Intraocular Light Scattering in Age-Related Cataracts

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Intraocular light scattering was studied in 34 controls and 65 patients with cortical, nuclear, or posterior subcapsular cataracts by measuring forward scatter and backscatter. Forward scatter was measured by the psychophysical direct compensation method. Backscatter was determined with the Lens Opacity Meter of Interzeg. Contrast sensitivity loss caused by forward scatter was assessed with a glare tester (Vistech MCT 8000). Mean forward scatter was in the upper range for subcapsular cataracts compared to nuclear and cortical cataracts. Experimental results of the glare test (the contrast loss) deviated systematically from expected results based on measured forward scatter. Mean backscatter was largest for nuclear, intermediate for posterior subcapsular, and almost zero for cortical cataracts. Thus, each cataract has a characteristic mean ratio between forward scatter and backscatter. However, this ratio varied considerably among individuals, especially for cortical and posterior subcapsular cataracts. As a rule, forward scatter cannot be derived from backscatter (or the slit-lamp image). Invest Ophthalmol Vis Sci 33:618–625, 1992

When light enters the eye it is scattered as a result of optical imperfections in the eye. This scattering can be subdivided into light scattered toward the retina (forward scatter) and light scattered backward (backscatter). Forward scatter results in a veiling illumination superimposed upon the retinal image and reduction of the retinal contrast. This phenomenon may lead to a variety of complaints, especially glare. Under pathological conditions, such as cataracts, scatter may be increased. The corresponding functional impairment is caused by an increase in forward scatter, not backscatter. For the clinician, indications for cataract surgery are derived largely from slit-lamp examination and visual acuity testing. But the slit-lamp image depends on backscatter, while visual acuity testing may underestimate functional visual impairment. Because forward scatter is known to have functional importance, glare testing has become an additional tool for cataract evaluation. Glare is generally assumed to be the direct result of forward scatter, but the relation has not been studied. Studying this relation would be interesting as would studying the relation between forward scatter and visual acuity and the relation between backscatter and visual acuity.

Because no technique has been available to measure forward scatter independently of glare-like effects, efforts have been made only to clarify the relation between visual acuity, back scatter, and glare sensitivity. The relation between glare sensitivity and backscatter in healthy eyes was studied in the 1960s. A linear relationship was found, but later studies could not confirm this. More recently, this relation was studied for pathological conditions, especially in advanced age-related cataracts (AARC). For this purpose, AARCs often are subdivided according to location into nuclear, cortical, and posterior subcapsular cataracts (NC, CC, and PSC, respectively). No significant correlation between glare sensitivity and backscatter was found for any of these types. For the relation between backscatter and visual acuity in AARC, a moderate correlation was reported, possibly due to NC. With a variety of glare testing techniques, data also were collected on the relationship between glare and visual acuity. The results were inconclusive. They include no correlation for unspecified types of AARC in a large population, but good correlations for NC or CC and poor correlation for PSC in small populations.

Recently, a technique became available for measuring forward scatter in patient populations. We used it to document forward scatter in AARC and to study its relation to backscatter, visual acuity, and glare sensitivity.

Materials and Methods

Ninety-nine subjects, 45–85 years old (mean age = 66.6; standard deviation = 9.6), were recruited...
from the outpatient department. Best corrected visual acuity had to be equal to or higher than 0.25. Thirty-four subjects without ocular pathology formed the control group. Sixty-five subjects had only AARC. Patients selected from the files predominantly had CC, NC, or PSC. All patients were reexamined and their cataracts were reclassified. In 13 cases, a mixed classification resulted. In each patient, the eye that best met our criteria was tested after informed consent had been obtained. See Table 1 for group sizes and ages.

Visual acuity, measured in a darkened refraction lane using a high contrast rear illuminated translucent letter (Sloane’s chart) chart with a luminance of 850 cd/m², was expressed in decimal notation.

Forward scatter (straylight) was assessed by the direct compensation method.¹⁴,¹⁵,¹⁶ This psychophysical method gave accurate and consistent results in recent studies of 129 normal subjects¹⁶ and several smaller groups of patients.¹⁴,¹⁷,¹⁸,¹⁹ The subject placed his head on a chin rest and fixed one eye on the center of one of four white rings (the straylight sources) with inner radii of 1.95, 3.9, 7.8, or 15.4 cm; outer radii of 3.9, 7.8, 15.4, or 30.8 cm; and subtending mean angles (φ) of 3.5, 7.0, 13.6, or 25.4°, respectively. The illuminance (E) at the eye resulting from the four rings was 10, 39, 115, and 153 lux, respectively. The presented ring flashed on and off at a frequency of 8 Hz. A test field with a radius of 1° was in the center. When this field was dark, it appeared to flicker as a result of entoptic scattering of light from the surrounding ring.

In the test field, a light could be flashed on and off in counterphase with the presented ring. The luminance of this light could be adjusted to compensate for the flickering straylight. The subjects were asked to respond promptly when the flicker disappeared. Because the flicker sensitivity of the eye has a threshold, the flicker disappears over an extended range of luminance values. The lower limit of this interval was established by increasing the luminance of the test field, starting from zero. The test field luminance then was further increased until the straylight was overcompensated, as indicated by reappearance of the flicker. Next, the test field luminance was decreased until the flicker disappeared again. This allowed the upper value of the interval to be found. The luminance (L) of the test field was read from a dial and expressed in cd/m².

For each ring, the upper and lower values of the interval (L in cd/m²) were determined three times, and the six values were averaged. The straylight parameter, s(φ) = φ² × L / E, was calculated. (This straylight parameter corresponds to k in the Stiles-Holladay approximation²⁰ for straylight over larger angles: L / E = k / φ². We have found¹⁶ that k is not really constant. This is why we use s(φ) instead of k.) The standard deviation of s(φ) was below 0.05 log units for normals.¹⁶ Log[s(φ)] was averaged over the four angles for each patient for statistical analysis (Table 1 and Figs. 2 and 5). The apparatus was calibrated every 15 sessions.

To study glare sensitivity, the loss of contrast sensitivity caused by a glare source was determined with the Vistech MCT 8000 (Vistech Consultants, Inc., Dayton, OH).²¹,²² It assesses glare sensitivity by a method similar to that of Paulson and Sjöstrand.³ Contrast thresholds for sine wave gratings were determined twice, once with the glare source on and once with the glare source off. The spatial frequencies were 1.5, 3, 6, 12, and 18 cycles per degree. The glare source consisted of an oval of small lights in front of both eyes, about half of them visible with the eye tested. We estimated this oval to have a mean radius of 12.9°. The space average luminance at the gratings was 40 foot-Lamberts (137 cd/m²), and the illuminance at the eye caused by the glare source (E) was 680 lux. Because the straylight parameter at 12.9° [s(12.9)] could be derived by interpolation, the luminance of the light added to the test field because of the glare source could be calculated as L = s(12.9) × E/φ²

Table 1. Means and standard errors of the means for each of the subpopulations

<table>
<thead>
<tr>
<th>Cataract</th>
<th>No</th>
<th>CC</th>
<th>NC</th>
<th>PSC</th>
<th>CC + NC</th>
<th>CC + PSC</th>
<th>NC + PSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>34</td>
<td>16</td>
<td>19</td>
<td>17</td>
<td>3</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64.6</td>
<td>68.6</td>
<td>73.2</td>
<td>59.7</td>
<td>73.7</td>
<td>68.4</td>
<td>64.3</td>
</tr>
<tr>
<td>SEM</td>
<td>1.6</td>
<td>1.7</td>
<td>1.6</td>
<td>2.5</td>
<td>2.6</td>
<td>3.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Log (dec. VA*)</td>
<td>0.00</td>
<td>0.23</td>
<td>0.37</td>
<td>0.23</td>
<td>0.28</td>
<td>0.25</td>
<td>0.29</td>
</tr>
<tr>
<td>Log (straylight†)</td>
<td>1.13</td>
<td>1.36</td>
<td>1.53</td>
<td>1.68</td>
<td>1.52</td>
<td>1.50</td>
<td>1.59</td>
</tr>
<tr>
<td>Log (contr. loss)</td>
<td>0.02</td>
<td>0.07</td>
<td>0.04</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Lens opacity</td>
<td>0.04</td>
<td>0.19</td>
<td>0.24</td>
<td>0.51</td>
<td>0.14</td>
<td>0.38</td>
<td>0.26</td>
</tr>
<tr>
<td>SEM</td>
<td>0.01</td>
<td>0.06</td>
<td>0.06</td>
<td>0.12</td>
<td>0.19</td>
<td>0.20</td>
<td>0.08</td>
</tr>
<tr>
<td>22.4</td>
<td>23.3</td>
<td>39.3</td>
<td>27.1</td>
<td>37.3</td>
<td>21.1</td>
<td>35.9</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>1.9</td>
<td>1.9</td>
<td>2.2</td>
<td>8.0</td>
<td>1.1</td>
<td>4.8</td>
<td></td>
</tr>
</tbody>
</table>

* Decimal visual acuity.
† φ²/L/E.
= \text{s}(12.9)^2 \times 680/12.9^2$. Contrast loss of the grating due to the glare source then could be calculated from the formula, contrast loss factor = \text{luminance of test field} + \text{luminance of straylight at test field} / \text{luminance of test field} = [137 + \text{s}(12.9)^2 \times 680/12.9^2] / 137. Positioning of the eye was critical for receiving the proper amount of glare light. Refractive errors were corrected for the appropriate viewing distance. The natural pupil was used. Mean contrast sensitivity loss was calculated over the three lower spatial frequencies. The two higher spatial frequencies often are not seen at all by cataract patients.\textsuperscript{4}

A parameter for backscattered light was obtained with the Lens Opacity Meter of Interzeag.\textsuperscript{6,23,24} This device measures light scattered back from the lens. The pupil size must be made 4 mm or larger by decreasing a background light. Five measurements in a row were taken to obtain a mean score and standard deviation (from the order of 0.67). Although backscattered light is measured, the readings of the Lens Opacity Meter are called “lens opacity values” by the manufacturer.

Because we chose to use the natural pupil, we accepted the fact that pupil sizes would differ. Pupil size, estimated during the tests, was found to be 3–4 mm during straylight testing. As indicated above, backscatter was measured at a pupil size of slightly more than 4 mm. When the head is positioned against the Vistech MCT 8000, measurement of the pupil diameter is impossible. Considering the brightness of the MCT 8000, compared to the conditions of the straylight test, and the relation between brightness and pupil diameter, we presume that the pupil size was about 3–3.5 mm. These differences may have introduced some inconsistency in the material.

After these tests were completed, the pupils were dilated and the eyes were examined by slit-lamp biomicroscopy and ophthalmoscopy by two investigators. The cataracts were classified as described above.

## Results

In Table 1, means and standard errors of the means for the parameters of this study are presented for each of the subpopulations. The groups of patients with mixed cataracts were small (3, 3, 7, and 0) and were excluded from further analysis.

The 34 controls had a visual acuity of about 1. The straylight values were comparable to those for age-matched normals.\textsuperscript{16} The log contrast loss was close to zero, as expected. The mean lens opacity value of 22.4 was a bit high compared to published values\textsuperscript{24} for 65-year-old subjects (mean = 19, SD = 4).

In Figure 1, the straylight parameter s(\(\phi\)) is plotted as a function of scatter angle for the four cataract groups. To study how the shape of this function is influenced by progression and type of cataract, the following statistical analysis was performed. For each patient log[s(\(\phi\))] was decomposed in a series of orthogonal polynomials. Each of the coefficients of the polynomials was tested against the mean value of log[s(\(\phi\))]. Analysis of covariance showed that the coefficients depend significantly (first order polynomial \(P < 0.01\), second order polynomial \(P < 0.001\)) on the mean. But no significant difference in this dependence was found to exist between the four groups. To illustrate this finding, each of the subpopulations was divided into two equal groups based on the mean value of log[s(\(\phi\))] (Fig. 1). The upper curves give the means for the half of the respective subpopulation with the highest straylight values. The lower curves give the means for the other half. Corresponding to the statistical analysis, Figure 1 illustrates that low straylight corresponds to a more pronounced curvature. The curved shape for the normal population was found earlier,\textsuperscript{16} partially explained,\textsuperscript{25,26} and compared to literature data.\textsuperscript{27}

Figure 2 shows the relationship between visual acuity and the straylight parameter for the groups CC, NC, and PSC (\(r = 0.64, 0.79,\) and 0.69, respectively). The loss of contrast sensitivity in relation to visual acuity is given in Figure 3 (\(r = 0.56, 0.62,\) and 0.54, respectively). Lens opacity values are compared with visual acuity in Figure 4 (\(r = -0.03, 0.60,\) and 0.33, respectively). If statistical normality is assumed, all of these \(r\) values except one is significant at or below the 1% level.
NC, and PSC, $r = 0.28$, $0.77$, and $0.37$, respectively. Figure 6 shows the relation between glare-induced contrast sensitivity loss and straylight. $S(12.9)$ was used because the glare source of the MCT 8000 is

**Fig. 2.** Visual acuity versus the straylight parameter for each type of cataract (boxes) compared with the group without cataract (pluses). CC: $r = 0.64$ ($P < 0.5\%$), NC: $r = 0.79$ ($P < 0.5\%$), PSC: $r = 0.69$ ($P < 0.5\%$). The arrows connect the means for the two groups.

Figure 5 shows the relation between the logarithmic mean of the straylight parameter and the lens opacity values. For the figure as a whole, $r = 0.45$. For CC,

**Fig. 3.** Visual acuity versus contrast loss factor due to glare. CC: $r = 0.56$ ($P < 0.5\%$), NC: $r = 0.62$ ($P < 0.5\%$), PSC: $r = 0.54$ ($P < 0.5\%$). See also the legend of Figure 2.
Fig. 5. Relation between the straylight parameter (forward scatter) and lens opacity (backscatter). The straylight values are the logarithmic means over the four visual angles determined for each subject. Correlation coefficients for the whole population for CC, NC, and PSC are 0.45 ($P < 0.5\%$), 0.28 ($P < 5\%$), 0.77 ($P < 0.5\%$), and 0.37 ($P < 0.5\%$), respectively.

contrast sensitivity loss equals (optical) retinal contrast loss, using the formula given in the methods section.

**Discussion**

The results showed intraocular straylight increases with cataracts (AARC). This was expected because of the well known increase in glare with AARC.

Fig. 6. Relationship between the straylight parameter and contrast loss. Straylight values were calculated at a visual angle of 13 degrees. The dotted line represents the expected relationship if contrast sensitivity loss equals optical retinal contrast loss.
Surprisingly, the angular dependence was found to be about the same for the different types of AARC (Fig. 1). The forward scattering properties of the cataractous entities seem to be basically similar. This is unexpected because the three types of AARC have different morphologies. Apart from light absorption in AARC, no data on the optics of AARC are available to compare to this result.

Maybe the three types of AARC would differ more if small angle effects (blurred focus, multiple image) were compared to larger angle effects as studied in the present report. An indication for such a difference can be found in Figure 2 if visual acuity is assumed to reflect small angle effects. Figure 2 suggests that PSC, compared to the other types of AARC, has modest small angle effects relative to large angle effects. This corresponds to the finding that in PSC visual acuity underestimates the handicap because of the more serious glare problems. This is confirmed in Figure 3, which illustrates that PSC produces more contrast loss under glare conditions than NC and CC. In CC and NC, straylight and, correspondingly, contrast loss seem to progress basically at an equal pace compared to visual acuity.

Within the AARC types, differences also seem to exist between small angle effects and large angle effects because the correlation between visual acuity and straylight parameter is not very good (Fig. 2). The relationship between glare sensitivity and visual acuity should be even less precise because glare results from forward scatter with some error (see Fig. 6). Indeed, the correlation coefficients of Figure 3 are lower than those of Figure 2. Thus, for individual patients, neither straylight nor glare sensitivity can be predicted on the basis of visual acuity. This agrees with the findings for PSC obtained in another study, but contradicts the results for NC and CC. We cannot explain this discrepancy except for noting the number of subjects was small.

That the straylight parameter for the cataracts themselves is not shown in Figure 1 should be noted. The straylight parameter of Figure 1 is the combined result of normal scatter in the eye and scatter in the cataract. Assuming that multiple scattering is unimportant, an estimate of the isolated cataract straylight parameter can be obtained. The mean straylight parameter for the two normal subpopulations was subtracted (linearly) from the straylight parameter for the six cataract subpopulations of Figure 1. The resulting curves decreased slightly with scatter angle (not shown). Therefore, straylight intensity from cataracts seems to follow rather precisely the classical power law. The powers for the six subpopulations were between $-2.0$ (Stiles-Hollanday) and $-2.3$.

It would be interesting to compare this result with in vitro data on the angular dependence of straylight in cataracts. However, the relevant data contradict ours. In vitro straylight intensity was found to be rather constant over the central $45^\circ$. This would predict the straylight parameter as presented in the present report to increase quadratically with scatter angle. We also have started to do an in vitro study measuring straylight intensity originating from the central $4 \text{ mm}$ of isolated human lenses. The preliminary results more or less agree with the in vivo data. A methodological difference is that in the original study a $1.5 \text{ mm slit}$ was used, concentrated on cataractous areas.

The finding that the angular dependence does not differ (much) between the three AARC groups indicates that only one measurement of straylight suffices in AARC studies. If one straylight value would be known for a patient, the complete straylight function generally would follow. A mean value for a large angular area should be measured. For Figures 2 and 5, we used the mean over the four angles of the present study.

Light scattering media (another example is a fog), as a rule, scatter light in all directions, from $0^\circ$ to $180^\circ$. Because scattering in the three AARC types was found to have the same angular dependence from $3.5^\circ$ to $25.4^\circ$ the angular dependence may be thought to be the same all over. This seems not to be the case. Figure 5 shows correlation between forward scatter and backscatter (lens opacity) to be rather low. However, within the NC group it seems to be higher compared to CC and PSC. Again, this strengthens the notion that NC is optically less regular than CC and PSC. For practical purposes it is important to note that forward scatter that causes disability glare cannot be derived from slit-lamp imaging or objective backscatter measurements, possibly except for NC. In vitro, the relation between backscatter and forward scatter has been found to be good if only clearly cataractous areas were selected.

Backscatter (lens opacity) was found to have a different relationship with visual acuity than forward scatter (Fig. 4). Backscatter is clearly largest for NC, very small for CC, and intermediate for PSC. However, interindividual differences are large. Therefore, the mean for a group cannot be applied to individual patients. Correspondingly, other studies on the relationship between backscatter and visual acuity in NC, CC, and PSC reported a significant correlation only for NC.

Studies on the backscatter of different parts of the normal and cataractous human lens showed the most consistency in the nuclear region. Cortical and posterior subcapsular cataracts tend to be more variable.
The data on straylight can be used to better understand the visual defect, especially glare. Effects of increased straylight on the following visual functions have been calculated and determined experimentally in earlier reports for small series of patients. These functions include contrast sensitivity, \(^{14}\) cortical and retinal electrical responsiveness to checkerboard stimulation, \(^{17}\) and perimetric sensitivity. \(^{16}\) Glare generally is assumed to be based on retinal contrast loss causing loss of contrast sensitivity. The dotted line in Figure 6 gives contrast loss in the present glare tester as a function of straylight (see Methods). This line shows contrast loss in this tester to increase little up to straylight values of 40. This is confirmed by the data points.

Actually, most data points are closer to one than the dotted line in the left part of Figure 6. Some are even below one. This implies enhancement of contrast sensitivity in the presence of a veiling luminance. In analyzing the data of Corkill and Lythgoe, \(^{32}\) Schouten \(^{39}\) also found improvement in the presence of moderate veiling light. The explanation is as yet unclear. Maybe this phenomenon is related to the well documented observation that contrast sensitivity improves when the test field is not surrounded by darkness. \(^{34}\) In the case of veiling light, this improvement must compete with deterioration because of optical contrast loss. If this phenomenon were to be substantiated, it would invalidate glare testing as a way to estimate low levels of straylight.

Finally, we want to stress, as others \(^{2,35}\) have, the need for standardization in the field of glare testing or straylight measurement. \(^{36}\) Currently, the results of different authors cannot be compared directly. The designs of several glare testing methods make deriving an estimate for straylight from the results impossible. This fact could be used as an impetus for standardization. The formula used in Figure 6 is an example of this approach. Straylight then could be expressed as \(L / E\) or \(\phi^* L / E\). This is physically well defined. Moreover, a large database of normal data expressed in these units is available, and in vitro measurements on cataracts can be easily converted to these units.

**Key words:** cataract, light scattering, aging, glare, straylight

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**References**


