA) effects are usually small, but a decrease in VA may result from capsular phimosis or obliteration of the pupillary area by capsule contraction.
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By means of the straylight meter, it is now possible to study, in a precise manner, straylight effects of the capsulorrhexis. Such study may reveal an optimal capsulorrhexis size in a functional manner. This study was designed to determine the effect of size and opacity of the anterior capsulorrhexis on postoperative straylight and thus disability glare in patients with pseudophakia.

METHODS

Straylight measurements were performed prospectively in 47 consecutive patients with pseudophakia (56 eyes). All patients had undergone uncomplicated phacoemulsification with implantation of a posterior chamber IOL in the capsular bag. In all patients, a continuous curvilinear capsulorhexis (CCC) was performed as part of the phacoemulsification procedure. A foldable aspheric IOL (Acrysof SN60WF or SA60AT IOL; Alcon, Hünenberg, Switzerland) was implanted in the capsular bag after irrigation and aspiration of the cortical remnants. Exclusion criteria were other ocular conditions, especially corneal or vitreous opacities, pupil abnormalities, posterior capsule opacification, intraoperative complications that result in a damaged CCC, and decentered implants.

Straylight measurements and slitlamp examinations took place at a median time after cataract extraction of 49 days (10% - 90% interval, 8-539 days). Pupil diameter was measured with a standardized template in increasing steps of 0.5 mm under ambient lighting conditions, correspondent to the light level in the straylight meter. Best-corrected VA (BCVA) was determined with the Early Treatment of Diabetic Retinopathy Study chart (which measures logMAR acuity), in accordance with the modified Early Treatment of Diabetic Retinopathy Study protocol. Straylight measurements were achieved in accordance with the compensation comparison principle, by means of the straylight meter. The pupils were then dilated with tropicamide and phenylephrine eyedrops. Thirty minutes later slitlamp examination was performed. Horizontal and vertical diameters of the capsulorrhexis opening were measured in steps of 0.1 mm by means of the adjustable ruler on the slitlamp. A semi-quantitative (range, 0-5) slitlamp grading of the opacity of the anterior capsular rim was recorded, with 0 indicating clear; 1, mild opacification; 2, moderate diffuse opacification; 3, moderate diffuse opacification with areas of intense opacification or capsular folding; 4, intense opacification with capsular folding; and 5, densely white opacification with capsule contraction and/or capsular phimosis that obscures details of posterior intraocular structures. Funduscopy of the posterior segment was performed and the presence and amount of vitreous opacities documented. Straylight measurements were repeated.
Contributions of the capsulorrhexis to straylight

With the straylight meter the task of the patient is a series of short forced-choice comparisons between 2 flickering fields.\textsuperscript{13, 30} The amount of straylight is expressed in the straylight parameter, $s$, usually given as the logarithm, $\log(s)$. The parameter will be expressed in this manner, unless otherwise stated. Higher $\log(s)$ values indicate more straylight and more sensitivity to glare. Only reliable measurements defined as an expected standard deviation (ESD) less than 0.1 log unit were included, which results in actual repeated-measures standard deviations of approximately 0.07 log unit.

A model was formulated to relate the difference in straylight measurements between natural and dilated pupils to capsulorrhexis size and opacity. Somewhat simplified, the model can be explained as follows. Note that straylight relates to the fraction of light that is scattered. To be precise, the straylight parameter is defined as the point spread function (usually limited to the part $>1^\circ$) multiplied by the angle squared.\textsuperscript{31} The point spread function is defined as the fraction of all light that originates from a point source that is scattered toward a position in visual space at some angular distance, per steradian. Suppose this product is $a$ for the combination cornea-IOL-posterior capsule (so, $s_{\text{undilated}}=a$)\textsuperscript{31} and $b$ for the capsulorrhexis alone. However, $b$ contributes to only the part of the pupil covered by capsulorrhexis. The fraction covered is denoted $F$. If we further assume $b$ to be proportional to the grade of opacification, then in dilation, $s_{\text{dilated}} = a + bF$, and the difference in measured straylight can be modelled as follows:

$$s_{\text{dilated}} - s_{\text{undilated}} = bf = C \times \text{Grade} \times F,$$

with $C$ a constant to be fitted to the data.

Procedures were approved by the Medical Ethical Committee of the Academic Medical Center in Amsterdam, where the study took place. Consent was obtained from all patients after explanation of the study procedures.

The data were analysed by means of SPSS statistical software, version 12.0.2 (SPSS Inc., Chicago, Illinois). Statistical analysis was performed by means of paired $t$-tests to compare increase in straylight before and after pupil dilation and Pearson correlation to compare VA and straylight. The threshold for significance was $0.05$. When both eyes from some study participants are used as part of the sample, the eyes studied do not represent a true independent sample of the population because paired eyes may behave similarly to one other. This factor somewhat decreases the statistical power of the sample. This effect may be small and may not influence conclusions, but the only way to determine if the effect is important is to calculate statistics by means of general estimating equation models. In this case, because there were so few paired eyes and because the $P$ values were not close to the threshold of significance, the influence was considered not important.
RESULTS

The mean age of the patient population was 66.2 years (range, 31-87 years). Mean BCVA was logMAR 0.2, (range, 1.6 to -0.1; Snellen VA fraction: mean, 20/30; range, 3/100 – 20/16). The mean pupil diameter before dilation was 2.8 mm (range, 2 – 4 mm). After dilation the mean pupil diameter became 5.7 mm (range, 3 – 7 mm). All IOLs were clear; none contained a great amount of glistenings or other opacities.

In 91% of eyes the margins of the capsulorrhexis could be seen only after pupil dilation. In 5 eyes a narrow edge of the anterior capsule was visible before pupil dilation. The capsulorrhexis was usually smaller than the dilated pupil (mean diameter of the CCC, 4.5 mm; range, 2.9-6.2 mm). Most anterior capsular rims were opaque in the area of contact with the IOL material, which leads to a white ring over the peripheral IOL optic (62.5% greater than grade 1; Table 8.1).

**TABLE 8.1 Incidence of Anterior Capsule Opacity**

<table>
<thead>
<tr>
<th>Opacity Scale Score</th>
<th>Patients With Anterior Capsule Opacity, %</th>
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<td>0</td>
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</tr>
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<td>0.5</td>
<td>14.3</td>
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<tr>
<td>1</td>
<td>10.7</td>
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<td>0</td>
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</table>

The mean straylight value before pupil dilation was a log(s) of 1.25 (range, 0.68 to 2.13; Figure 8.1). The mean straylight value after pupil dilation increased to a log(s) of 1.46 (range, 0.88 - 2.22; Figure 8.1). Forty-five eyes (80.4%) showed an increase in straylight after pupil dilation (Figure 8.1 and Figure 8.2). The mean increase in log(s) after pupil dilation was 0.21 log unit, which corresponds to a 62% increase in straylight. The increase in straylight after pupil dilation was statistically significant (paired *t*-test, *P* < 0.0001). No statistically significant relationship was found between straylight values and BCVA in our population (Pearson correlation, -0.174; 2-tailed *P* = 0.200). Because only undilated eyes were considered, the range of straylight may not have been great enough to detect a correlation. To exclude the influence of postoperative corneal edema, a comparison was made between patients who were examined within 30 days...
Contributions of the capsulorrhexis to straylight

FIGURE 8.1 Comparison of straylight values in our population with pseudophakia before (□) and after (●) mydriasis as a function of age. The gray line represents normal age values, the solid black lines represent the borders of the 95% confidence interval.

FIGURE 8.2 Comparison of straylight values before (x-axis) and after (y-axis) pupil dilation. Eighty percent of patients showed an increase in straylight levels after pupil dilation. The solid line represents y = x.
after phacoemulsification (mean log(s), 1.35) and patients who were examined 30 days or longer postoperatively (mean log(s), 1.36). No significant differences in straylight values between these groups were found.

In Figure 8.3 the difference in the s value between dilated and undilated pupils is shown and fitted with the model function explained in the “Methods” section. The constant C that relates the straylight value to the capsulorrhexis grade was found to be 19.

**DISCUSSION**

Studies have been performed with pseudophakic eyes to determine which factors influence quality of vision postoperatively. However, straylight-dependent symptoms occur separately from VA-associated symptoms. Statistically, some relation between VA and straylight may occur in the population because media disturbances can be expected to affect both VA and straylight, although probably not to the same degree. In our population the relation did not reach statistical significance, in correspondence with earlier research that shows a weak relationship. This information stresses that straylight results from different processes than VA. Because straylight measurement rests on an equalization test, VA cannot in a causative sense influence the result of a straylight test. During straylight measurement, the patient observes
which of two test fields shows more flicker. The point of identity between these two test fields is not influenced by VA. Identity remains the same, independent from VA. This has been verified in laboratory experiments (van den Berg, September 1990, unpublished data). It must be stressed that straylight is an aspect of visual function, although the term straylight might suggest it to be a purely optical entity. Straylight assesses the strength of the hindering spreading of light as seen by the person. However, it is the spreading at relatively large angles (typically > 1º) as opposed to the spreading of light that governs VA and contrast sensitivity (in the range of minutes of arc). It governs disability glare and in general the quality of vision in most visual scenes because of the general prevalence of large luminosity differences in that type of scene. Both VA and contrast sensitivity do not take that factor into account. In extreme cases of media turbidity both domains of light spreading may overlap, and the distinction gets lost. Normally, straylight is an independent aspect of visual function. A study of 2422 drivers investigated the ways that straylight measurements relate to lens opacity grading (Lens Opacities Classification System III), VA, contrast sensitivity, and self-reported impairments of visual function. From correlation analysis, it was found that straylight is a vision impairment not directly related to VA and contrast sensitivity, and, moreover, that if VA is known, contrast sensitivity has limited added value. As mentioned previously, this independence of straylight and VA may be understood from the underlying processes that govern both aspects of visual function. A VA assessment is not sufficient to assess the visual disability of a person and visual problems caused by straylight. Additional vision measures are required to understand the impact of vision loss on everyday life. The results of the large study of European drivers support this assertion. Straylight measurements are necessary to fully understand the subjective concerns of the patient. With the straylight meter it is possible to capture functional concerns, such as straylight and disability glare, in an objective parameter s. In this study, a functional model was developed that shows the effect of capsulorrhexis size and anterior capsule opacity on the parameter s. Figure 8.3 is a graphic representation of this functional model, as explained in the “Methods” section.

The model function describes, in a quantitative sense, the way the difference in straylight before and after pupil dilation in pseudophakic eyes is dependent on the amount of opacity of the anterior capsular rim and size of the capsulorrhexis. In healthy, phakic eyes, straylight values remain approximately equal between natural and dilated pupils. However, among patients with pseudophakia, pupil dilation seems to play a significant role in increasing straylight as capsulorrhexis becomes visible in the pupil area and starts to affect visual function by the increase of intraocular light-scatter. When more of the pupillary area is taken up by the anterior capsular rim, this rim will contribute more to the falling of scattered light into the eye in a proportional manner. The proportionality constant (b) will depend on the opacity of this rim. The proportionality constant was chosen as C x (grading of the rim), and the constant C was estimated to be 19. This
model supposes a directly proportional relationship between (subjective) grade and (objective) amount of straylight. Closer analysis of the data suggested that this relationship is nonlinear, with the higher grades giving relatively more (than proportionally) straylight compared with the lower grades. Because the improvement of the model fit shown in Figure 8.3 was small, the linear model is still a good approximation, and the nonlinearity was not included in the present model. The linear model gives an approximation of the expected differences in straylight values between natural and dilated pupils and is good enough to detect and quantify clinically relevant variation.

To implement this quantitative measure into ophthalmic practice, it is necessary to consider the known effect of an increase in straylight on visual performance. In healthy, young eyes the normal straylight value is approximately 0.87 log($s$) ($s = 7.4$). With increasing age, the straylight value in healthy eyes may increase to approximately 1.17 log($s$) ($s = 15$) at the age of 65 years. This means a 2-fold increase in the straylight parameter ($s$). A large part of the otherwise-healthy elderly population accepts this increase and may not even realize its occurrence because the increase in straylight develops gradually. In Figure 8.3 the difference in the straylight parameter ($s$) between dilated and natural pupils is shown on the y-axis (∆$s$). With consideration of the described example, a ∆$s$ of 15 would double the amount of straylight when the pupil is dilated compared with the normal value for a 65-year-old patient. This value ($s = 30$, which corresponds to log($s$) = 1.47) is considered a limit value for safe driving because higher ∆$s$ means more straylight and problems with disability glare. In accordance with the functional model, ∆$s$ is influenced by both grading of anterior capsule opacity and the area of the pupil surface covered by capsulorrhexis. This means that in ophthalmic practice, there are two ways to ensure a minimum of straylight concerns in patients with pseudophakia. First, polishing of the anterior capsule during phacoemulsification to minimize postoperative anterior capsule opacity may be performed routinely. Intraoperative cleaning of the anterior capsule may also help in the stabilisation of the size of the capsulorrhexis opening and prevent contraction.

The second way to reduce postoperative straylight concerns is to ascertain that the capsulorrhexis does not occupy too much space in the pupillary area. The minimum diameter of the capsulorrhexis necessary to prevent the induction of extra straylight to the amount of a ∆$s$ of 15 can be determined with the model. In this study, the mean grade of anterior capsule opacity was 1.7, and the mean pupil diameter after dilation was 5.7 mm. When these values are taken into account, the model determines that at a capsulorrhexis diameter of 4 mm, doubling of straylight occurs. If we consider doubling to be an acceptable limit value, then capsulorrhexis diameter should be at least 4.0 mm to minimize the occurrence of serious postoperative straylight problems in scotopic light conditions. In our study capsulorrhexis size was, as a rule, larger; this is why most points in Figure 8.3 cluster close to zero.
Contributions of the capsulorrhexis to straylight

Figure 8.1 shows that large variations in straylight exist among patients with pseudophakia before pupil dilation who therefore did not have anterior capsule involvement. Straylight increases with age in healthy eyes, mostly because of increased disturbances to optical media, such as cataracts. In pseudophakic eyes the effect of age on the amount of straylight is supposed to be less important because the disturbing cataract is removed. However, as can be seen in Figure 8.1, straylight values do not return to values of a young, normal eye. Some influence of age or surgery on pseudophakic eyes is thus assumed and should be clarified by further research. Relationships between several intraocular factors and postoperative glare complaints were studied previously. Influences of IOL type, IOL strength and posterior capsule opacification on glare in patients with pseudophakia were shown. In this study two different types of IOL were included, both manufactured by Alcon and made of acrylic. The SN60WF is a blue-blocker and corrects for some spherical aberration, whereas the SA60AT does not have these characteristics. The SN60WF is thinner than the SA60AT. A large range of IOL powers were included, which leads to (small) differences in IOL thickness as well. Although these characteristics should not affect forward scatter, some influence of these factors on straylight values cannot be excluded. Currently, these effects are being studied in-vitro. In our study none of the IOLs contained a great amount of glistenings or other opacities. When only a few glistenings are present, it is not likely to influence straylight values in a major way. This was experimentally established (unpublished data) with the set-up of the studies on straylight from human donor crystalline lenses and can theoretically be understood by means of the calculations that relate scatter (worst case; ie, isotropic) to straylight, as detailed earlier. Because in our study only paired measurements of the same eyes (before and after pupil dilation) were compared, the effect of the capsulorrhexis was isolated. Influences of other intraocular factors were considered more or less stable within each patient and were excluded from the functional model. The exclusive use of intraindividual comparisons also made the large variation in postoperative intervals and age in our study population acceptable. Separate studies that use the new straylight assessment technology should be performed to determine the importance of other intraocular factors on straylight levels.

The functional pupil area in the elderly patient is limited because of age-related miosis. Although the effect of the anterior capsular rim may be negligible during the daytime, under scotopic lighting conditions it may become clinically relevant and lead to glare. Another possible source of increased straylight concerns postoperatively is a surgically damaged iris or pupil, which results in an oversized and/or poorly reacting pupil. Previous studies that focused on the effect of pupil diameter on glare perception in patients with pseudophakia found mostly that mean glare score increased significantly with moderate pupil dilation. The introduction of anterior capsule
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... opacities into the pupillary area is generally suggested to cause this effect.\textsuperscript{5,14} This effect was also shown in our study. It is important to protect the integrity of the pupil during surgery, and to allow it to constrict normally in bright light conditions postoperatively.\textsuperscript{4}

In summary, straylight concerns can be a source of dissatisfaction in otherwise satisfied patients with pseudophakia. Measurements with the straylight meter are clinically useful in the evaluation of visual dysfunction not detected by VA assessment. This measurement can be used to verify and better understand subjective concerns of glare disability. In this study it has been possible to document and quantitatively assess the influence of the anterior capsular rim on the postoperative occurrence of disability glare. Through a functional model, we have been able to determine the minimum diameter of the capsulorrhexis (4.0 mm) that is necessary to avoid the occurrence of a serious straylight increase under scotopic lighting conditions.
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