Pentacam Tomograms: A Novel Method for Quantification of Posterior Capsule Opacification

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PURPOSE. To develop and validate a method to quantify posterior capsule opacification (PCO) in eyes after cataract surgery and intraocular lens implantation using Scheimpflug Pentacam tomograms and compare its validity with slit lamp retroillumination image analysis.

METHODS. One hundred twenty-four pseudophakic eyes of 124 patients were divided into two groups. Group 1 consisted of 40 eyes with visually significant PCO, and group 2 consisted of 84 eyes without visually significant PCO. Pentacam Imaging was performed after full mydriasis using the 50-scan acquisition protocol, and high-resolution tomograms were reconstructed and analyzed using ImageJ freeware. Retroillumination photographs were captured for group 1 eyes using the Topcon digital slit lamp, and these were analyzed using POCOman software to calculate an aggregate severity grade and percentage PCO value. Correlation coefficients were calculated for PCO values obtained using POCOman and ImageJ.

RESULTS. Mean PCO percentage value obtained using POCOman software was 23.54 ± 6.25 U, mean aggregate PCO severity grade was 0.46 ± 0.28 U, and mean pixel-intensity value using ImageJ was 31.071 ± 8.26 U. There was a significant positive correlation between the percentage PCO (P = 0.000; r = 0.864) and PCO severity grade (P = 0.001; r = 0.490) obtained for group 1 eyes using slit lamp retroillumination images and PCO pixel intensity obtained using Pentacam tomograms.

CONCLUSIONS. Retroillumination photographs are the standard for quantifying PCO. Pentacam tomograms are easier to obtain and are free of flash reflections, and they allow for a more objective analysis. The correlation between the two methods demonstrates that ImageJ analysis of Pentacam tomograms is a viable tool for PCO analysis. (Invest Ophthalmol Vis Sci. 2008;49:2004–2008) DOI:10.1167/iovs.07-1056

Cataract extraction is the most commonly performed ophthalmic surgical procedure, and posterior capsule opacification (PCO) remains the most common postoperative cause of impaired visual acuity.1 Abundant research has been conducted into the prevention and treatment of PCO, and several factors have been established to influence the occurrence of PCO.2 There is continued focus on several experimental and clinical trials, including studies of surgical techniques, intraocular lens design, and drugs to reduce the incidence of PCO. An objective quantitative measurement of PCO is of paramount importance to assess the efficacy of such trials. Although several imaging systems have been reported, at present there is no consensus on an optimal quantification method for PCO analysis. Most of the efforts to design an objective system such as the Posterior Capsule Opacification (POCO),3 Automated Quantification of After-Cataract,4 Evaluation of Posterior Capsule Opacification,5 and the AA System6,7 have been based on analyzing slit lamp retroillumination images.8 However, all these systems have been partially objective. The slit lamp retroillumination images have the disadvantage of reflection artifacts or Purkinje spots. Proprietary software algorithms have been developed to remove these artifacts by fusion of multiple digital images from the same eye.9 photographed in slightly different directions of gaze,10 but this involves a learning curve and is tedious. The use of Scheimpflug imaging to quantify PCO was first reported in 1995 by Lasa et al.11 The earlier Scheimpflug systems could only capture images in one meridian at a time,11 and Hayashi et al.12,13 had analyzed data using single-slit Scheimpflug images in up to four meridians. Subsequently, several studies have been published using Scheimpflug image, and the results have been correlated with histologic findings.14

The Pentacam is a recently introduced rotating Scheimpflug system. The Scheimpflug principle has already been established in the assessment of lens thickness and densitometry,15 corneal transparency, thickness, and curvature, anterior chamber depth,16 and in the detection of intraocular lens (IOL) tilting.17 However, Pentacam is the first Scheimpflug camera-based instrument that can capture images in multiple meridians in a single automated scan.

The purpose of this study was to introduce a new system of measurement that can objectively quantify PCO and to analyze whether the results obtained using this system statistically correlate with the aggregate severity grade and percentage PCO obtained using the POCOman system.18

METHODS

The study was approved by the Hospital Ethics Committee, and all patients gave informed consent in accordance with the Declaration of Helsinki. The patients were recruited from the cataract clinic of Grewal Eye Institute. This was designed as a prospective, nonrandomized, comparative study.

To avoid any bias attributed to the IOL as a result of the different scatter light intensities from the anterior IOL surface,19 the same type of acrylic IOL (AR40c; AMO, Inc., Irvine, CA) was implanted in all the patients.

Exclusion criteria were any of the following: any ocular pathology except cataract managed with surgery and PCO; best-corrected visual acuity after surgery of less than 20/40; pupillary diameter of less than 4 mm after full mydriasis; severe contraction of the anterior capsule opening.

One hundred twenty-four eyes of 124 patients were included in the final analysis. All patients underwent detailed slit lamp examination, Pentacam imaging, and retroillumination photography under full mydriasis. Best-corrected visual acuity (BCVA) using the Snellen chart and...
contrast sensitivity using the Vector Vision charts (CSV-1000; Vector Vision, Columbus, OH) were recorded before mydriasis.

Based on slit lamp retroillumination images (Topcon SLD7; Topcon Digital Imaging System; Topcon, Tokyo, Japan) and visual acuity data, one of the authors (GSB or SPSG) identified the presence of significant PCO. They were blinded to whether the patient had undergone phacoemulsification or posterior chamber intraocular lens implantation in the previous 2 weeks or earlier than that. They identified 40 eyes of 40 patients with significant PCO; these constituted group 1 of the present study analysis. Eighty-four eyes of 84 patients did not have any significant PCO on clinical observation; these eyes constituted group 2 in the final analysis.

Pentacam Scan

For all the patients, Scheimpflug scanning was performed using a rotating Scheimpflug camera (Oculus Pentacam Rotating Scheimpflug Camera; Oculus, Wetzlar, Germany; Pentacam software version 1.09). The Pentacam system captures images of the anterior segment of the eye by a rotating Scheimpflug camera. The patient is seated with his or her chin on a chin rest and forehead against the forehead strap and is asked to fixate straight ahead on a fixation target. The operator visualizes a real-time image of the patient’s eye on a computer screen, with the machine marking the pupil edge and center and corneal apex. The operator can manually focus and align the image. Arrows are displayed on the screen to guide the operator’s alignment of the instrument in the horizontal, vertical, and anteroposterior axes. To reduce operator-dependent variables, the automatic release mode of the Pentacam was used to automatically determine when correct focus and alignment with the corneal apex had been achieved and then to capture an image. The anterior surface of the cornea is calculated with no optical distortion and the tear film has no effect on measurements. Each successive layer, such as the posterior corneal surface and the anterior lens surface, is calculated by ray tracing, with the calculation taking into account optical distortion.

Imaging was performed after full mydriasis using the 50 scans setting obtained in 2 seconds. The Pentacam Rotating Scheimpflug Camera software reconstructs the tomogram from the Scheimpflug images and calculates a virtual model of the anterior segment of the eye. The automatic-release mode was used, and Pentacam tomograms were reconstructed in the high-resolution mode. The slicing function in the three dimensions offers a detailed view of the different layers of the eye. The 50-scan mode permits capturing the maximum accuracy and details of the tomograms. The high-resolution tomogram was rotated so as to be aligned in the vertical plane with the ‘show lens’ option checked, and the image was saved in jpeg format.

Pentacam Tomogram Analysis

The density value of the PCO on the Scheimpflug slit image was calculated in terms of pixel intensity (DG). NIH ImageJ medical imaging software (NIH ImageJ; National Institutes of Health, Bethesda, MD), developed by the National Institutes of Health and available as a free download from http://rsb.info.nih.gov/ij/ (accessed October 11, 2007), was used for this purpose. PCO tomograms obtained using the Pentacam software were exported to ImageJ software. The visually significant central 4-mm pupillary area was selected using the circle selection tool on the ImageJ software. A 4-mm central region was chosen because it matches the most optically important portion of the visual axis; using larger diameters frequently includes the anterior capsulotomy edge. The scale on ImageJ was defined by measuring the size in pixels for a feature of known true size. In this case, the 6-mm IOL optic diameter was first calculated on an image. The number of pixels that corresponded to 6 mm was calculated. For the Pentacam tomograms, 1 mm corresponded to 36.52 pixels on the screen.

The 4-mm central region selected for analysis matched the central 4-mm diameter area of PCO analyzed on POCOman. To select an area with a 4-mm diameter that corresponded to the 4-mm diameter area analyzed on the POCOman software, a circle with an area of 16,752 pixels was drawn (Fig. 1). The circle was then added as a "region of

FIGURE 1. Selecting the central 4-mm diameter area on the Pentacam tomogram using ImageJ.

FIGURE 2. Applying the edge detection tool using ImageJ on the selected central 4-mm diameter area.

FIGURE 3. Slit lamp Retroillumination Image analysis using the POCOman software system.
Interest,” a feature available in ImageJ (version 1.38x). This feature helps to define and save the region of interest in the initial image. The region selection could be replicated on all Pentacam tomograms while ensuring the circle size of 16,752 pixels and the position on the circle selected remained constant across all images, thus maintaining standardization of the analysis. Subsequent to the selection of the area to be analyzed, the “find edges” tool was applied on the area (Fig. 2). This edge detection software function allowed the detection and delineation of the edges of the selected area with an opacified posterior capsule. The ImageJ “measure” function was then applied. This included area densitometry to measure the scattering light intensity (pixel intensity), which is the opacification density of the posterior capsule. Pixel intensity is based on the classification of each pixel into a range from 0 to 255 (256 steps), depending on the intensity of the pixel on the computer screen.

ImageJ automatically averaged the pixel intensity value of the entire target area. Therefore, the averaged value of the pixel intensity (PCO density) of the posterior capsule in the tomogram image was calculated. Standardization and calibration of the Pentacam tomogram image are automated by Pentacam software, and the blue background is identical for all images, allowing for standardized analysis using ImageJ.

Repeatability of the System
To determine the repeatability of this system, five Pentacam scans were performed on each eye, and five PCO tomograms were obtained. Each patient was asked to sit back and relax for 3 minutes between scans. The joystick of the Pentacam system was completely retracted after each scan and subsequently realigned to ensure that every measurement was independent of the previous one. Intraoperator repeatability of this image analysis method was calculated in 20 patients by analyzing five consecutive tomograms of each patient.

POCOman Image Analysis
Slit lamp retroillumination photographs in jpeg format were captured using slit lamp retroillumination imaging (Topcon Digital Imaging System; Topcon) at a 6-megapixel resolution. The images were captured at a uniform slit beam width and angle, with observation and illumination arm aligned coaxially. These images were analyzed (RJ) using the POCterior Capsule Opacification MANual (POCO) system, available as a free download from http://83.146.11.19/poco/POCOman.html (accessed October 11, 2007).

PCO severity grade and percentage PCO were calculated on the POCO system. The POCO system provides a semiobjective method of grading PCO using a computerized sectoral overlay of the digital image. The IOL optic edge is defined, and subsequently the area of anterior capsulorrhexis is selected. Information outside this area is discarded from subsequent analysis. The area within the defined capsulorrhexis is masked to identify it as the area for analysis. A grid overlay is then placed over the area, and segments with greater than 50% PCO are marked as mild, moderate, or severe PCO by the operator (Fig. 3). The calculate function, which provides an aggregate PCO severity grade and a percentage PCO for the posterior capsule, is then used. PCO severity can be graded by visual reference to icons of PCO as follows: 0 = clear, 1 = mild, 2 = moderate, and 3 = severe. Severity score ranged from 0 (totally clear) to 3 (total severe opacification). Severity score was calculated according to the formula: \[
\text{Severity score} = \frac{(\text{area of grade 1} \times 1) + (\text{area of grade 2} \times 2) + (\text{area of grade 3} \times 3)}{\text{total area}}.
\]
The area analyzed on POCOman had a diameter of 4 mm, which was calculated by comparing the diameter of the area analyzed to the diameter of the IOL optic (6 mm) using the linear distance calculation tool on ImageJ.

Statistical Analysis
All the data were analyzed using commercial software (SPSS 13; SPSS, Chicago, IL). Pearson correlation coefficient \((r)\) was calculated to determine the correlation between ImageJ analysis and POCOman. The Bland–Altman method was used to analyze repeatability of ImageJ analysis. \(P < 0.05\) was considered significant.
RESULTS

Mean ages of the patients were 63.4 ± 18.16 (range, 44–75 years) years in group 1 and 63.19 ± 13.36 (range, 46–81 years) years in group 2. Mean BCVA was 0.33 ± 0.19 (approximately 20/60; range, 20/30–20/400) in group 1 and 0.92 ± 0.25 (approximately 20/25; range, 20/15–20/40) in group 2. The ImageJ method of calculating PCO pixel intensity value demonstrated good repeatability. The 95% limits of agreement were ±2.910 U (Fig. 4). Mean PCO percentage value obtained using POCOman software was 23.34 ± 6.25 U, mean severity grade for PCO was 0.46 ± 0.28 U, and mean pixel intensity value using ImageJ was 31.071 ± 8.26 U. There was a statistically significant positive correlation between pixel intensity obtained using ImageJ and PCO percentage value ($P = 0.000; r = 0.864$; Fig. 5). The aggregate severity grade for PCO obtained using POCOman also correlated with the ImageJ pixel intensity ($P = 0.001; r = 0.490$; Fig. 6). There was no significant correlation of PCO density with BCVA.

Mean pixel intensity calculated using the Image J software in group 2 was 8.75 ± 7.42 U, which was significantly different from the PCO pixel intensity in group 1 ($P = 0.0015$).

DISCUSSION

The present study demonstrated a significant correlation between the Pentacam Scheimpflug tomograms and slit lamp
retroillumination images in calculating PCO. The advantages of the Pentacam tomograms over the slit lamp retroillumination images are that there are no flash reflections in the tomograms and the generation of the tomogram is almost operator independent when the Pentacam automatic release mode is used. Images are also obtained more quickly, require minimal operator expertise, and involve a quick learning curve. Subjective elements inherent in first obtaining retroillumination images on the slit lamp and subsequently assessing the area and severity of PCO are reduced because the operator-dependent component is limited to the placement of the circle selecting the region of interest for performing the edge detection.

Pentacam Scheimpflug tomogram images have a distinct advantage over the previous Scheimpflug camera (Anterior Eye Segment Analysis System EAS 1000; Nidek, Tokyo, Japan) on which PCO density was analyzed in the central 3-mm region. Because the tomogram is reconstructed from 50 Scheimpflug images, it covers almost the entire area of the posterior capsule instead of a single slit beam meridian or the average density calculated from four meridians. The rotating Scheimpflug camera allows 50 images to be reconstructed into a single image (Fig. 7).

Before the availability of the Pentacam tomograms, there was no way to correlate the value of PCO obtained on Scheimpflug images with the slit lamp images because the principles of the two photographic techniques are different. Tomograms allow the creation of a Scheimpflug-based PCO image in the same plane as a slit lamp retroillumination image, and the two may be compared (Fig. 8).

In our study, during the analysis stage, the main source of variability was the placement of the 4-mm circle that delineated the region of interest. We used the region of interest function on ImageJ to place the circle at the same point relative to the image in all the tomograms. It is also feasible to establish algorithms that use anatomic landmarks to automate the placement of the circle.

The Pentacam Rotating Scheimpflug Image-based ImageJ analysis system for quantification of PCO produced highly reproducible results that correlated with the results obtained from analysis of slit lamp–based retroillumination photographs using the POCOman system.

Given that the tomograms are easier and quicker to obtain, provide PCO pixel intensity in up to 50 meridians, have no observer bias, and allow for a more objective analysis than slit lamp images, Pentacam tomograms have the potential to become a grading system for PCO. In conclusion, the tomogram-based analysis described in this article provides a reproducible method to quantify PCO and should prove useful in the investigation of strategies to limit this important complication of cataract surgery.

References