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ORIGINAL RESEARCH

Enhanced Penetration for Axial Length Measurement of Eyes with Dense Cataracts Using Swept Source Optical Coherence Tomography: A Consecutive Observational Study

Nino Hirnschall · Ralph Varsits · Birgit Doeller · Oliver Findl

ABSTRACT

Introduction: The aim of this study was to find cases in which the axial eye length could not be measured with partial coherence interferometry (PCI) technology and to assess if it could be measured using swept source optical coherence tomography (ss-OCT) technology.
Methods: All patients were measured at their pre-assessment visit 1 week prior to cataract surgery using conventional optical biometry (PCI technology, IOLMaster 500, Carl Zeiss Meditec AG, Jena, Germany). Patients in whom one or both eyes could not be measured using PCI technology were invited to participate in the study and to be measured with the ss-OCT (IOL Master 700, Carl Zeiss Meditec AG, Jena, Germany) device.
Results: Altogether, 1226 eyes of 613 patients were measured consecutively, and 78 eyes were not measured successfully with PCI technology. Among those with unsuccessfully measured eyes, 23 patients were willing to participate in the study, and two of those were also unsuccessfully measured with the ss-OCT device (8.7%, 2/23). However, 91.3% (21/23) of the eyes that were unsuccessfully scanned with PCI technology were measurable with the ss-OCT device. The estimated overall rate of unsuccessful scans with the ss-OCT device was 0.5% (6/1226) ($p_{\chi^2} < 0.01$).
Conclusion: ss-OCT technology significantly improves the rate of attainable axial eye length measurements, especially in eyes with posterior subcapsular cataracts, but also in eyes with dense nuclear cataracts, except for white cataracts.

Keywords: Biometry; Cataract; Swept source optical coherence tomography

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INTRODUCTION

The introduction of partial coherence interferometry (PCI) has significantly improved axial eye length measurements in comparison to ultrasound measurements [1, 2]. This is because the accuracy of PCI measurements is significantly higher than the accuracy of applanation ultrasound measurements, and because the results of PCI are less dependent on the examiner [3–5]. However, conventional PCI

technology has one important disadvantage: in contrast to ultrasound, dense nuclear and posterior subcapsular cataracts may reduce the signal-to-noise ratio of the measurement, resulting in an unsuccessful measurement [6, 7]. Although the introduction of a composite scan method has reduced this problem, 4.7% of eyes still cannot be measured with PCI technology [8].

Recently, swept source optical coherence tomography (ss-OCT) was introduced for optical biometry [9]. Among the significant differences between PCI and ss-OCT technology are the wavelength and the measurement setup employed in each.

The aim of this study was to find cases that could not be measured with PCI technology and to assess if they could be measured using ss-OCT technology instead.

METHODS

This study included data from patients who underwent cataract surgery. The data were analyzed retrospectively. Patients with severe corneal scarring or head tremor were excluded from this study. All procedures involving human participants were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

All patients were measured at their pre-assessment visit one week prior to cataract surgery using conventional optical biometry (PCI technology, IOLMaster 500, Carl Zeiss Meditec AG, Jena, Germany). At least five scans were performed with PCI technology in all cases. If the SNR of the composite scan was <2.0, the scan was classified as unsuccessful.

Patients in whom one or both eyes could not be measured were invited to participate in the study and to be measured with the ss-OCT (IOLMaster 700, Carl Zeiss Meditec AG) device. As this device was located at another location 40 min away by public transport, patients were asked to come for this additional appointment within the following three days. When successful, only one measurement (consisting of six scans) was performed with the ss-OCT (Fig. 1); otherwise, a maximum of five measurements (i.e., 30 scans in total) were performed to get one successful scan. In contrast to the PCI device, the ss-OCT device does not provide a composite scan or a signal-to-noise ratio. Therefore, each scan was analyzed separately and was defined as successful if the device was able to give a value for axial eye length. Regarding the protocol of the IOLMaster, a scan was only classified as successful if no warning was given by the device.

Specification of the ss-OCT Device

The ss-OCT (IOLMaster 700) device uses a wavelength of 1055 nm and has a scan depth of 44 mm and a scan width of 6 mm. Its resolution in tissue is 22 μm and its measurement speed is 2000 A-scans per second.

Statistical Analysis

Excel 12.2.0 was used for descriptive statistical analysis. Frequencies are given as percentages and significance testing of proportions was performed using Fisher's exact test. $p < 0.05$ was considered to indicate statistical significance.

RESULTS

Altogether, 1226 eyes of 613 patients were measured consecutively on different measurement days using PCI technology in this study. Among those patients, 65 [78 eyes = 6.4% (78/1226)] were not measured successfully (i.e., 52 patients in whom one eye could not be measured successfully and 13 patients in whom neither eye could be measured successfully). Twenty-three of those 65 patients were willing to participate in the study. The 23 patients were on average 68.4 years of age (SD 14.8; 32–88 years). The female:male distribution was 11:12. Eight patients had a best corrected visual acuity of finger counting or less, 9 patients had a best corrected visual acuity ranging between
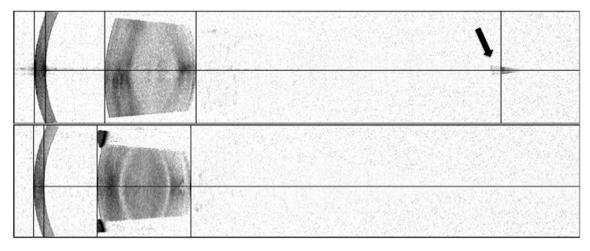
Fig. 1 Successful (top) and unsuccessful (bottom) longitudinal ss-OCT scans. The arrow depicts the macula

finger counting and 20/200 Snellen, and 5 patients had a best corrected visual acuity of better than 20/200 Snellen. Mean axial eye length (measured with ss-OCT) was 24.07 mm (SD 1.22 mm; 22.06–26.71).

Two of these 23 patients were measured unsuccessfully with ss-OCT technology (2/23; 8.7%). Table 1 presents the reasons for unsuccessful measurement with the PCI device and the ss-OCT device.

As 91.3% (21/23) of the unsuccessful scans using PCI technology were measurable with the ss-OCT device, the estimated rate of unsuccessful scans with the ss-OCT device was 0.5% (6/1226). This is a significant reduction ($p_{\chi^2} < 0.01$) of 92.2% (0.5/6.4) compared to PCI optical biometry.

Table 1 Reasons for unsuccessful scans using the PCI device and the ss-OCT device

Reason	PCI	ss-OCT
Nuclear cataract	10	2 (20%)
PSC	9	0 (0%)
Nuclear cataract + PSC	4	0 (0%)
Total	23	2 (8.7%)

DISCUSSION

ss-OCT technology was shown to significantly increase the proportion of successful axial eye length measurements compared to PCI technology. In fact, all cases with posterior subcapsular cataract were measured successfully with ss-OCT technology.

Twenty percent of the eyes with dense nuclear or white cataracts that were not measurable with PCI technology were also not measurable with the ss-OCT device. In total, the number of unsuccessful scans was reduced from 6.4% to 0.6% when the ss-OCT device was used. Srivannaboon et al. [10] compared the same two devices in a different study setting. They used a much smaller sample size, but performed a direct comparison by measuring all patients with both devices. The main focus of their study was data comparability and the reproducibility of the ss-OCT device, which were found to be good. Similar results were obtained by Shammas et al. [11], Kunert et al. [12], and Kurian et al. [13].

The proportion of unsuccessful scans with PCI technology in Srivannaboon's study was slightly lower than the proportion in our study (5% vs. 6.4%), possibly due to differences in the study populations or their smaller sample size. Similar to our findings, they observed a significantly higher proportion of successful scans in the ss-OCT group compared to the PCI group.

Akman et al. [14] reported a higher proportion of unsuccessful scans (9.0%), but the proportion of eyes with nuclear cataracts and posterior subcapsular cataracts that were unsuccessfully measured by the PCI method but were successfully measured using the ss-OCT device was almost the same as in the present work.

The main reason for the higher success rate of ss-OCT technology is the higher wavelength used (1055 nm) compared to PCI technology (780 nm, IOLMaster), as a shorter wavelength results in a reduced penetration depth due to scattering [15]. This phenomenon is commonly known as Rayleigh scattering, which involves an inverse correlation between scattering and wavelength (to the fourth power).

The advantageous sensitivity of ss-OCT devices compared to time-domain OCT (basically the sum of multiple PCI scans) was recognized more than 10 years ago, but the wavelength used at that time was higher (1300 nm) [16]. Additionally, the feasibility of using ss-OCT technology for biometric measurements of the human eye was proven more than 10 years ago. However, those devices were prototypes and used a different wavelength (1310 nm) to that employed by ss-OCT devices today [17]. One of the first uses of ss-OCT technology for axial eye length measurements was published in 2009 by Chong et al. [18]. They used a similar wavelength to that of the investigated device (1060 nm) and a tunable filter, but they used a much shorter coherence length (28 mm to measure an axial eye length 20 mm in physical size). They were able to measure pigs' eyes successfully in their study. There is a good correlation between cataract density and Rayleigh scattering, and it should be noted that because the amount of scattering is inversely proportional to the fourth power of the wavelength, a longer wavelength is significantly less prone to Rayleigh scattering [19].

One drawback of this study is that not all of the eyes that were unsuccessfully measured with PCI technology were measured with ss-OCT technology because the ss-OCT device was situated in another clinic some distance away. The geographical distance to that clinic was an obstacle for several patients—possibly even more so for patients with very dense cataracts, as they tended to be older and/or to have reduced mobility.

CONCLUSIONS

In summary, ss-OCT technology significantly improves the rate of attainable axial eye length measurements, especially in eyes with posterior subcapsular cataracts, but also in eyes with dense nuclear cataracts, except for white cataracts. It is possible that the use of an even higher wavelength would increase the number of successful scans, but it may also reduce the scan resolution.

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Compliance with Ethics Guidelines. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Data Availability. The datasets obtained and/or analyzed during the current study are available from the corresponding author on reasonable request.

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