The Effect of Posterior Capsule Opacification on Visual Function

William R. Meacock,1 David J. Spalton,1 James Boyce,2 and John Marshall1

PURPOSE. To investigate how posterior capsule opacification (PCO) affects visual function in pseudophakic eyes.

METHODS. One hundred and six eyes that had undergone uncomplicated phacoemulsification were recruited sequentially. Patients with surgical complications or other ocular disease were excluded. PCO was assessed by a digital retroillumination camera using a software program based on the analysis of texture in the image, and the percentage area within the central 3 mm of the posterior capsule was calculated. Visual function assessment included Early Treatment Diabetic Retinopathy Study (ETDRS) high- and low-contrast visual acuity, contrast sensitivity with the Pelli-Robson and CSV-1000 grating charts, and forward light-scatter by the direct-compensation method (van den Berg).

RESULTS. The percentage PCO required for decline in high-contrast ETDRS was 78%; for low-contrast acuity and Pelli-Robson, 46%; for CSV-1000 contrast sensitivity, 38% to 51%; and for forward light-scatter, less than 1% PCO.

CONCLUSIONS. Central PCO affects psychophysical test results with differing degrees of sensitivity. Forward light-scatter is the most sensitive, followed by contrast sensitivity and visual acuity. (Invest Ophthalmol Vis Sci. 2003;44:4665–4669) DOI: 10.1167/iovs.02-04654

Posterior capsule opacification (PCO) is the most common complication of cataract surgery, and when it obscures a visual axis Nd:YAG laser, capsulotomy is necessary to restore visual function. This treatment has significant adverse medical, social, and financial consequences.1,2 Reduction of PCO has been reported with modifications of the surgical procedure3 and intraocular lens (IOL) material4,5 or design6–8 and, to assess the benefits of such strategies, an objective measurement of a change in the posterior capsule is necessary.

Until relatively recently, the criteria for defining the significance of PCO were based on Nd:YAG capsulotomy rates. Many of the criteria for deciding when an Nd:YAG capsulotomy is needed are subjective and may lead to biased application.9–11 Systems that objectively measure PCO can be broadly divided into those that use retroillumination imaging and those that analyze PCO from back-scattered light to measure PCO density. A number of retroillumination systems have been used to provide either a grade of PCO12 or a percentage area of opacification,13 but none of these has correlated the effect of PCO with visual function. Hayashi et al.14 used an anterior eye segment analysis system (EAS-1000; Nidek, Gamagori, Japan) to measure the density of the central 3 mm of the posterior capsule by recording backscatter from the posterior capsule. The St. Thomas' digitized retroillumination imaging system produces high-resolution images with even illumination, which maximizes the detection of PCO with computer image analysis to reduce observer bias. The reproducibility and validity of this system and its clinical usefulness have been demonstrated.15 In prior studies, however, investigators have not attempted to correlate these images with visual performance. It is important to know what effect PCO has on visual function and whether retroillumination imaging can give us some appreciation of the visual performance of patients.

Optical imperfections, such as PCO, cause forward light-scatter within the eye, which results in a veiling illumination superimposed on the retinal image, causing a loss in contrast. The purpose of this study was to investigate whether the analysis of retroillumination images of PCO could be predictive of visual performance, by cross-correlating them with a number of psychophysical tests of visual acuity, contrast sensitivity, and forward light-scatter. By evaluating several different tests of visual performance, we made an attempt to determine what aspects of visual function were affected by PCO.

METHODS

Subjects

One hundred six patients (46 men, 60 women; age range, 60–85 years; mean, 74), who had undergone routine cataract surgery were recruited sequentially after appropriate ethics committee approval and a signed consent. The study adhered to the tenets of the Declaration of Helsinki. The criteria for inclusion in this study were as follows: (1) uncomplicated phacoemulsification surgery during the prior 2 to 3 years, (2) a well-centered posterior chamber IOL, and (3) full cooperation, with the ability to perform psychophysical tests for visual function. Exclusion criteria included: (1) coexistent ocular disease or amblyopia, (2) refractive error of more than ±5 D sphere or more than ±2.5 cylinder, (3) media opacities (excluding PCO), and (4) inadequate mydriasis (<6 mm). All patients underwent psychophysical tests of visual function and digital retroillumination imaging of the posterior capsule at the same visit.

Visual Function Psychophysics

All patients underwent careful refraction and wore full refractive correction during the tests. Measurements were made monocularly, and the fellow eye was occluded. All vision tests used a forced-choice procedure. Before testing, pupil size was determined in ambient light with a ruler scale and found to be 3 to 4 mm in all patients.

Visual Acuity. High-contrast (100%) visual acuity was measured at 4 m, using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart, which was retroillumiinated at a luminance of 130 cd/m2 (Lighthouse Low Vision Products, New York, NY).

Low-contrast visual acuity was measured using the Bailey-Lovie chart (National Vision Research Institute, Carlton, Victoria, Australia) on which there was a 10% contrast between the letters and background. The chart luminance was held at 85 cd/m2, and the measure-
ments expressed in logarithm of the minimum angle of resolution (logMar).

Contrast Sensitivity. Contrast sensitivity was measured with both the Pelli-Robson letter sensitivity chart (Metropia Ltd., Cambridge, UK) and the CSV-1000 test (Vector Vision; Haag Streit, Harlow, UK), used to assess contrast sensitivity at different spatial frequencies. The Pelli-Robson chart displays 16 groups of Sloan optotypes arranged in triplets of equal contrast. The letters subtend 3 c/deg of visual angle when viewed at 1 m with a chart luminance of 85 cd/m². The successive triplets diminish in contrast from 96% to 1% in 0.15 log units, and contrast threshold is determined by the last group in which at least two of three letters are correctly identified.

The CSV-1000 is a retroilluminated chart that tests contrast sensitivity over a range of spatial frequencies. The luminance of the chart is maintained at 85 cd/m² and is viewed at 2 m. It presents sine wave gratings with four spatial frequencies (3, 6, 12, and 18 c/deg), with each spatial frequency being presented on a separate row of the test. For each frequency, there are 17 patches: the first (far left) represents a very high contrast grating. The remaining 16 are arranged in pairs, one above the other, across the row. For each pair, one patch presents the grating, whereas the other is blank but of the same luminance. The patches decrease in contrast across the row from left to right, and the patient indicates whether the grating appears in the top or bottom patch for each pair. The contrast threshold is measured from the last correct response. The contrast sensitivity levels in each row range from 0.7 to 2.08, 0.91 to 2.29, 0.61 to 1.99, and 0.17 to 1.55 log units for 3, 6, 12, and 18 c/deg, respectively.

Forward Light-Scatter. Forward scatter was measured with the van den Berg straylight meter (Observator BV, Ridderkirk, The Netherlands), which uses the direct-compensation technique.16-17 A glare source is provided by a concentric ring of light-emitting diodes at 10° eccentricity to the fixation light. The diodes flicker at 8 Hz, and flicker is observed in the central fixation target as a result of forward scatter. In the central field, an adjustable flickering light source is presented in counterphase with the scattered light. The subject's task is to abolish the flicker perception by increasing the brightness of the counterphase light source. This is the measure of the forward scatter (stray light). The average of five readings was determined after excluding the highest and lowest values and was taken as the log stray-light value.

Repeatability of Visual Function Tests
The repeatability of the visual function tests was measured in 21 normal eyes of 21 patients, aged between 60 and 70 years (mean, 69). They had undergone Scheimpflug imaging of the lens to demonstrate the absence of lens opacity and fundus photography to exclude age-related macular degeneration. All patients performed the psychophysical tests in random order and then repeated them 1 week later.

Retroillumination Imaging of the Posterior Capsule
Each patient had imaging of the posterior capsule after pupil dilation. The digital retroillumination camera system used was based on a slitlamp (model 120; Carl Zeiss Meditec, Oberkochen, Germany) with optics to provide axial illumination to the camera light path from a flash pack through a fiber-optic cable.18 The images were acquired through a digital camera (DSC 420; Eastman Kodak, Rochester, NY) and then analyzed at a separate site. For all images, only the area corresponding to the central 3 mm of the posterior capsule was investigated. The percentage area of the central 3 mm of the posterior capsule covered by PCO was calculated by dedicated software based on texture.15-19 (Figs. 1, 2). Each pixel within the rhesis was classified as transparent or opaque, depending on the image texture in its immediate locality, as follows. The image was first enhanced by reducing variations due to changes of total illumination, contrast range, and

![Figure 1](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933433/) Raw retroillumination image with the central 3-mm area shown within the circle.

![Figure 2](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933433/) Final segmentation image showing the percentage of PCO within a central 3-mm zone (opacity is black).

![Figure 3](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933433/) Distribution of central 3-mm percentage of PCO in all patients.

### Table 1. Bland-Altman Reproducibility of Visual Function Tests

<table>
<thead>
<tr>
<th>Visual Test</th>
<th>Reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-contrast visual acuity (ETDRS)</td>
<td>−0.01 ± 0.05</td>
</tr>
<tr>
<td>Low-contrast (10%) visual acuity</td>
<td>0.00 ± 0.05</td>
</tr>
<tr>
<td>Pelli-Robson</td>
<td>−0.05 ± 0.16</td>
</tr>
<tr>
<td>CSF at 3 c/deg</td>
<td>−0.04 ± 0.20</td>
</tr>
<tr>
<td>CSF at 6 c/deg</td>
<td>0.01 ± 0.20</td>
</tr>
<tr>
<td>CSF at 12 c/deg</td>
<td>−0.04 ± 0.22</td>
</tr>
<tr>
<td>CSF at 18 c/deg</td>
<td>−0.02 ± 0.20</td>
</tr>
<tr>
<td>Van den Berg straylight meter</td>
<td>−0.02 ± 0.14</td>
</tr>
</tbody>
</table>

Data are the mean difference ± 2 SD.
nonuniformity. Zooming in on the image made it possible to observe opaque regions within the capsulorrhexis, characterized by the appearance of clumps of, on average, between three and four slightly darker pixels, as distinct from the random variation of intensity observed in transparent areas. The variance of the intensity of the clumps within a locality of each pixel was used as the classification index to categorize the pixel as either transparent or opaque. The result of the classification was a segmented image consisting of disjointed regions of contiguous pixels that were either transparent, shown as white, or opaque, shown as black. One benefit from such a display is that the clinical acceptability of the classification may be assessed by comparison of the segmented image with the original.

### Statistical Methods

The repeatability for each test was calculated using the Bland-Altman method. This involved calculating the mean difference of two repeated test measurements and the standard deviation of the differences. For the test to have good repeatability 95% of the differences must be less than 2 SD.

Normality of the data was tested with the Kolmogorov-Smirnov test. The visual function and percentage PCO data were not normally distributed, and association of the data was calculated using Spearman’s rank order correlation. Further analysis of the data was performed with nonlinear regression, to determine the threshold percent-

### Table 2. Spearman and Hinge Point Values for Association of Visual Function and PCO Area within the Central 3 mm of the Posterior Capsule

<table>
<thead>
<tr>
<th>Visual Test</th>
<th>Spearman Rank Correlation*</th>
<th>% PCO Hinge (95% CI)</th>
<th>P (Hinge Points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETDRS</td>
<td>0.57</td>
<td>78 (67–91)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Low contrast Acuity</td>
<td>0.69</td>
<td>46 (21.1–45.9)</td>
<td>0.002</td>
</tr>
<tr>
<td>Pelli-Robson</td>
<td>0.62</td>
<td>46.0 (30.8–59.1)</td>
<td>0.01</td>
</tr>
<tr>
<td>CSF at 5 cpd</td>
<td>0.59</td>
<td>58.1 (24.2–41.1)</td>
<td>0.01</td>
</tr>
<tr>
<td>CSF at 6 cpd</td>
<td>0.82</td>
<td>41.0 (37.3–49.8)</td>
<td>0.01</td>
</tr>
<tr>
<td>CSF at 12 cpd</td>
<td>0.73</td>
<td>44.7 (29.1–51.2)</td>
<td>0.02</td>
</tr>
<tr>
<td>CSF at 18 cpd</td>
<td>0.73</td>
<td>51.2 (42.0–59.3)</td>
<td>0.04</td>
</tr>
<tr>
<td>Van den Berg</td>
<td>0.69</td>
<td>1.0 (0.004–1.006)</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

* All are \( P < 0.0001 \).

![Figure 4](http://iovs.arvojournals.org/pdfaccess.ashx?url=data/journals/iovs/933433/) Scattered plots with hinge points for visual acuity (A), low-contrast visual acuity (B), Pelli-Robson contrast sensitivity (C), and contrast sensitivity at 3 cyc/deg with CSV-1000 (D).
age PCO at which the decline in visual function occurred. These data points are known as "hinge" values. A detailed description of the sophisticated statistical method is provided elsewhere, but in essence this technique is used to find, with statistical significance, where in the data one variable (in this case percentage PCO) causes a decrease in the second variable (visual function parameter).

RESULTS

Visual Function Psychophysics

The results of the Bland-Altman reproducibility test are presented in Table 1. It was found that all the results were highly reproducible. The high repeatability of the results is probably because normal subjects were evaluated; it might be slightly worse in patients with PCO.

Correlation of the Central 3-mm PCO Area with Visual Function

The distribution of the percentage PCO for all patients is shown in Figure 3. For the percentage area of PCO over the central 3 mm of the posterior capsule, there were high correlation coefficients ($r$) with all the visual tests, ranging from 0.57 with ETDRS to 0.82 with the CSV-1000 at 6 cyc/deg (Table 2). It was possible to locate a hinge point in the scatterplots for each visual test—that is, to find the threshold of percentage of PCO at which visual function started to deteriorate (Table 2, Figs. 4, 5). Despite similar correlation coefficients for the different visual tests, the hinge points varied. For ETDRS visual acuity it was 78% PCO; for contrast sensitivity it ranged from 38% at 3 cyc/deg to 51% at 18 cyc/deg. The hinge point for forward light-scatter was close to zero, at 1%.

DISCUSSION

In this study, we set out to determine how the extent and severity of PCO in the central area of the retroillumination image was related to visual impairment. From the images, the percentage area of PCO was used to investigate the relationship between PCO and visual function. The central 3 mm of the posterior capsule was chosen for detailed analysis, as this corresponds to the functional area for vision in the elderly patient with age-related pupillary miosis. More peripheral capsule changes, however, may be clinically relevant in younger patients with larger pupils or under mesopic light conditions, such as night vision for driving, or in those needing treatment for peripheral retinal lesions.

PCO area was measured in the images using a well-established method as an index of PCO severity. In the correlation of central PCO area and visual function, hinge points were determined statistically for each visual test to find out the area of PCO within the central 3-mm zone that must be present to decrease that particular visual function. The value of the hinge point (in terms of percentage of PCO), determined the sensitivity of each test for detecting the change in visual function: the lower the hinge point, the more sensitive the psychophysical test. The tests could be broken down into three categories according to their sensitivity (Figs. 4, 5): the first was high contrast ETDRS visual acuity which showed no decline until 78% of the central 3-mm capsule was covered with PCO and therefore was the least sensitive test, as is well
recognized from clinical experience. The second group of tests measured low contrast acuity or contrast sensitivity and produced intermediate hinge point values. For contrast sensitivity, these values were similar across the range of spatial frequencies, indicating that contrast sensitivity function is globally affected by PCO. This is in agreement with Tan et al. who found that contrast sensitivity function over all spatial frequencies improved after YAG capsulotomy. The third category measured forward light-scatter, with the van den Berg straylight meter, which was the most sensitive test. The low hinge point (<1%) demonstrated that there was a progressive increase in forward light-scatter with increasing percentage coverage by PCO. Tan et al. demonstrated a greater improvement in forward light-scatter than either visual acuity or contrast sensitivity after Nd:YAG capsulotomy, which also shows it to be a very sensitive test. Studies investigating the effect of cataract on visual function have shown that forward light-scatter is a better predictor of functional visual loss than is visual acuity. Previous reports have demonstrated a poor correlation between clinical vision tests and lens opacity, whereas in this study correlations between visual function and PCO were good. A possible explanation for this could be that in the present investigation we used retroillumination assessment of the central 3-mm pupil area rather than backscatter measurements of the whole lens in the cataract studies. It is possible that even better correlations could be obtained if the central 1 mm area were measured.

Visual loss in elderly pseudophakic eyes is caused by both the optical filtering effect of PCO and the gradual decline in the neural elements of image transduction, such as photoreceptor loss and axonal loss in the optic nerve. Forward light-scatter has the advantage of being relatively free of neuronal interactions in comparison to visual acuity or contrast sensitivity, which are influenced by loss of neural function. Thus, the effect of PCO on vision could be determined in isolation by measuring forward scatter, which is not affected by the neural degradative processes. The van den Berg test had a good reproducibility score and is therefore a reliable test in selected patients. However, elderly patients found it difficult to perform, and it is not universally applicable as a clinical test. High-contrast ETDRS acuity underestimated the visual problems of PCO and is therefore clearly an inadequate test for this purpose. As has been found by others, contrast sensitivity and low-contrast acuity are useful tests, in that both are clinically sensitive and easy to perform.

References