Light scattering levels from intraocular lenses extracted from donor eyes

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ABSTRACT

Purpose

To assess light scatter levels of intraocular lenses (IOLs) extracted from donor eyes, in order to understand straylight elevation documented earlier in pseudophakic population studies, and to identify potential sources of light scattering in IOLs.

Methods

Light scattering of 74 donor lenses was measured with the Oculus C-Quant device adapted for *in vitro* analysis of IOLs. Straylight was assessed at 2.5 and 7.0 deg scatter angle, and results were compared to straylight of a 20-year-old and 70-year-old crystalline lens, and to that of a lens with cataract. To identify potential changes to the IOL material, the IOLs were examined with a light microscope and a slit lamp.

Results

At 2.5 and 7.0 deg the straylight parameter (mean ±SD) was 5.78 ±4.70 deg^2/sr and 5.06 ±4.01deg^2/sr, respectively. Forty-one percent of the IOLs showed lower straylight than that of the 20-year-old lens; in 14% scattering intensity was higher than in the 70-year-old lens; none showed straylight comparable to that of the cataractous lens. Increased straylight was associated with surface deposits, snowflake-like degeneration, and glistenings. The incidence rate of lens-related complications differed between different IOL groups.

Conclusions

Microscopic structural alterations inside IOLs explains for an important part the straylight elevations found in pseudophakic eyes. A clear correlation with degeneration and/or alteration of implanted IOLs is found. Although these IOL-related complications are not likely to affect visual acuity, they give rise to straylight which is known to result in disability glare and other complaints.

INTRODUCTION

Straylight in pseudophakia has been studied since the 1980s. Ever since, it has been found that straylight of the pseudophakic eye does not, as a rule, return to the level of a young eye following surgery.[1-5] The literature shows that in the absence of posterior capsule opacification (PCO), straylight is increased up to a level known to be a serious hindrance to the patients' vision in 10% of the pseudophakic eyes.[5] The reason for straylight elevation in pseudophakia is yet unknown.

Straylight is a perceptual quantity corresponding with the functional effect of light scattering in the eye.[4, 6-9] In a young, healthy eye, the light is primarily scattered by the cornea and the crystalline lens. However, fundus reflectance and light transmittance of the eye wall are also deemed important.[4, 6-9] All sources of straylight in the eye but one (*i.e.*, the lens) are considered relatively independent of age.[4, 6-9] The straylight level of the young eye is 0.90 log(s) (s=7.9 deg^2/sr).[3, 4, 8-11] Aging of the crystalline lens causes straylight to increase, and an approximate 2-fold increase (1.20 log[s]; s=15.8 deg^2/sr) has been found at the age of 65 years.[3, 4, 8-11] For comparison, 1.52 log(s) (s=33.1 deg^2/sr), on average, has been reported in the eye with cataract.[12] Increased straylight results in disability glare, which is always exacerbated under dynamic light conditions.[3, 4, 6-9] It is depicted by the patient as blinding by light sources, hazy vision and/or as a loss of contrast.[3, 4, 6-9]

Clinical studies have shown a significant straylight decrease after cataract surgery. Yet, as previously mentioned, some pseudophakic patients experience high straylight levels.[5, 13-15] This could be attributed to postoperative complications related to the implanted intraocular lens (IOL). A main concern is biocompatibility of IOL materials, which might degrade or alter once placed in a dynamic eye environment. Several *in vitro* studies on lenses explanted due to IOL pathology have reported increased light scattering in most cases.[16-19] Changes to the IOL material that have been considered as important sources of light scattering are calcium and/or phosphate precipitations on the lens surface, snowflake degeneration, and glistenings.[16-20] An *in vitro* study on lens explants deemed free of any pathology has also shown higher straylight in 2 of 6 analyzed cases.[A] This indicates that the onset of IOL complications might occur in a subclinical form, and standard ocular examination might not be capable of early detection of this complication.

The aim of this study was to assess the contribution to straylight from IOLs obtained from donor pseudophakic eyes, and to identify potential underlying causes of increased straylight in pseudophakia. To this end, we measured light scattering in donor lenses and examined them with a light microscope and a slit lamp.

METHODS

Seventy-four monofocal IOLs from donor pseudophakic eyes were studied. The donor eyes were obtained from the Cornea Bank Amsterdam. No *a priori* data on the donor eyes and the IOLs were available. The lenses were stored in balanced salt solution (BSS) at room temperature. The IOLs were examined with the slit lamp and the light microscope. To separate different IOL groups, IOLs of the same model were matched based on slit-lamp images. Although the shapes of the haptic and optic may be clues to the specific IOL models, substitutes exist for well-known IOL brands that are available on the market. So, the authors could not identify lens types with certainty. For this, individual patient records were needed, which were not accessible to the authors.

Straylight of the IOLs was analyzed with an adaptation of the C-Quant (Oculus).[21, 22] **Figure 1** shows the optical diagram of the C-Quant adaptation.[21] The C-Quant device is a clinical straylight meter which uses a psychophysical approach to assess straylight.[4, 9, 23] In this instrument, straylight of the eye is measured by using the retina as null detector, and is defined and quantified by the concept of equivalent luminance.[4, 8, 9, 23-25] In essence, the test consists of comparing known light to (unknown) straylight. The adaptation includes optical components and a wet-cell (**Figure 1**). An IOL is placed in the wet-cell and submerged in BSS. An optical design of the adaptation enables a C-Quant test to be performed on an IOL (not the eye), yet by using the eye of an observer as null detector, regardless of the refractive power of the IOL. A diaphragm is placed behind the IOL to block light of a straylight source; hence, only the test field is seen to the observer where known and unknown straylight levels are compared (**Figure 1**). The observer's eye is used to judge the test field projected by the IOL. As the IOL is conjugated with the crystalline lens, the adaptation simulates "looking" through an implanted IOL. The only difference being the exposure to the straylight source, to obtain a pure measure of the light scattering aspect of the IOL.

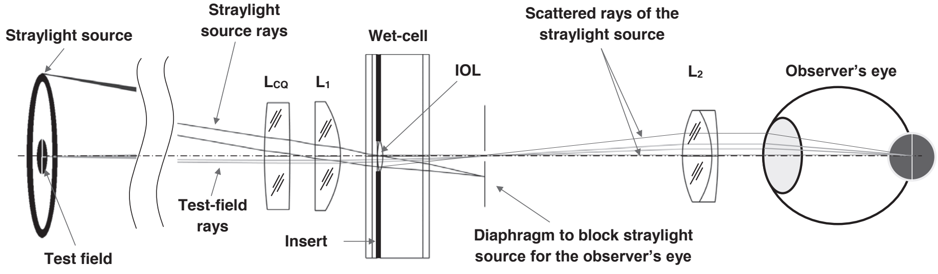

Figure 1. Schematic drawing of the C-Quant adaptation. L_{CQ}=lens of the C-Quant, IOL=intraocular lens, L=lens. For more details on the adaptation, please refer to the Methods section. Reprinted from *Biomed Opt Express 2017;8:1889-94*.

Straylight was measured at 2.5 and 7.0 deg scatter angle to study straylight-angular dependence.[26] A clinical C-Quant evaluates straylight at 7.0 deg.[23] A modified C-Quant with a tube elongated by a factor of 2√2 was also used to measure straylight at 2.5 deg.[20] Both the clinical and modified C-Quant give straylight results presented as logarithm of the straylight parameter, log(s). Note straylight can be expressed by either the straylight parameter "s" or its logarithm "log(s)," *e.g.* log(s)=1 equals s=10. Straylight of the donor lenses was compared to known (isolated) levels of the crystalline lens at the ages of 20 (0.38 log(s); s=2.4 deg^2/sr) and 70 (1.05 log(s); s=11.3 deg^2/sr) years, and to a 95-year-old lens (1.52 log(s); s=33.1 deg^2/sr) to simulate the effect of cataract.[12] These straylight levels were calculated based on the CIE model as described elsewhere.[24, 25]

RESULTS

The mean straylight (± standard deviation) at 2.5 deg and 7.0 deg was 5.78 ±4.70 deg^2/sr and 5.06 ±4.01deg^2/sr, respectively. Thirty (41%) of the 74 IOLs showed straylight that was below the level of that of the crystalline lens aged 20 years. Straylight was above the level of the 70-year-old crystalline lens in 10 IOLs (14%). However, none showed a straylight level that is close to that of the cataractous lens. **Figure 2** demonstrates the results graphically.

Eight IOL groups of the same model were identified that comprised 61 IOLs (82%). **Figure 3** shows overview images (one for each group) of the IOL models. **Table 1** reports the median straylight values of the 8 IOL groups at the 2.5 and 7.0 deg scatter angle **Figure 2** presents straylight for each group of IOL model as well as for the IOLs that could not be grouped, with the results compared to the straylight levels of the crystalline lens.

Thirty-four IOLs (43%) were free of any IOL pathology; the remaining 40 lenses showed different levels of lens opacification. **Table 1** presents incidence rates of lens opacification in the 8 groups. Surface deposits were found in groups 1 (one lens), 2, 3 (one lens) and 6. The observed white-brown foci of degeneration in groups 2 may also impress as snowflake degeneration. Glistenings were found in groups 4, 5 and 8. **Figure 4** shows slit-lamp and microscopic images of IOLs with snowflake-like degeneration, surface deposits, and glistenings.

Table 1. Straylight and the incidence rate of IOL complications in the 8 lens groups.

Angle [deg]	Median straylight parameter s ±SD [deg^2/sr]							
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
2.5	3.1 ±5.2	8.8 ±4.5	1.2 ±6.1	5.3 ±4.2	3.8 ±3.2	10.4 ±3.2	1.7 ±10.5	2.2 ±0.9
7.0	2.1 ±4.1	9.9 ±3.6	1.9 ±2.5	5.4 ±1.9	2.8 ±3.9	10.3 ±3.6	2.1 ±7.3	1.7 ±0.3
	IOL complications							
	1/5	7/7	1/8	5/9	6/10	10/10	0/6	4/6

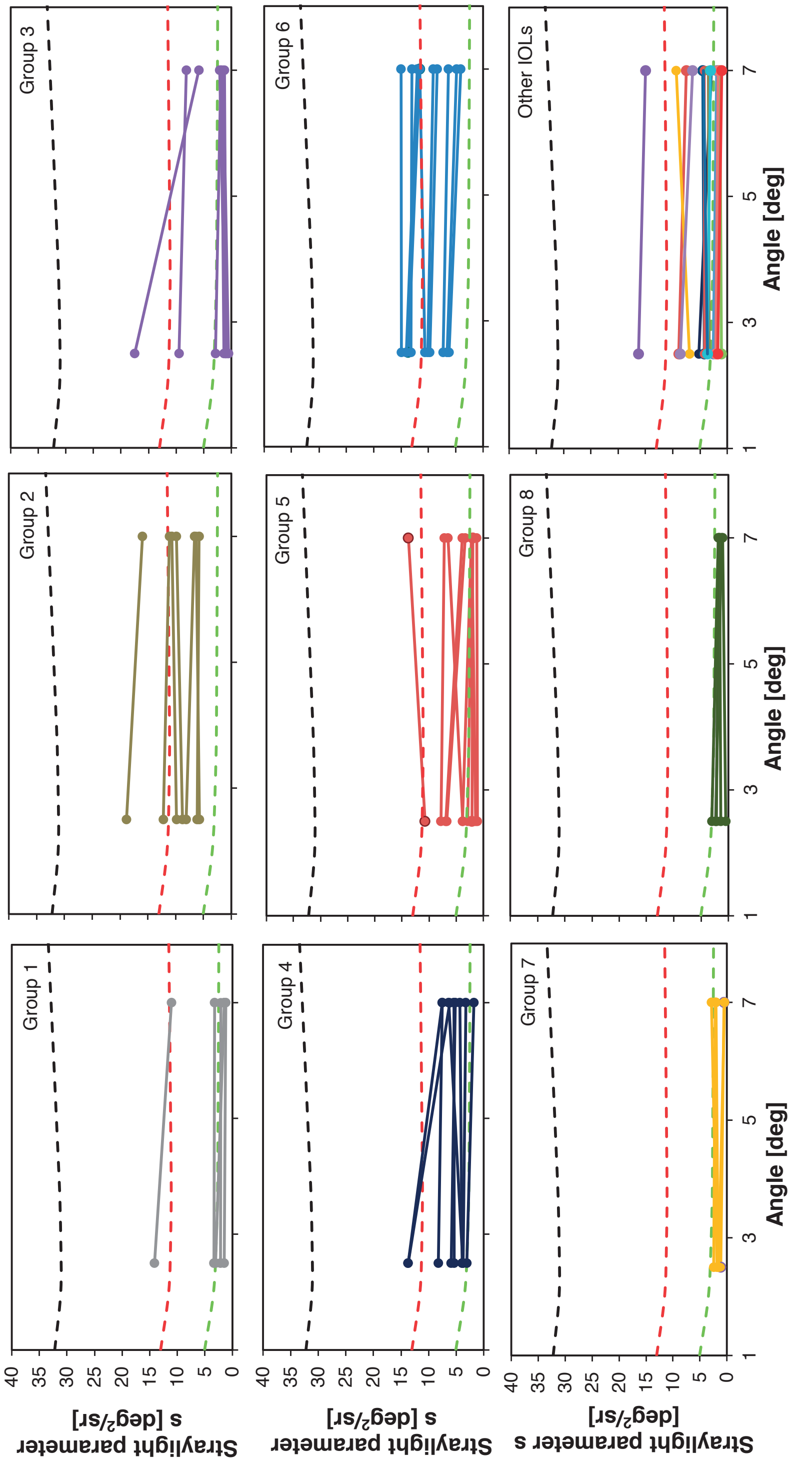

Figure 2. Straylight of donor IOLs measured at 2.5 and 7.0 deg scatter angle. The results are stratified by lens model. The green and red dashed line represents straylight of the crystalline lens at the age of 20 and 70, respectively. The black dashed line simulates the effect of cataract, which is comparable to a straylight level of a 95-year-old lens.

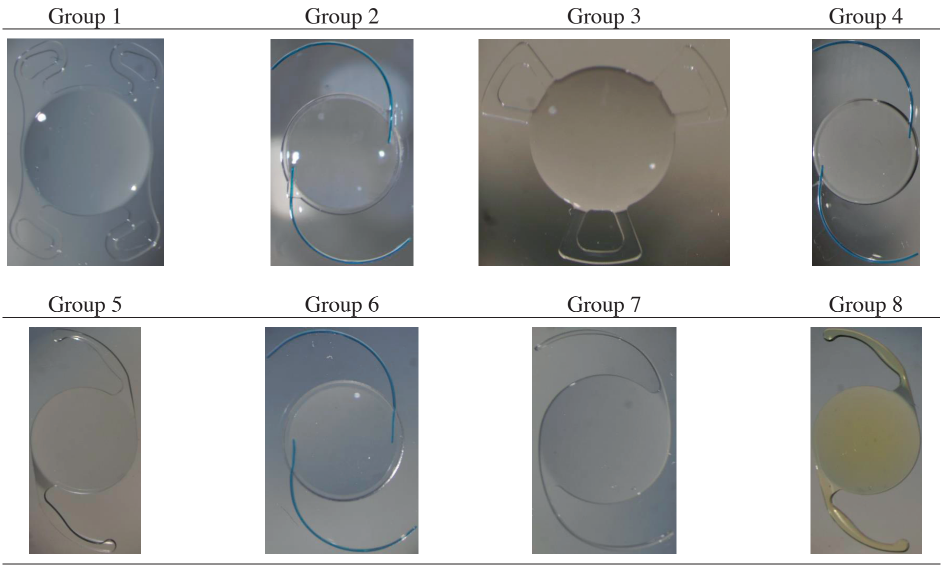

Figure 3. Exemplary photographs of matched IOL groups.

DISCUSSION

The study aimed to assess the contribution to straylight for a random sample of IOLs, in order to understand straylight elevation generally found in pseudophakic eyes.[5] The study found that IOLs from donor eyes are in general not free from straylight. Significant amounts of straylight were found, but differences seem to exist among the IOLs; both between groups of IOL models and within groups. This may be similar to the reported differences in straylight between pseudophakic eyes.[5] Scatter sources that are shown in **Figure 4** appear to be the most likely cause for the observed straylight increase. The incidence rate of the complications may differ between IOL models (**Table 1**).

A recent review paper on straylight in uncompromised pseudophakia (*i.e.*, without PCO) showed straylight elevation with serious straylight hindrance affecting 10% of the pseudophakic patients.[5] This must be compared to our current *in vitro* finding that seriously increased straylight occurred in 14% of the studied donor IOLs. Mean straylight has been found to be 1.21 log(s) in pseudophakic eyes, corresponding to s=16 deg^2/sr.[5] **Table 1** shows median s values in donor IOLs of about 0.3 to 1.0 log(s) (s=2 to 10 deg^2/sr). Since light scattering in the human eye is additive, we can approximate the straylight in an aphakic eye by subtracting the straylight value in our reported donor IOLs from that of the average pseudophakic eye. This would result in log(s)= 0.78 to 1.15, corresponding to s=6 to 14 deg^2/sr. These values must be compared to the values for the young normal eye, being on average log(s)=0.90 (s=7.9 deg^2/sr).[4] Therefore, the results of this study

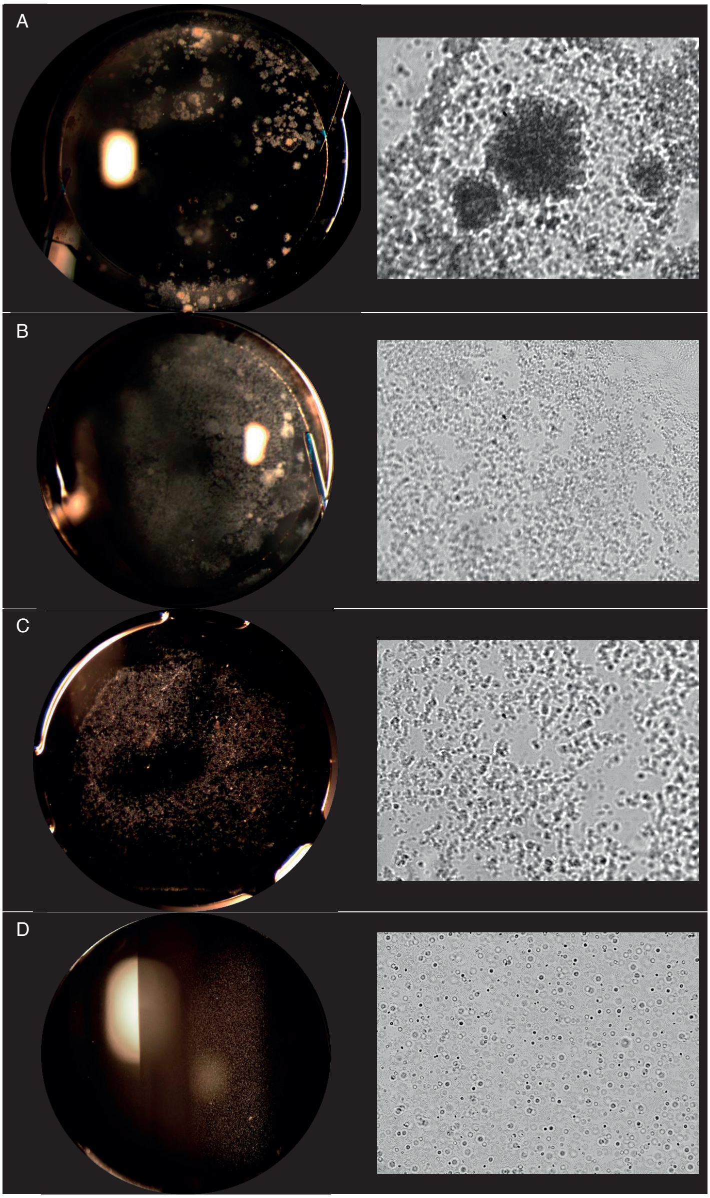

Figure 4. Slit-lamp (left) and microscopic (right) exemplary images of donor lenses with different types of IOL opacification. A) A 3-piece IOL (Group 2) with foci of white-brown opacification (left) that impresses as snowflake degeneration, and an isolated pattern of opacification (right); s(7deg) = 16.0 deg^2/sr. B) A 3-piece IOL (Group 6) with confluent whitish opacification located in the central and mid-peripheral lens area (left), with crust-like deposits (right); s(7deg) = 15.0 deg^2/sr. C) A 1-piece IOL (Group 3) with whitish deposits concentrated within the central and mid-peripheral area of the lens with irregular clearing in the center (left), with crust-like deposits (right); s(7deg) = 5.9 deg^2/sr. D) A 1-piece IOL (Group 5) with numerous glistenings within the IOL bulk seen with the slit lamp (left) and the microscope (right); s(7deg) = 13.8 deg^2/sr.

indicate that higher than expected straylight in pseudophakia may be caused by light scattering originating from implanted IOLs. Although this seems an important finding, this only partially explains straylight results of *in vivo* studies, as one may wonder why only 6% of the pseudophakic patients show straylight levels comparable to that of the young eye, if straylight of 41% of the studied lenses was low. This warrants further investigation.

It must be realized that the studies in pseudophakia relate to different IOL types. We, however, could not make a comparison of the present results with those studies on basis of IOL type. The reason is that data on the studied donor lenses were not accessible, so we were not able to identify the studied lenses with certainty. The mean straylight values found in those studies varies from log(s)=1.10 log(s) to 1.47 log(s), corresponding to s=12.6 to 29.5 deg^2/sr.[5] Individual log(s) values may differ much more (e.g. 0.68-2.13 log[s][15] = 28-fold difference). These ranges of variation seem to be larger than can be accounted for with the present study. The values found in the present study could only account for, say a 2- to 3-fold straylight difference. One may speculate about other potential sources of light scattering that might contribute to the reported differences between pseudophakic eyes, such as subclinical onset of PCO, pupil size and capsulorhexis diameter, age-related changes of the vitreous, and pigmentation level.

Light scattering characteristics depend on the size of the scattering particles (small vs. large particles).[26] **Figure 2** shows that relatively large particles (no less than of wavelength size) dominate scattering in the studied lenses, as straylight-angular dependence was found to correspond relatively well with the Stiles-Holladay approximation.[27] This was confirmed by the slit lamp and light microscopy examination, as large numbers of finite particles could be seen in some studied IOLs (**Figure 4**) revealing the presence of surface deposits, snowflake-like denegation, and glistenings.

Table 1 indicates that the highest rate of the IOL-related complications was found in Group 2 and 6. This finding also correlates with the highest straylight values found in these groups. Moreover, **Figure 2** demonstrates a consistent pattern of straylight elevation in the 2 groups. **Figure 4**A (Group 2) shows surface deposits and confined white-brown discolorations that might appear like snowflake degeneration[28, 29] The snowflake degeneration has been found in Poly(methyl methacrylate) (PMMA) lenses.[16, 28, 29] **Figure 4**B shows surface deposits that could be a potential reason for increased straylight in Group 6. Deposits were also found in one lens of Group 3 (**Figure 4**C) and Group 1 resulting in significant straylight elevation. Calcium and/or phosphate precipitates have been attributed to IOL surface deposits.[16, 17, 29-38] This postop complication has often been associated with hydrophilic lenses.[16, 17, 29, 33, 34, 36, 37] However, studies have reported calcium deposits on hydrophilic lenses with hydrophobic coating[30], silicone,[16, 29, 32, 35] and PMMA lenses[31] as well.

Straylight of explanted IOLs with calcium deposits/snowflake degeneration has been studied.[17, 19] One study showed straylight of 2 hydrophilic acrylic IOLs with severe opacification to be 1.8 and 2.9 log(s) (s=63.1 and 794.3 deg^2/sr) for 7.5 deg scatter angle.[17] Werner et al.[19] measured straylight of hydrophilic, silicone and PMMA IOLs that were explanted because of calcification/snowflake degeneration. They reported that average straylight (at 7.5 deg) of the calcified lenses (hydrophilic and silicone IOLs) was 1.63 log(s) (s=42.7 deg^2/sr); and of PMMA lenses with the snowflake degeneration it was 1.60 log(s) (s=39.8 deg^2/sr).[19] These values are much higher than straylight reported in the present study, as we found the highest value to be 1.20 log(s) (s=15.8 deg^2/sr). This, however, could be expected as those explanted lenses can be considered the top of the iceberg. IOLs are typically explanted when opacification affects visual acuity, but the donor IOLs might have provided satisfactory visual acuity throughout the donors' lifespan despite the presence of IOL degenerations and increased straylight. This may also indicate, that some IOL-related complications may go undetected, and so the incidence rate of lens complications might be understated.

Formation of glistenings is another postop complication that was found in the analyzed lenses. Glistenings are fluid-filled microvacuoles with a size ranging from 1 to 20 µm that have been especially, but not exclusively, associated with AcrySof IOLs.[39] Some cases of glistenings in other IOL materials have also been reported.[40, 41] Glistenings were found in Group 4, 5 and 8 with an incidence rate of 55%, 60% and 67%, respectively. Although the highest rate was found in Group 8, this group also shows the third lowest straylight among the 8 IOL groups. This finding may suggest that glistenings have lower potential for straylight elevation than surface deposits/snowflake-like degeneration. This is in agreement with literature, as explantation of lenses with the surface deposits/snowflake degeneration[16, 17, 28-38] has been more often reported than explantation of lenses with glistenings.[18, 42, 43]

Light scattering of 2 explanted, multifocal IOLs with glistenings has been studied by Van der Mooren et al.[18] They reported that straylight (at 2.5 deg) of the 2 analyzed lenses was below the level of that of the 70-year-old crystalline lens.[18] We also found that in Group 4, 5 and 8 all IOLs but 3 showed straylight below this level. A recent laboratory study on the relation between straylight and glistenings has demonstrated how the intensity of the scattered light depends on the size and number of the microvacuoles.[20] A model of the straylight effect of glistenings was proposed,[20] which can be used to estimate the number of microvacuoles. **Figure 1** shows a straylight value of s=13.8 deg^2/sr (1.14 log[s]) at 7.0 deg in Group 5, which is the highest among the IOLs with glistenings. If this value is entered in the model, the glistenings number is estimated to be (approx.) 2 800 per mm^2. Such a large number of microvacuoles would fall into the highest grade.

The slit-lamp and microscopic analysis, and the straylight measurements indicated that in the absence of structural changes to IOL material, light scattering remains at a low level. Forty-one percent of the studied lenses showed straylight below that of the 20-year-old crystalline lens, corresponding with 43% of IOLs that were free of any pathology. This is a likely reason for the observed difference between groups with the extreme straylight levels, *i.e.* group 2 and 6 (the highest) vs, group 3 and 7 (the lowest). As 100% complication rate was observed in groups with higher straylight, but in group 3 and 7 it was 7% (one lens).

In conclusion, it was found that straylight elevation in pseudophakic eyes may result from IOL-related complications. The presence of surface deposits/snowflake-like degeneration gives rise to a significant straylight increase, and should always be considered as a potential hindrance to patient's vision even if visual acuity remains unaffected. The reason for the observed differences in the incidence rate of postop complications between different IOL materials must be studied.

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