Confocal fundus imaging with a scanning laser ophthalmoscope in eyes with cataract

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Abstract

Aims/Background—The study aimed to determine the influence of increased intraocular light scatter on the contrast in scanning laser ophthalmoscope (SLO) images and to examine to what extent SLO images can visualise the fundus through media opacities due to cataract. **Methods**—Intraocular light scatter was estimated from measurements of letter contrast sensitivity before and after cataract surgery in five eyes. SLO images were obtained before and after surgery using confocal apertures of 1, 2, 4, and 10 mm, at laser wavelengths of 633 and 780 nm. Visibility of the fundus was determined by measurements of retinal contrast. SLO images were compared with standard fundus photographs.

Results—SLO images obtained before surgery revealed details of the retina that were unresolvable in the fundus photographs because of light scattering. By using one of the three smallest apertures, image contrast was further improved. However, no simple relations between aperture size, estimated light scatter, and image contrast could be found.

Conclusion—SLO imaging was found to be superior to fundus photography for viewing the retina in eyes with cataract. Owing to the inhomogeneous nature of cataracts, the optimal choice of confocal aperture and laser wavelength is not simple and must be individualised.

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Every year in Sweden about 40 000 people undergo cataract surgery. The majority of these patients obtained satisfactory postoperative vision. However, in a minority of eyes, cataract surgery fails to restore visual acuity. A common explanation is age-related macular degeneration that has not been diagnosed preoperatively owing to inadequate examination of the fundus through the cataractous lens.

The conventional methods for fundus

examination are indirect ophthalmoscopy and fundus photography. Unfortunately, the image quality of the retina obtained from both these methods is greatly affected by increased intraocular light scattering (see Fig 1).

By using a scanning laser ophthalmoscope (SLO) some of the problems of intraocular light scattering due to cataract may be reduced. The SLO illuminates only a small area of the retina at a time and uses a small entrance beam. By positioning confocal apertures in front of the detector scattering light can be reduced which further improves the quality of the image.^{1 2}

The Rodenstock 101 offers a choice of confocal aperture sizes in combination with different laser wavelengths. However, it is not obvious how to combine these variables. Manivannan *et al*³ have shown that it is possible to achieve a good retinal image in a cataractous eye with an infrared SLO, and a theoretical model was derived by Beckman *et al*.⁴ The intention of the present study was to find optimal combinations of aperture sizes and laser wavelengths yielding the highest possible quality of retinal images through cataractous eyes.

Patients and methods

Five patients, three women and two men, participated in this initial study (Table 1). They were all referred to the eye clinic at Sahlgren's Hospital for cataract surgery. Ages ranged from 50 to 82 years and visual acuity (VA) varied between 0.16 (20/125) and 0.5 (20/40). All patients were tested a few weeks before surgery. Extracapsular cataract extraction (ECCE) was performed with implantation of a posterior chamber intraocular lens (IOL). Postoperative measurements were performed 2-8 weeks after surgery.

Each patient's VA and letter contrast threshold (c) were tested with a standard VA test chart⁵ and a Pelli-Robson (P-R) letter chart.⁶ P-R contrast sensitivity was defined as $-\log_{10}(c)$, where c is the lowest contrast at which at least two out of three letters on the chart could be identified. From contrast

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Table 1 Data and test results from five patients with cataract before and after surgery. Light scatter is estimated from equation (1). Contrast enhancement is defined as the ratio between pre- and postoperative image contrast

Patient	Sex	Age	Cataract type*	Scatter	Preoperative results		Postoperative results		Maximum contrast ratio (aperture size (mm))	
					VA	P-R	VA	P-R	633 nm	780 nm
IO	F	50	PSC	0.9	0.16	0.75	1.3	1.65	0.5 (2)	0.5 (2)
LS	M	70	PSC	0.8	0.25	1.05	1.3	1.8	0.4 (4)	1.0 (1)
AL	F	75	CC	0.3	0.5	1.5	0.8	1.65	0.6 (1)	1.0 (1)
LA	F	82	NC+CC	0.3	0.3	1.5	0.5	1.65	0.4 (1)	0.4 (1)
AF	M	68	PSC+NC	0.0	0.4	1.65	1.0	1.65	0.7 (2)	1.0 (4)

*PSC=posterior subcapsular cataract; CC=cortical cataract; NC=nuclear cataract.

Fig 1A

Fig 1B

Figure 1 Canon fundus photographs taken (A) before and (B) after cataract surgery in the left eye of patient LS. The cataract is estimated to scatter about 80% of the transmitted light.

threshold measurements before and after cataract surgery the fraction of light that was scattered in the extracted cataractous lens can be estimated.⁷ This estimation assumes that the impairment of contrast sensitivity before surgery is caused by increased intraocular light scatter only, and that postoperative contrast threshold is equivalent to retinal contrast threshold. The fraction of light being scattered was estimated using the equation:

$$k = \frac{c_{\text{pre}} - c_{\text{post}}}{c_{\text{pre}}} \quad (1)$$

where c_{pre} and c_{post} are contrast thresholds measured before and after surgery. After these clinical tests the pupil was dilated with cyclopentolate (Cyclogyl 1%). After full dilatation the fundus of each patient's cataractous eye was photographed with a standard fundus camera (Canon CF-60U). Field of view was 60°, flash, aperture size, and exposure time automatic. Ektachrome 100 film (Kodak) was used.

SLO images were obtained from all patients using a Rodenstock SLO 101 and recorded on a VCR (Super VHS). The field of view was 40°. The inbuilt refraction error correction was used and set to each eye's refraction as determined by subjective refractioning. Laser wavelengths were 633 and 780 nm. Laser power varied between 50 and 150 μW at 633 nm and 0.2 to 2 mW at 780 nm. The diameter of the beam entering the eye was about 1 mm. In the Rodenstock SLO 101 the reflected light is focused onto the confocal aperture and the detector by a lens system with a focal length of about 180 mm. Four different confocal apertures with diameters of 1, 2, 4, and 10 mm were tested. The automatic gain function was used to keep the video signal constant.

SLO images from each patient, wavelength, and confocal aperture were digitally stored (TIFF) on a PC using a frame grabber (Image/VGA-Plus Board). The SLO image quality in each eye was evaluated by estimating the contrast of the inferior branch retinal vein, using an image analysing program (OPTIMAS). Contrast was defined as $(I_{\text{max}} - I_{\text{min}})/(I_{\text{max}} + I_{\text{min}})$, where I_{max} and I_{min} are maximum and minimum intensities, respectively. For each eye its postoperative contrast served as a reference. Contrast measurements were made at the same retinal location before and after surgery. OPTIMAS software allows luminance measurements along a line placed perpendicular to the vessel. The lowest luminance value on the vessel was compared with mean background luminance. For each wavelength and each confocal aperture the ratio between preoperative and postoperative contrast was calculated. Hence, the more image quality improved after surgery – that is, the more light that was scattered by the cataractous lens, the smaller the contrast ratio. For example, with an ideal imaging method, allowing perfect image quality through a cataractous lens and with no improvement after surgery, contrast ratio would be unity.

An attempt was made to perform similar contrast measurements on fundus photographs obtained before and after cataract surgery. Fundus photographs were digitised using a scanner (Scanmaker 35t) and analysed in the same way as the SLO images. However, in two cases the analysis failed because no contrast could be measured in the preoperative photographs and the contrast ratio was thus zero. In the other three cases, postoperative photographs were not of sufficient quality to allow comparison. The reason for the poor image quality was inadequate mydriasis after surgery. With the SLO allowing imaging through much smaller pupil size, no such difficulties were encountered.

Results

The results from measurements of VA and P-R contrast sensitivity are presented in Table 1. All patients improved their VA after surgery. P-R contrast sensitivity was improved in all patients but one (AF) indicating that

Fig 2A

Fig 2B

Fig 2C

Fig 2D

Figure 2 Scanning laser ophthalmoscope images taken before surgery at a laser wavelength of 633 nm in the same eye as in Figure 1A (patient LS). Four different confocal aperture sizes were used: (A) 10 mm, (B) 4 mm, (C) 2 mm, (D) 1 mm.

intraocular light scattering was the main cause of the reduced contrast sensitivity in this group of patients. Estimated light scattering values ranged from 0 to 90%.

Figures 1 to 4 illustrate the differences in

image quality between conventional fundus photography and confocal SLO imaging at 633 and 780 nm. Figure 1A presents a fundus photograph taken before cataract surgery in a 70-year-old man with nuclear cataract (patient

Fig 3A

Fig 3B

Fig 3C

Fig 3D

Figure 3 Scanning laser ophthalmoscope images taken before surgery at a laser wavelength of 780 nm in the same eye as in Figure 1A (patient LS). Four different confocal aperture sizes were used: (A) 10 mm, (B) 4 mm, (C) 2 mm, (D) 1 mm.

Fig 4A

Fig 4B

Figure 4 Scanning laser ophthalmoscope images taken 8 weeks after surgery in the left eye of patient LS at a laser wavelength of (A) 633 nm and (B) 780 nm, using a 2 mm confocal aperture.

LS). Preoperative VA was 0.25 and intraocular scattering was estimated to about 80%. The photograph in Figure 1B was taken 8 weeks after surgery. Figure 2 presents preoperative SLO images obtained from the same eye using four different confocal apertures (aperture diameters: A: 10 mm, B: 4 mm, C: 2 mm, and D: 1 mm) at a laser wavelength of 633 nm. Figure 3 presents SLO images using the same aperture sizes as in Figure 2, but at a laser

wavelength of 780 nm. All SLO images revealed details that were hidden in the fundus photograph taken preoperatively. In general, the image quality was improved by a smaller confocal aperture.

As a reference, Figure 4 presents SLO images taken postoperatively in the same eye as in Figures 2 and 3 using the 2 mm confocal aperture at laser wavelengths of 633 nm (Fig 4A) and 780 nm (Fig 4B). As expected the image contrast was improved when the light scattering lens was removed. Resolution was much better in a conventional fundus photograph than in an SLO image (Fig 1B). However, in a conventional fundus photograph, colour adds an additional modality that partly could explain the subjective sense of superiority of image quality.

In Figure 5, contrast ratio is plotted against confocal aperture size for wavelengths 633 nm (Fig 5A) and 780 nm (Fig 5B). As expected, SLO images obtained with the largest aperture (10 mm) showed the smallest contrast ratio (that is, preoperative contrast was poor). With smaller apertures the image quality was improved, although the optimal aperture size differed between eyes (Table 1). In general, contrast ratio was larger with a wavelength of 780 nm. However, absolute contrast values were higher with 633 nm and so was spatial resolution, both before and after lens extraction. Estimated light scatter and optimal aperture size were not related to contrast enhancement in any obvious way.

Discussion

Fundus examination in eyes with cataract is often difficult. Our study shows that fundus imaging with the SLO was superior to conventional photography in such eyes regardless of confocal aperture size. Since the largest aperture did reduce light scatter less efficiently than the smaller, the main reasons for image enhancement seemed to be the high collimation of the laser beam and the scanning illumination of the retina.¹

With smaller confocal aperture sizes, image quality was improved. However, with the smallest aperture (1 mm) contrast was sometimes reduced. The main reason for this is probably the reduced light intensity reaching the detector combined with the limitation of

Figure 5 Calculated contrast enhancement versus confocal aperture size for laser wavelengths of (A) 633 nm and (B) 780 nm. (■) Patient IO; (●) patient LS; (▲) patient AL; (◆) patient LA; (□) patient AF.

laser power because of safety regulations. Another reason could be inadequate focusing due to the reduced depth of focus.

Image quality was not in any simple way related to the psychophysically estimated light scattering in the cataractous lens, nor was it related to the type of cataract (Table 1). We believe that this could be explained by the inhomogeneity of cataracts, allowing the narrow laser beam to penetrate less opacified regions of the lens. During the examination the technician was encouraged to move the beam within the pupil, searching for the best possible retinal image quality.

In this initial study we have shown that the SLO allows retinal imaging through severe cataract. This may facilitate the clinical evaluation and provide prognostic information before cataract surgery. The presence of macular changes is probably the most important prognostic factor and there is a need for methods that can improve preoperative visualisation of macular structures. We are presently investigating whether the SLO can

provide such important preoperative information.

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