SCIENTIFIC REPORT

Influence of cataract on optical coherence tomography image quality and retinal thickness

M E J van Velthoven, M H van der Linden, M D de Smet, D J Faber, F D Verbraak

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Background: As optical coherence tomography (OCT) is widely used for diagnosis and monitoring of ocular pathology, especially in the elderly people, the influence of cataract on image quality and macular retinal thickness was studied.
Methods: In 29 patients scheduled for cataract surgery, preoperative and postoperative OCT scans were obtained. Cataracts were categorised as nuclear, posterior or cortical. Parameters for image quality (signal-to-noise ratio (SNR)) and signal strength and macular thickness were compared. A three-level expert grading scale was used to evaluate the discriminative abilities of SNR and signal strength.
Results: Nuclear cataracts (n = 12) provided better preoperative scans (higher SNR/signal strength) than posterior (n = 7) and cortical (n = 10) cataracts ($p<0.004$). Postoperatively SNR and signal strength increased significantly in all patients ($p<0.001$). The SNR was better at discriminating poor from acceptable and good scans than signal strength (area under the receiver operating curve: 0.879 and 0.810, respectively). Postoperative macular thickness overall showed a significant increase (p = 0.005), most evident in patients with posterior cataracts (p = 0.028).
Conclusions: OCT imaging is influenced by cataract; image quality is reduced preoperatively and macular thickness measurements are slightly increased postoperatively. In individual patients, OCT scans remain reliable for gross clinical interpretation, even in the presence of cataract.

In the elderly population, cataract is a common cause of media opacity that can affect diagnostic imaging quality. Optical coherence tomography (OCT) is an important ophthalmic diagnostic tool, particularly in macular diseases affecting the ageing population, such as age-related macular degeneration and diabetic retinopathy.[1] OCT imaging relies on near-infrared light. Similar to fundus photography and scanning laser ophthalmoscopy,[2 3] a cataract is likely to cause light scattering and degrading of the image quality.

Variations in OCT measurements before and after cataract surgery have been reported in only a few case series, particularly focusing on cystoid macular oedema (CMO).[4 5] One study[6] showed an improved signal-to-noise ratio (SNR) in OCT scans after YAG (yttrium aluminium garnet)-laser treatment of posterior capsule opacification, without an effect on macular thickness. Ching *et al*[7] recently reported a decreased retinal thickness in patients after phacoemulsification accompanied by an increase in SNR.

Recently, signal strength was introduced in the StratusOCT software (Carl Zeiss Meditec, Dublin, California, USA) as a new measure of image quality. Our study aimed to assess the influence of cataract on OCT scans, to determine the ability of SNR and signal strength to evaluate image quality, and to evaluate preoperative and postoperative macular thickness measurements in patients undergoing cataract surgery.

MATERIALS AND METHODS

Patients enroled for cataract surgery at the Academic Medical Centre, Amsterdam, The Netherlands, were recruited for the study between September and December 2003. Patients were eligible when media opacity was limited to the presence of a cataract, refractive error was between S+4 and S−4, and there was no retinal pathology, such as proliferative diabetic retinopathy, age-related macular degeneration, severe uveitis or glaucoma, affecting central fixation. All participants gave verbal consent, and the study complied with the Declaration of Helsinki. The protocol design was submitted to the institutional review board and judged to meet the required ethical standards set in Dutch law on human experimentation.

Patients underwent full ophthalmic examination preoperatively and 4 weeks postoperatively. Cataracts were classified as nuclear, cortical or posterior, based on the highest score using the Lens Opacities Classification System III (LOCSIII) scoring system.[8] If the score was >NO3–NC3 and <C3 and P3, the cataract was categorised as nuclear. If the score was ⩾C3 it was categorised as cortical and if it was ⩾P3 it was categorised as posterior. If the score was ⩽NO3–NC3, the highest C or P score was used to categorise the cataract. After pupil dilation at both visits, patients were scanned with OCT (StratusOCT, V.2.0.2 and V.4.0.1) by the same OCT photographer. Both macular thickness and fast macular thickness protocols were carried out; for each protocol three scans were made, of which the best one was used in the final analysis.

Only preoperative scans were used for a subjective, three-level expert grading (1, poor; 2, adequate; or 3, good) by three observers. All individual scans were randomly presented, and the observers were blinded for objective image quality and the LOCS score. The three scores were summed into an overall expert assessment: score 3–4, poor; 5–7, acceptable; and 8–9, good. To evaluate postoperative change in image quality, the SNR (in dB) and the signal strength (no unit) were obtained for the individual scan. The SNR and signal strength of the six radial lines were averaged and used for analysis. Differences in preoperative and postoperative macular thickness were analysed as an average retinal thickness of all nine areas using the 6 mm map, and for the central foveal area (area with 1 mm diameter). If errors were detected in the output of the retinal thickness maps, individual scan lines were taken out of the map analysis after evaluation of the automated algorithm's performance in defining the retinal thickness.

Statistical analysis was carried out for the whole group and per cataract category using SPSS V.12.0.2. κ agreement and

Abbreviations: CMO, cystoid macular oedema; LOCS, Lens Opacities Classification System; OCT, optical coherence tomography; SNR, signal-to-noise ratio

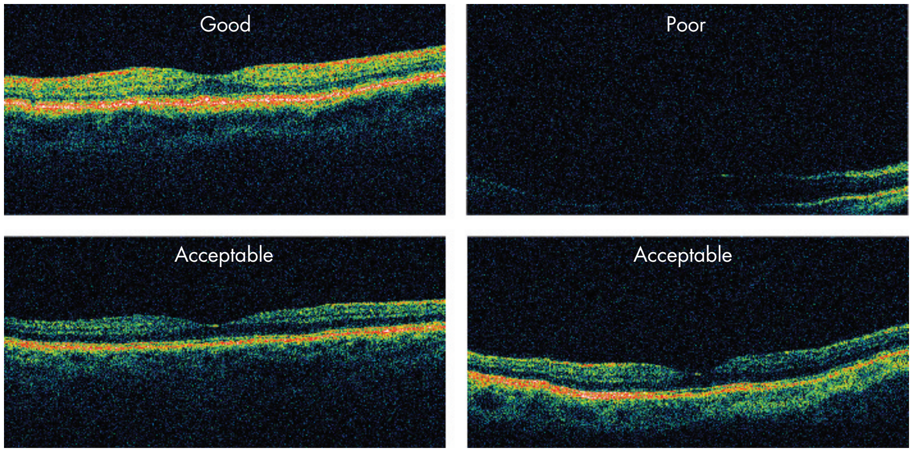

Figure 1 Optical coherence tomography scans of varying image quality based on the expert assessment.

Spearman's correlations were calculated for the expert assessment. The summed expert assessment was used as the golden standard for image quality to assess the ability of the SNR and signal strength to discriminate poor OCT scans from acceptable and good scans by calculating areas under the receiver operating characteristic curve. Non-parametric testing for paired data was carried out to compare preoperative and postoperative image quality parameters (SNR and signal strength) and thickness measurements. For all analyses, $p<0.05$ was considered to be significant.

RESULTS

In total, 30 patients (30 eyes) were recruited for the study. One patient was excluded because of a dense cataract through which a preoperative OCT scan could not be obtained (NO4–NC4–C4–P5). Twenty nine patients (29 eyes) were left for analysis. The overall mean (standard deviation (SD)) age was 70.5 (10.6) years, with a significant difference between the patients with nuclear ($n = 12$), cortical ($n = 10$) and posterior ($n = 7$) cataract (75.9 (9.4) years, 70.7 (10.1) years, 60.9 (6.5) years, respectively, $p = 0.012$). Median preoperative visual acuity for nuclear cataracts was 0.45 (0.32–0.80), for cortical cataracts 0.56 (0.2–1.0) and for posterior cataracts 0.4 (0.1–0.63). No significant difference was observed in visual acuity between the cataract groups.

Figure 1 shows OCT scans of varying quality. In 3 of the 174 OCT scans scored by the experts, an SNR was not obtained. The overall agreement was fair (mean $\kappa = 0.41$), and showed a marginal positive correlation (Spearman's rank correlation: mean $r = 0.658$, $p<0.001$). In the summed expert assessment, 14% of the scans were qualified as poor, 41% as acceptable and 45% as good. In the patients with a predominance of nuclear cataract, 63% of the scans were graded as good versus 38% and 26% of the scans in patients with predominantly cortical and posterior cataracts. Only 4% of the scans in patients with predominantly nuclear cataract were poor versus 22% in patients with cortical cataract and 19% in those with posterior cataracts. This was confirmed in the averaged SNR and signal strength per cataract category (table 1). Receiver operating characteristic curves for discriminating poor scans from acceptable and good scans are shown in fig 2.

No significant differences were found in retinal thickness measurements or image quality parameters between the two different scan protocols, and the results presented here are based on the fast macular thickness protocol scans. Both SNR and signal strength increased significantly postoperatively (table 1). Nuclear cataracts ($n = 12$) provided better preoperative scans (higher SNR/signal strength) than posterior ($n = 7$) and cortical ($n = 10$) cataracts ($p<0.004$). Table 1 shows the change in average retinal thickness and retinal thickness in the central foveal area. Preoperatively, there was no difference in average retinal thickness between the subgroups. No correlation was found between preoperative retinal thickness and age. Postoperative change in average retinal thickness for all eyes was found to be significantly increased. Subgroup analysis showed a statistically significant difference only in the posterior cataract group. As none of the patients developed CMO, the increased thickness cannot be ascribed to this cause. A similar effect in retinal thickness was found in the individual map areas (not shown). Figure 3 shows the relationship between the change

Table 1 Preoperative and postoperative values of quality parameters (signal-to-noise ratio and signal strength) and retinal thickness per cataract category and for the whole group

	Nuclear (n = 12)		Cortical (n = 10)		Posterior (n = 7)		Total (n = 29)	
Parameters	Mean (SD)	p Value*	Mean (SD)	p Value*	Mean (SD)	p Value*	Mean (SD)	p Value*
Preop SNR	36.96 (3.95)		32.78 (7.91)		34.69 (3.76)		35.38 (5.88)	
Postop SNR	40.43 (4.83)	0.015	41.57 (2.62)	0.005	38.60 (3.27)	0.018	40.38 (3.87)	<0.001
Preop SS	6.61 (1.35)		5.30 (2.44)		5.40 (1.43)		5.87 (1.86)	
Postop SS	7.89 (1.29)	0.003	8.38 (1.24)	0.005	7.38 (1.61)	0.018	7.94 (1.36)	<0.001
Preop RT	242.3 (14.5)		231.7 (26.6)		255.5 (46.1)		241.8 (29.1)	
Postop RT	243.1 (19.2)	0.182	241.7 (14.2)	0.093	264.7 (47.8)	0.028	247.4 (31.1)	0.005
Preop RT (A1)	212.9 (23.7)		201.7 (39.9)		232.4 (83.6)		213.8 (48.6)	
Postop RT (A1)	214.8 (25.0)	0.289	210.4 (26.9)	0.678	240.4 (78.9)	0.244	219.5 (44.3)	0.258

*Wilcoxon signed-rank test for paired data (preoperative and postoperative data).
A1, central foveal area of the retinal thickness map (1 mm diameter); preop, preoperative; postop, postoperative; RT, retinal thickness; SNR, signal-to-noise ratio (dB); SS, signal strength (no unit).

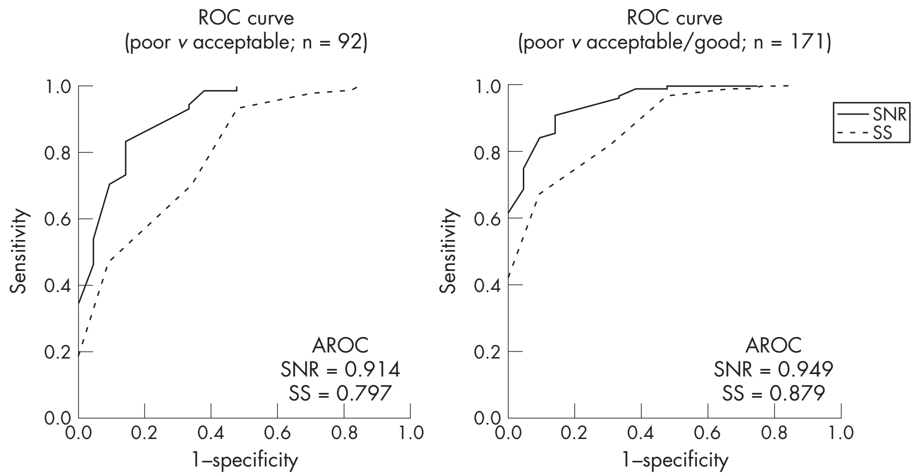

Figure 2 Receiver operator characteristic (ROC) curves for signal-to-noise ratio (SNR) and signal strength (SS) discriminating poor scans from acceptable (left) and from acceptable/good optical coherence tomography scans (right). SNR was better in discriminating poor scans than SS. AROC, area under the ROC curve.

in OCT signal quality (SNR and signal strength) and the change in retinal thickness. This relationship was most evident in patients with cortical cataracts (not shown).

DISCUSSION

Despite the fact that OCT is widely used by ophthalmologists to diagnose and monitor patients, the influence of cataract on OCT imaging quality is scarcely investigated. This study shows that cataracts do have an influence on OCT image quality, but that this influence varies with the type of cataract. Objective parameters of image quality (SNR and signal strength) improved in all cases after removal of the cataract. However, the data suggest that nuclear cataracts have less influence on OCT image quality relative to cortical and posterior cataracts. For the whole group, postoperative OCT scans also showed a considerable increase in retinal thickness after removal of the cataract. However, subgroup analysis showed significance only in the posterior cataract group. It must be said, however, that the sample group is relatively small, which makes statistical analysis of subgroups more difficult, despite the use of non-parametric testing.

Although cataracts have less influence on OCT than on fundus photography or confocal scanning ophthalmoscopy,[2 3 9] more severe cataracts do influence image quality. It can be hypothesised based on the nature of nuclear cataract that this cataract mainly absorbs the near-infrared light but causes minimal light scattering. Therefore, only the intensity of the back-reflected signal will be decreased, but the light beam itself remains intact. On the basis of the nature of posterior or cortical cataracts, it can be hypothesised that in these cataracts the incident and back-reflected light beams are more affected by scattering. Plaques in posterior cataracts will probably distort the OCT image early on, but only cortical cataract close to the visual axis will affect OCT image quality. This leads to more severe distortions of

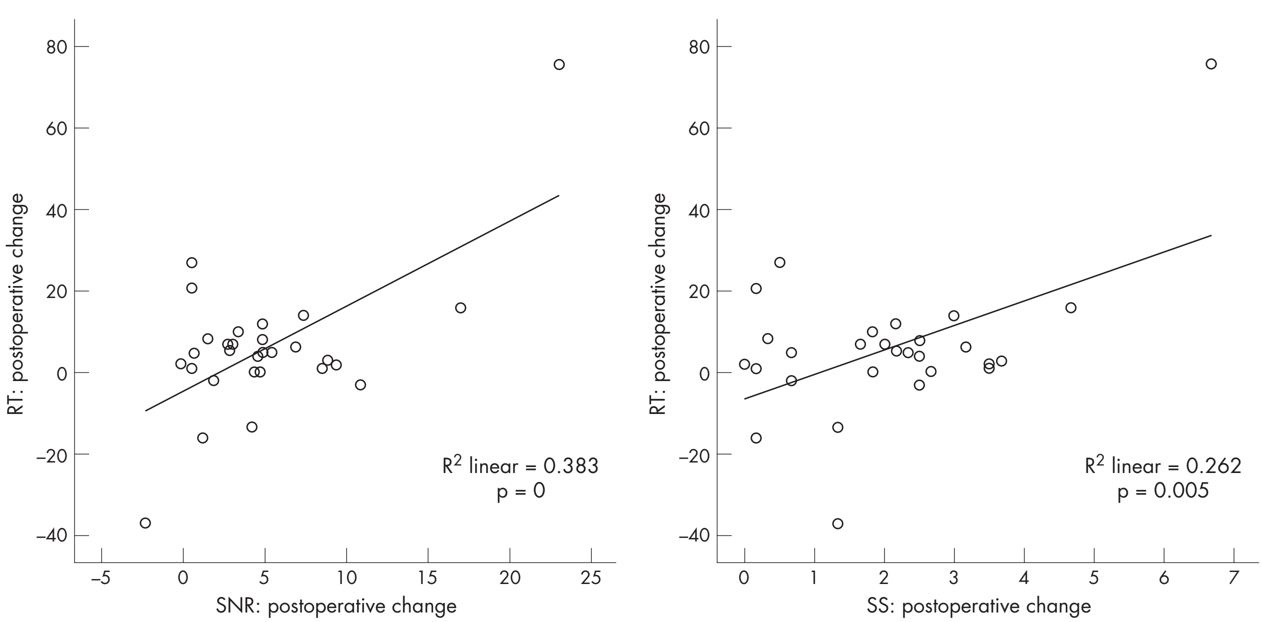

Figure 3 Scatter plots of postoperative change in retinal thickness (RT) versus change in image quality given by signal-to-noise ratio (SNR, left) and signal strength (SS, right). The plots show a correlation between the change in RT and the change in both SNR and SS. This was most evident for the cortical cataracts (not shown).

reflected light contributing to the OCT scans. Despite reduced image quality, the OCT scans still have diagnostic value and can be used for individual monitoring of retinal thickness, given that only 14% of the OCT scans were assessed as poor by the experts, and only one patient could not be scanned at all. In individual monitoring of patients with OCT, it must be taken into account that OCT measurements can differ after removal of the cataract, especially in predominantly posterior cataracts.

SNR and signal strength both proved to be reliable measures for image quality, but in this study population SNR was better at discriminating poor OCT scans from acceptable and good scans (fig 2). Stein *et al*[10] found that signal strength was better at this discrimination than SNR. However, Stein *et al* had a relatively small number of scans compared with the present study, and they assessed mainly the optic nerve and retinal nerve fibre layer. In their conclusion, they did state that their newly developed Quality Index was not optimal for qualifying macular scans.[10] We only looked at macular scan lines, which may demand stricter quality guidelines than optic nerve or retinal nerve fibre layer scans. The foveolar area is a relatively signal-poor section in the scan. This might also explain the relative superiority we found for SNR and the fair agreement that was observed in the expert assessment.

There were no patients with signs of CMO postoperatively. Although we did not find a structural postoperative thinning in retinal thickness with the OCT2 like Ching *et al*[7], the improved quality of the OCT signal after surgery may probably result in a better detection of the retinal borders by the software algorithm. The correlations shown in fig 3, although significant, do not seem to be strong, but there does seem to be a trend towards increased retinal thickness measurement with increased SNR or signal strength. Hence, it cannot be ruled out that improved OCT signal quality will lead to a systematic increase in retinal thickness.

Overall we can state that cataract influences both OCT image quality and retinal thickness measurements. Cortical and posterior cataracts influence the OCT signal more than nuclear cataracts, and this needs to be taken into account when interpreting OCT scans in elderly patients. Even in the presence of cataract, OCT scans of individual patients remain reliable for clinical interpretation of gross retinal pathology, such as CMO, meaning that a foveal contour is often discernable, whereas detail on intraretinal structures might be lost. SNR and signal strength are both reliable parameters for image quality, but we could not show that the new parameter, signal strength, is superior.

Authors' affiliations

M E J van Velthoven, M D de Smet, F D Verbraak, Department of Ophthalmology, Academic Medical Centre, Amsterdam, The Netherlands
M H van der Linden, OMC Haarlem, Haarlem, The Netherlands
D J Faber, Laser Centre, Academic Medical Centre

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Correspondence to: M E J van Velthoven, Department of Ophthalmology, Academic Medical Centre, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands; m.e.vanvelthoven@amc.uva.nl

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