Optical coherence tomography: beware of optical illusions

Kok, P.H.B.
The relationship between the optical density of cataract and its influence on retinal nerve fibre layer thickness measured with spectral domain optical coherence tomography

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ABSTRACT

Purpose: The purpose of this study was to model the influence of cataract on Spectral Domain Optical Coherence Tomography (SDOCT) image quality and Retinal Nerve Fibre Layer (RNFL) thickness measurements.

Methods: SDOCT images, made with two different devices (3DOCT-1000, Topcon and Cirrus HD-OCT), before and after cataract surgery were compared and judged against measurements from normal subjects using artificial filters simulating the effects of cataract. Optical density of the images was calculated based on a mathematical model described previously.

Results: In total, forty-eight eyes were included for pre- and postoperative cataract extraction measurements. OCT image quality significantly (p<0.001) improved postoperative and postoperative RNFL thickness was significantly (p<0.001) thicker in both groups of patients. The measurements using artificial filters showed a rather precise linear relation between change in filter induced optical density and change in RNFL thickness (R=0.941, p<0.001 for 3DOCT-1000 and R=0.785, p<0.001 for Cirrus HD-OCT). For the patient groups, the relation was less marked, 3DOCT-1000 Rs=0.697, p<0.03 and Cirrus HD-OCT Rs=0.444, p<0.03. The predictive potential based on the found linear relationship between OCT-effective optical density of cataract and the cataract-induced underestimation was however limited, and mean difference ± SD between predicted and measured RNFL thickness were 1.68 ± 7.55 (3DOCT-1000) and 3.71 ± 2.97 (Cirrus HD-OCT) micron.

Conclusions: A linear relationship exists between OCT-effective optical density of cataract and underestimation of RNFL thickness measured with OCT. This finding holds promise to correct for cataract-induced changes in RNFL measurements, but will differ for each type of OCT device.
INTRODUCTION

Glaucoma causes characteristic structural damage to retinal ganglion cells and their axons, which results in a decrease in visual function. When glaucoma is detected at an early stage, loss of vision can in theory be prevented. Both structural and functional measures are important in the diagnosis and follow-up of glaucoma. Although evidence remains controversial, it is thought that structural damage precedes functional damage. Optical Coherence Tomography (OCT) is a noninvasive imaging technique used to scan the retina and measure retinal thickness and segmented retinal nerve fibre layer (RNFL) thickness using interferometry of low coherence light. Previous studies have shown that OCT measured RNFL thickness can be used to differentiate between normal and glaucomatous eyes.

Even though OCT-based glaucoma studies are hampered by rapid changes in OCT technology, several studies reported an association of thinner RNFL measurements at baseline with the development of glaucomatous change over a 4–5 year follow-up period.

OCT is an optical measurement technique. As such, its image quality is influenced by opacities in the optical path. Loss of OCT image quality, because of disturbances in the optical media, is caused by attenuation of the light in the OCT scanning spot on the retina. In the elderly population, cataract is the most common cause of media opacity that is known to influence the OCT image quality and measurements. It has been demonstrated that RNFL thickness measurements are affected by cataract. The more advanced the cataract, the less the signal quality and the thinner the recorded RNFL thickness. As cataract and glaucoma often coexist in the same eye, cataract can be a confounding factor in the diagnosis and follow-up of glaucoma patients using OCT.

The purpose of this study was to further define and model the influence of cataract on SDOCT image quality and the RNFL thickness measurements. SDOCT images acquired with two different devices before and after cataract surgery are compared and judged against measurements using artificial filters simulating the effects of cataract.

The eventual goal was to establish a relationship between the optical density of cataract and its influence on RNFL thickness measurements to correct for cataract-induced changes in these measurements.

MATERIALS AND METHODS

Pre- and postoperative cataract extraction measurements

Patients scheduled to undergo cataract surgery, receiving a monofocal single piece intraocular lens implant (Acry-Sof®, SN60WF; Alcon Inc., Fort Worth, TX, USA), in the Academic Medical Center, Amsterdam, the Netherlands, or in the Zonnestraal eye clinic in Hilversum, the Netherlands, and who were willing and able to sign an informed consent were recruited for this prospective study. The research followed the tenets of
the Declaration of Helsinki and was approved by the committee of research involving human subjects. Exclusion criteria were hypermetropia of more than +5 dioptres of sphere, myopia of more than -8 dioptres of sphere and the presence of other ocular pathologies which could have an influence on the OCT scans such as diabetic retinopathy, age-related macular degeneration, vascular occlusions, ocular opacities other than cataract. In addition, patients with complicated cataract extraction and postoperative abnormalities such as cystoid macular oedema (CME) were excluded. Visual acuity, lens opacities classification system (LOCS) grading and SDOCT images were obtained for all included patients. Every patient underwent an examination before, and at least 3 weeks after the cataract surgery. Visual acuity was originally measured with ETDRS charts and converted into log(MAR). Lens opacifications were scored after pupil dilation with 0.5% phenylephrine hydrochloride and 0.1% tropicamide using the LOCS III system. If the LOCS score was >NO3–NC3 and <C3 and <P3, the cataract was categorized as nuclear. If the score was >C3, it was categorized as cortical and if it was >P3 it was categorized as posterior. In case of NO3–NC3, or lower, the highest C or P score was used to categorize the cataract (C = P did not occur).

Depending on the clinical site, a 3D volume scan of the optic disc was made in the dilated eye using either the 3DOCT-1000 MarkII, Topcon Medical Systems, Tokyo, Japan (Academic Medical Center) or the Cirrus HD-OCT, Carl Zeiss Meditec, Inc., Dublin, CA, USA (Zonnestraal eye clinic). As output variable, the mean average peripapillary RNFL thickness of a 3.4mm diameter circle was used. The image quality parameter [Qfactor (QF) for 3DOCT-1000 or signal strength (SS) for Cirrus HD-OCT] was collected for analysis. While performing the scans, effort was taken to acquire the images with maximum QF and SS. SDOCT scans were judged on the presence of artefacts and misidentifications of the retinal layers. Minor artefacts were corrected manually. Scans with major artefacts were excluded from further analysis.

Measurements in healthy subjects using artificial filters

Artificial filters were used as previously described. In that study, it was found that the attenuation of the light in the OCT scanning spot on the retina, expressed as optical density, fully described the loss of OCT image quality, irrespective of the nature of the filter, that is, type of cataract. In the present study, only a set of reflective attenuation (Balzers) filters were used to model a range of optical density with corresponding decrease in the OCT image quality. These filters had the same range of optical density values as those observed in cataract patients (six successive filters, optical density ranging from 0.04 to 0.75, see Table 2). Four healthy subjects (mean age, 36.5 years; range, 28–54 years) were scanned with both SDOCT devices (3DOCT-1000, Cirrus HD-OCT) using this set of filters. 3D volume scans (512 a-scans· 128 b-scans) of the optic disc were acquired after pupil dilation with 0.5% phenylephrine hydrochloride and 0.1% tropicamide. Particular care was taken in positioning the subjects’ eye and the filters by checking for potential tilt. The tilt of the filters was estimated to be <10°; in this manner, a maximum error of
Cataract-induced change in RNFL thickness

2% was accepted. Only horizontal b-scans were accepted, as observed on the screen of the device, avoiding tilt of the eye relative to the scanning light. All measurements were taken twice by the same experienced examiner.

QF or SS values and the average peripapillary RNFL thickness provided by the OCT software were collected for analysis after averaging values from the two measurements.

Comparison of measurements in healthy subjects using artificial filters with those in cataract patients using optical density recalculated from image quality parameter

Similar to the model used in the previous study, optical density was used to provide a measure of light attenuation in the OCT scan. By using the optical density values of the filters and of the cataracts, a comparison of these measurements could be made. Optical density measurements of the filters determined for a wavelength of 830 nm were used to correct for the central wavelength of 840 nm of both SDOCT systems. These calibrated optical density values are listed in Table 2. For the patients (cataracts), optical density was calculated from the quality parameters QF and SS of the pre- and postoperative OCT scans using the regression equations calculated from the analysis of the measurements with filters.

SS, ranging 0–10 and QF, ranging 0–100 are both image quality parameters based on the signal-to-noise ratio and the uniformity of the signal strength within a scan. Both manufacturers do not further specify their image quality parameters.

Statistics
Pre- and postoperative parameters were compared by paired two-tailed t-test. Optical density and RNFL thickness of patients with nuclear, cortical and posterior cataract were compared using nonparametric Kruskal–Wallis test. Nonparametric correlation of parameters was performed using Spearman correlation tests.

Linear regression was performed to determine the regression equation between optical density and image quality parameters. Correlation of optical density with change in RNFL thickness by the effect of artificial filters was performed using Pearson correlation test. Homogeneity of regressions was tested using ancova.

In this study, p<0.05 was considered as statistically significant. Statistical software Microsoft Excel (Microsoft Office Excel 2003, Microsoft Corporation, Redmond, WA, USA) and SPSS (spss 16.0; SPSS Inc., Chicago, IL, USA) were used for data analysis.

RESULTS
Pre- and postoperative cataract extraction measurements
Forty-eight eyes of thirty-four patients underwent pre- and postoperative cataract extraction measurements. Twenty eyes were scanned with 3DOCT-1000 and twenty-eight eyes with Cirrus.

HD-OCT. Three scans made using the 3DOCT-1000 were excluded from the analysis because of misidentification of the RNFL boundaries. In case of the Cirrus HD-OCT,
also three preoperative scans were excluded from analysis; one scan because of a motion artefact and two scans because of misidentification of the RNFL boundaries. In total, 17 3DOCT-1000 and 25 Cirrus HD-OCT scans were used for pre- and postoperative comparison. No statistically significant differences in mean age and mean visual acuity were demonstrated between the two groups. Based on their LOCS score, the group of patients scanned with the 3DOCT-1000 consisted of patients with statistically significant (p<0.03) more severe cataracts as compared with the group of patients scanned with Cirrus HD-OCT. See Table 1.

**Measurements in healthy subjects using artificial filters**

Next to the calibrated optical density values for each filter, Table 2 shows the mean image quality parameter values per SDOCT device resulting from the measurements in four healthy subjects.

### TABLE 1. Cataract patient characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cirrus HD-OCT, Zeiss</th>
<th>3DOCT-1000 Mark II, Topcon</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (eyes:patients)</td>
<td>28 : 17</td>
<td>20 : 17</td>
</tr>
<tr>
<td>Gender (M:F)</td>
<td>8 : 9</td>
<td>3 : 14</td>
</tr>
<tr>
<td>Age (years)</td>
<td>72.8 ± 6.8</td>
<td>74.5 ± 9.0</td>
</tr>
<tr>
<td>LOCS III score</td>
<td>NO 3.0 ± 0.5</td>
<td>NO 3.8 ± 1.2</td>
</tr>
<tr>
<td>(mean ± SD)</td>
<td>NC 3.0 ± 0.5</td>
<td>NC 3.8 ± 1.3</td>
</tr>
<tr>
<td></td>
<td>C 1.8 ± 0.6</td>
<td>C 2.1 ± 1.4</td>
</tr>
<tr>
<td></td>
<td>P 0.5 ± 0.6</td>
<td>P 1.7 ± 1.6</td>
</tr>
<tr>
<td>Type of Cataract</td>
<td>9 : 17 : 2</td>
<td>13 : 4 : 3</td>
</tr>
<tr>
<td>(Nuclear: Cortical :Posterior)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 2. Calibrated optical density values of reflective filters and their corresponding mean image quality parameter value per SDOCT device resulting from the measurements in four healthy subjects

<table>
<thead>
<tr>
<th>Filter nominal value</th>
<th>Optical density*</th>
<th>Cirrus HD-OCT, Zeiss Mean Signal Strength (SS) (range)</th>
<th>3DOCT-1000 Mean Qfactor (QF) (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>9.1 (9-10)</td>
<td>72.6 (65.4 – 84.7)</td>
</tr>
<tr>
<td>Reflective 79.2%</td>
<td>0.04</td>
<td>8.6 (7-9)</td>
<td>69.7 (61.3 – 79.9)</td>
</tr>
<tr>
<td>Reflective 63%</td>
<td>0.11</td>
<td>7.8 (7-9)</td>
<td>66.4 (59.1 – 77.7)</td>
</tr>
<tr>
<td>Reflective 51.2%</td>
<td>0.26</td>
<td>6.4 (6-7)</td>
<td>55.1 (45.5 – 67.6)</td>
</tr>
<tr>
<td>Reflective 25.4%</td>
<td>0.54</td>
<td>3.7 (6-7)</td>
<td>34.2 (28.7 – 42.2)</td>
</tr>
<tr>
<td>Reflective 19.6%</td>
<td>0.67</td>
<td>2.2 (3-5)</td>
<td>26.6 (23.0 – 32.7)</td>
</tr>
<tr>
<td>Reflective 16.1%</td>
<td>0.75</td>
<td>1.6 (1-3)</td>
<td>x</td>
</tr>
</tbody>
</table>

* Optical density determined for a wavelength of 830 nm with a negligible difference <0.005 log to 840 nm, the central wavelength of SDOCT.
in healthy subjects. Regression analysis showed a statistically significant linear correlation of OCT image quality with optical density ($R = 0.938$, $p < 0.001$ for QF and $R = 0.957$, $p < 0.001$ for SS) as well as of change in optical density with the change in RNFL thickness ($R = 0.941$, $p < 0.001$ for 3DOCT-1000 and $R = 0.785$, $p < 0.001$ for Cirrus HD- OCT) measured after introducing the filters into the scanning beam of the OCT. Figure 1 depicts variation in slope of the correlation between optical density and change in RNFL thickness for both devices in the four subjects studied.

Comparison of the measurements in healthy subjects using artificial filters with those in cataract patients using optical density recalculated from image quality parameter.

Both the image quality parameter (QF or SS) and mean average RNFL thickness demonstrated a statistically significant postoperative increase ($p < 0.001$), see Table 3. As expected, a significant postoperative decrease in optical density compared with preoperative calculated optical density values was observed, see Table 3. A comparative analysis by subdividing the group by type of cataract (nuclear, cortical, posterior) revealed no significant differences in change in optical density between

**FIGURE 1:** correlation between decrease in average RNFL thickness with change in optical density in healthy subjects using artificial filters Filled circles: 3DOCT-1000 measurements; Linear regression for total (black fit line): $R=0.953$, constant=0.122, regression coefficient = $39.4 \pm 1.7$, $p<0.001$ Open triangles: Cirrus HD-OCT measurements; Linear regression for total (dashed fit line): $R=0.885$, constant=-0.193, regression coefficient = $10.7 \pm 0.7$, $p<0.001$. 
TABLE 3. Visual acuity, image quality, optical density and RNFL thickness values of cataract patients

<table>
<thead>
<tr>
<th>Parameter (mean ± SD)</th>
<th>Cirrus HD-OCT, Zeiss</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>p</th>
<th>3DOCT-1000 Mark II, Topcon</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual acuity (logMar)</td>
<td>0.30 ± 0.2</td>
<td>0.03 ± 0.1</td>
<td>&lt;0.001</td>
<td>0.41 ± 0.2</td>
<td>0.03 ± 0.1</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCT Image quality (Signal strength for Cirrus HD-OCT and Qfactor for 3DOCT-1000)</td>
<td>6.7 ± 1.3</td>
<td>8.1 ± 1.1</td>
<td>&lt;0.001</td>
<td>53.5 ± 19.6</td>
<td>76.6 ± 10.7</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical Density</td>
<td>0.38 ± 0.1</td>
<td>0.24 ± 0.1</td>
<td>&lt;0.001</td>
<td>0.48 ± 0.3</td>
<td>0.10 ± 0.2</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean RNFL thickness (micron)</td>
<td>85.94 ± 10.7 (n=25)</td>
<td>90.56 ± 9.9</td>
<td>&lt;0.001</td>
<td>91.27 ± 8.1 (n=17)</td>
<td>103.14 ± 9.7 (n=17)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
types of cataract (Table 4). Change in optical density significantly linearly correlated with change in measured RNFL thickness, with a Spearman correlation coefficient of \(0.697, p<0.03\) for 3DOCT-1000 and \(0.444, p<0.03\) for Cirrus HD-OCT. For both OCT devices, the homogeneity of the regression lines between the cataract patients and artificial filters proved to be not statistically different, \(p = 0.73\) for Cirrus HD-OCT and \(p=0.27\) for 3DOCT-1000. In Fig. 2, the correlation is depicted for the measurements in cataract patients.

**TABLE 4.** Comparing pre- and postoperative differences according to type of cataract

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nuclear (n=19)</th>
<th>Cortical (n=19)</th>
<th>Posterior (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average RNFL thickness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative mean ± SD</td>
<td>87.07 ± 9.4</td>
<td>83.87 ± 10.6</td>
<td>97.48 ± 14.7</td>
</tr>
<tr>
<td>Postoperative mean ± SD</td>
<td>94.38 ± 12.0</td>
<td>91.38 ± 12.0</td>
<td>109.21 ± 6.1</td>
</tr>
<tr>
<td>Change mean ± SD</td>
<td>7.31 ± 6.9</td>
<td>7.51 ± 4.7</td>
<td>11.73 ± 12.1</td>
</tr>
<tr>
<td>Optical density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preoperative mean ± SD</td>
<td>0.36 ± 0.2</td>
<td>0.43 ± 0.2</td>
<td>0.43 ± 0.1</td>
</tr>
<tr>
<td>Postoperative mean ± SD</td>
<td>0.15 ± 0.2</td>
<td>0.18 ± 0.1</td>
<td>0.22 ± 0.2</td>
</tr>
<tr>
<td>Change mean ± SD</td>
<td>0.20 ± 0.2</td>
<td>0.25 ± 0.2</td>
<td>0.21 ± 0.2</td>
</tr>
</tbody>
</table>

**FIGURE. 2.** Correlation between decrease in average RNFL thickness and change in optical density in cataract patients using optical density recalculated from image quality parameter. *Open circles:* 3DOCT-1000 measurements in cataract patients. Linear regression for total (black fit line): \(R_s = 0.697, p < 0.03\). *Filled triangles:* Cirrus HD-OCT measurements in cataract patients. Linear regression for total (dashed fit line): \(R_s = 0.444, p < 0.03\).
Furthermore, effort was made to predict and correct for cataract-induced underestimation of the RNFL. The predictive power based on the linear relationship between OCT-effective optical density of cataract and the cataract-induced underestimation proved to be limited. Regression equations used were for Topcon 3DOCT-1000: underestimation RNFL= 0.122+(39.4*optical density) and for Cirrus HD-OCT: underestimation RNFL=0.193+ (10.7*optical density). The mean difference in RNFL thickness change between predicted and measured values were, respectively, 1.68±7.55 micron for Topcon 3DOCT-1000 (R2=0.38) and 3.71 ± 2.97 for Cirrus HD-CT (R2=0.23).

DISCUSSION

In the present study, we further defined the effect of cataract on the OCT image quality as well as on RNFL thickness measurements. A decrease in OCT image quality causes an underestimation of RNFL thickness measurement and can affect glaucoma diagnosis and detection of glaucoma progression using OCT. There was a significant linear relationship between the decrease in optical density following cataract surgery and the subsequent increase in RNFL thickness measurement.

Just recently Mwanza et al. 25 published similar findings after studying the effect of cataract and its removal on image quality (SS) and RNFL thickness using time domain OCT in 45 patients, including 23 with glaucoma. They also concluded that cataract may decreases peripapillary RNFL thickness measurements and image quality of OCT scans, and therefore, thickness measurements should be interpreted with caution in glaucomatous eyes with significant cataract. Linear regression suggested that the more advanced the cataract, the less the signal quality (SS) and the thinner the RNFL thickness. (Mwanza et al. 2011) Other previous studies confirmed these findings and found a significantly thicker mean RNFL thickness after cataract surgery in comparison with preoperative measurements. 22-24 The ultimate goal of this study was to establish the nature of the relationship between the optical density of cataract and its influence on RNFL thickness measurements to correct for cataract-induced changes in this measurements. To quantify the influence of cataract on SDOCT image quality and RNFL thickness measurements, SDOCT images of patients before and after cataract surgery were compared with SDOCT images from normal subjects using artificial filters simulating the effects of cataract. To compare and correlate image quality of the scans, optical density was calculated for each cataract based on a mathematical model described previously. The assumption was made that the effects of a cataract in the optical light path (attenuation, scattering and refraction) would result in an overall attenuation of the light of the OCT scanning spot on the retina and would have a comparable effect as the set of filters. 21 There was a significant linear correlation between the decrease in RNFL thickness and the increase in optical density introduced by filters placed into the OCT scanning beam in normal eyes.
Likewise, the postoperative increase in RNFL thickness showed a significant linear correlation with a decrease in optical density following cataract surgery, however, with a rather large variability. Owing to this variability, the predictive value based on the observed linear relationship between OCT-effective optical density of cataract and the cataract-induced underestimation proved to be limited. Approximately one-third of the variability of change in RNFL thickness could be explained by optical density change. The standard deviation of the mean difference between predicted and measured values of the RNFL thickness were 7.55 (3DOCT-1000) and 2.97 (Cirrus HD-OCT) micron. For both OCT devices, the homogeneity of the regression lines between the cataract patients and artificial filters proved to be not statistically different.

There are several reasons for this variability. Two important things to take into account are the possible influence of the cataract surgery on intraocular pressure and the release of inflammatory mediators inducing a disturbed blood retinal barrier permeability with vessel leakage. These factors are highly individual and could introduce an increase in thickness measurements. All patients were measured within a window of 3–5 weeks postsurgery, at a time when these influences could still play a role.

Not all eyes demonstrate an equal amount of change in RNFL thickness, with identical change in optical density. An individual variation exists in the slope of the correlation between optical density and change in RNFL thickness for both devices in the four subjects studied. These differences can not be attributed to effects of the surgical procedure and could represent individual differences in reflectivity of the RNFL. Part of the variability among cataract patients will probably be caused by these individual differences in intraocular tissue scattering and RNFL reflectivity. Furthermore, Cirrus HD-OCT only provides discrete values of the SS, which will induce an increase in the variability in the calculated OD values of the cataract.

The change in RNFL thickness was four times larger for 3DOCT-1000 measurements than for Cirrus HD-OCT measurements as can also be seen by the difference in slope in Fig. 1. Consequently, a RNFL thickness measurement in the same patient will be significantly less influenced by cataract when scanned with the Cirrus HD-OCT compared to 3DOCT-1000. This difference may be attributed to differences in hardware, like superluminescent diode power, charge coupled device camera and software, like postacquisition processing of the signal. Probably all SDOCT devices on the market today will show a different influence of opacities on change in RNFL thickness. As cataract and glaucoma often coexist in the same eye, the results of this study have their clinical importance in the diagnosis and follow-up of glaucoma patients using OCT. It seems to be mandatory to make new RNFL measurements after cataract extraction in glaucoma patients to establish a new baseline value, whatever instrument used.

Further research is necessary to investigate the individual influence of image quality in the complex segmentation and thickness measurement of the RNFL. As an explanation for the influence of image quality in RNFL thickness measurements, it has been postulated that a weaker signal affects the identification of the posterior
boundary of the RNFL resulting in falsely low measurements. More noise in lower quality scans decreases accurate identification of retinal layers.\textsuperscript{27} The results of the present study support this suggestion and further define the linear correlation between decrease in RNFL thickness and change in OCT image quality (optical density).

There are several limitations to the present study. The number of patients is relatively small, which could also contribute to the low predictive power of optical density for the change in RNFL thickness following cataract surgery. However, the conclusion of the linear relationship between both entities is a first step to reach this goal. Previous studies have described a larger change in image quality parameter by posterior subcapsular opacities.\textsuperscript{25,28} This finding is not confirmed in the present study, perhaps owing to the low number of posterior cataracts included. Owing to sometimes the nonhomogeneously distributed opacities throughout a cataractous lens, the disturbance of the light contributing to a single b-scan OCT image can be unequal. This will lead to a variable quality of the resulting b-scan, and subsequently to variability in the RNFL thickness measurement. In contrast, the artificial filters used in this study are homogeneous and will not show this variability. Despite accurate care was taken to avoid tilt, of the eye relative to the scanning light of the OCT, a potential change in tilt of the eye between successive measurements cannot completely be ruled out. As the measurements using the filters were taken in one session and those in cataract patients in two sessions, a potential influence of the head tilt would have contributed mainly to higher variability in the cataract patients group.

In conclusion, a decrease in OCT image quality, such as that observed in patients with cataract, may cause an underestimation of RNFL thickness measurements and will affect glaucoma diagnosis and detection of glaucoma progression using OCT. Cataract-induced underestimation of RNFL thickness and the OCT-effective optical density of the cataract are linearly related. The predictive value based on this observed linear relationship was however limited. Correcting for the influence of optical density on OCT may also be useful to improve machine learning classifiers, which have been used in the past to improve diagnostic accuracy of OCT measurements.\textsuperscript{29}

A better understanding of the exact nature of the individual variability will help to make a reliable correction for cataract-induced changes in RNFL measurements but will differ for each type of OCT device. In general, it seems to be mandatory to make new RNFL measurements after cataract extraction in glaucoma patients to establish a new baseline value.

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Cataract-induced change in RNFL thickness


