EXTENDED REPORT

Repeatability and reproducibility of anterior chamber angle measurement with anterior segment optical coherence tomography

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Aim: To evaluate the repeatability and reproducibility of anterior chamber angle measurement obtained by anterior segment optical coherence tomography.

Methods: Twenty-five normal subjects were invited for anterior chamber angle imaging with an anterior segment optical coherence tomography (OCT) on one randomly selected eye in three separate visits within a week. Each eye was imaged three times under room light (light intensity = 368 lux) and three times in the dark during the first visit. In the subsequent visits, each eye was imaged once in the light and once in the dark. The angle opening distance (AOD 500) and the trabecular–iris angle (TIA 500) were measured by a single observer. Only the nasal angle was analysed. Intrasession and intersession within-subject standard deviation (Sw), precision (1.96×Sw), coefficient of variation (CVw) (100×Sw/overall mean), and intraclass correlation coefficient (ICC) were calculated to evaluate repeatability and reproducibility.

Results: For intrasession repeatability, the Sw, precision, CVw and ICC of AOD/TIA were 45 μm/2.4°, 88 μm/4.7°, 5.8%/4.8% and 0.97/0.95 in the light; and 45 μm/2.1°, 88 μm/4.2°, 7.0%/5.0% and 0.98/0.97 in the dark. For intersession reproducibility, the Sw, precision, CVw and ICC of AOD/TIA were 79 μm/3.5°, 155 μm/6.8°, 10.0%/7.0%, 0.91/0.89 in the light; and 64 μm/3.4°, 124 μm/6.6°, 9.9%/7.8% and 0.95/0.92 in the dark.

Conclusions: The anterior segment OCT demonstrated reliable anterior chamber angle measurement in different lighting conditions with good repeatability and reproducibility.

Although gonioscopy is the gold standard in the assessment of the anterior chamber angle, quantitative analysis of the angle dimensions has relied on ultrasound biomicroscopy (UBM). Pavlin *et al* introduced two parameters: the trabecular–iris angle (TIA) and the angle opening distance (AOD), to measure the angle width.[1 2] These measurements subsequently became the standard parameters in the evaluation of the anterior chamber angle. However, AOD and TIA measurements have been reported to have high variability.[3 4] Being a contact, immersion technique requiring the use of a scleral cup, the UBM could be limited to provide reproducible angle measurement. The compression of the eyeball by the scleral cup could potentially distort the actual dimension of the angle.[5] In addition, precise positioning of scan location is difficult, if not impossible, when the UBM probe is in place over the globe during imaging. Scanning is also cumbersome to perform in darkness. It is not surprising therefore that the anterior chamber angle measurement could be variable with UBM.

The anterior segment optical coherence tomography (OCT) (Visante anterior segment OCT, Carl Zeiss Meditec, Dublin, California, USA) was recently introduced to provide a non-contact approach for anterior segment imaging. The anterior segment OCT has higher scanning resolution than UBM (axial resolution of 18 μm vs 50 μm in UBM). In addition, with the aid of the built-in real-time charge-couple device displaying the position of the scan line, imaging can be performed in the dark without compromising the visibility of the scan location. The purpose of this study is to evaluate the repeatability and reproducibility of anterior chamber angle measurement using the anterior segment OCT in different lighting conditions.

METHODS

Subjects

Twenty-five healthy normal volunteers were invited for anterior chamber angle imaging on one randomly selected eye in three separate visits within a week. All volunteers had visual acuity of at least 20/40, with open angle on darkroom gonioscopy and with no evidence of ocular diseases. The study was conducted in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and approved by the clinical research ethics committee (Kowloon Central/East) with informed consent obtained.

Visante anterior segment OCT imaging

Each selected eye was imaged with the anterior segment OCT (ZEISS Visante OCT Model 1000, Carl Zeiss Meditec, Dublin, California, USA). The Visante OCT is a non-contact, high-resolution tomographic and biomicroscopic device designed for anterior segment imaging and measurement. The principle of the imaging is based on low-coherence interferometry, using a 1310 nm superluminescent light-emitting diode as the light source. Analogous to an ultrasound B-scan, the Visante OCT acquires multiple A-scans and aligns them to construct two-dimensional images. The scanning of the anterior chamber angle is a non-contact procedure during which the subject fixates on an internal fixation target. Each eye was imaged three times under room light (light intensity = 368 lux) and

Abbreviations: AOD, angle opening distance; CVw, coefficient of variation; ICC, intraclass correlation coefficient; OCT, optical coherence tomography; Sw, within-subject standard deviation; TIA, trabecular–iris angle; UBM, ultrasound biomicroscopy

three times in the dark during the first visit. In the subsequent two visits within a week, each eye was imaged once in the light and once in the dark. The anterior chamber angle was imaged with the ''anterior segment single'' protocol (scan length 16 mm; 256 A-scans) by a single examiner. The AOD and TIA were measured consecutively by a single observer. Since the objective of this study is to evaluate the repeatability and reproducibility of the anterior segment OCT for anterior chamber angle measurement, we only selected the nasal angle at 180° for analysis.

Measurement of AOD, TIA and pupil diameter

Although AOD can be measured with the caliper tool provided in the analysis software of the Visante OCT, we specifically wrote a program using Matlab version 6.5 (The Math Works, Natick, MA, USA) to measure AOD to minimise measurement errors due to caliper manipulation. The AOD 500 was calculated as the distance between the trabecular meshwork and the iris at 500 μm anterior to the scleral spur. The TIA was defined as an angle measured with the apex in the iris recess and the arms of the angle passing through a point on the trabecular meshwork 500 μm from the scleral spur and the point on the iris perpendicularly. The program automatically calculated AOD and TIA when these landmarks (scleral spur and iris recess apex) were manually located. The pupil diameter (iris tip to iris tip distance) was also measured automatically by the program when the iris tips were manually located. All the subjects included in this study had clear visibility of the scleral spur in the OCT images.

Statistical analysis

Statistical analyses were performed using SPSS version 11.0 (SPSS Inc, Chicago, Illinois, USA). Measurements of the anterior chamber angle and pupil diameter obtained in room light and in the dark were compared with the Wilcoxon signed ranks test. Intrasession repeatability was measured with three respective images (three in room light and three in the dark) obtained during the first visit. The intrasession within subject standard deviation (Sw), precision (repeatability coefficient) (1.96×Sw), coefficient of variation (CVw) (100×Sw/overall mean) and intraclass correlation coefficient (ICC) were calculated. Intersession reproducibility was determined with three respective images (three in room light, and three in the dark) obtained in each visit (the first image obtained during the first visit was used in this part of calculation). The intersession Sw, precision, CVw and ICC were then calculated. The association between the SD and the mean of the repeated measurements for AOD and TIA were evaluated with correlation analysis (Kendall's τ correlation coefficient).

RESULTS

The mean (SD) age of the 25 subjects was 27.1 (4.5) years with average spherical error −3.15 ±2.35 diopters. The mean pupil diameter measured in the dark, 5.7 (0.9) mm, was significantly larger than that measured in room light, 3.7 (0.8) mm ($p<0.001$). The mean AOD and TIA were 777 (259) μm and 49.7° (10.6), and 640 (272) μm and 43.1° (12.3), in room light and in the dark, respectively. The AOD and TIA measured in the dark were significantly less than those measured in the light (all with $p<0.001$). Table 1 presents the intrasession Sw, CVw, precision and ICC. The CVw of the AOD/TIA measurements ranged between 4.8% and 7.0% in different lighting conditions. High values of ICC (0.95–0.98) were also observed. There was no association between the SD and the mean of the repeated measurements for AOD and TIA (all with $p\geq0.148$).

The intersession Sw, CVw, precision and ICC are shown in table 2. The CVw of the AOD/TIA measurements were between 7.0% and 10.0% whereas the values of ICC were between 0.89 and 0.95 in different lighting conditions. There was no association between the SD and the mean of the intersession measurements for AOD and TIA (all with $p\geq0.076$).

DISCUSSION

In this study, anterior chamber angle measurement with the anterior segment OCT had good repeatability and reproducibility in both light and dark conditions. This result could be attributed to the fact that the scan position can be visualised and the pupil size can be optimally controlled with the imaging system. As pupil size is influential in the angle configuration, minimising the variation of pupillary response to light and accommodation is critical to obtain reproducible measurement of the angle. And this is made possible with the non-contact technique and the built-in customised internal fixation in the anterior segment OCT.

The differences in anterior chamber angle measurements in different lighting conditions have been previously investigated with UBM.[6 7] These findings illustrate the importance of standardising the lighting conditions when imaging the angle. In agreement with previous UBM studies, significant differences of angle measurements were found between light and dark conditions. And yet, comparable repeatability and reproducibility were achieved as long as the lighting condition had been standardised. Being able to optimally control the scan position and the pupil size, it is conceivable that the anterior segment OCT could potentially be more reliable for anterior chamber angle measurement than UBM. Nevertheless, using a signal source of super luminescent diode with wavelength of 1310 nm, it is not yet possible to visualise the ciliary body with the anterior segment OCT. Analysing anterior chamber angle parameters in relation to ciliary body position is still dependent on UBM imaging.

In a recent study using a slit-lamp OCT (Heidelberg Engineering, GmbH, Dossenheim, Germany), Muller *et al.* reported low intraobserver and interobserver variability for anterior chamber angle measurement for nine subjects in a single visit.[8] The ICC for AOD 500 and anterior chamber angle ranged between 0.93–0.97 and 0.91–0.94, respectively. In the present study with the Visante OCT, the intrasession ICC for AOD/TIA archived comparable values of 0.97/0.95 in the light and 0.98/0.97 in the dark. The excellent repeatability was also reflected by the high precision, which is defined as 1.96×Sw (table 1). For example, the difference between a subject's TIA and the true value measured in the dark would be expected to be less than 4.2° for 95% of observations. Good intersession reproducibility for the angle measurements was also evident. The intersession ICC for the angle measurements ranged between 0.89 and 0.95 and the coefficient of variation was at or below 10% (table 2).

Table 1 Intrasession repeatability: three consecutive measurements in a single visit

	Overall mean (SD)	Sw (95% CI)	CVw (%) (95% CI)	Precision (95% CI)	ICC (95% CI)
AOD in light	777 μm (259)	45 μm (36–54)	5.8 (4.6–6.9)	88 μm (70–105)	0.97 (0.94–0.98)
TIA in light	49.7° (10.6)	2.4° (1.9–2.9)	4.8 (3.9–5.8)	4.7° (3.8–5.6)	0.95 (0.91–0.98)
AOD in dark	640 μm (272)	45 μm (36–54)	7.0 (5.6–8.4)	88 μm (70–105)	0.98 (0.96–0.99)
TIA in dark	43.1° (12.3)	2.1° (1.7–2.6)	5.0 (4.0–6.0)	4.2° (3.4–5.0)	0.97 (0.95–0.98)

AOD, angle opening distance; CVw, within-subject coefficient of variation; ICC, intraclass correlation coefficient; Sw, within-subject standard deviation; TIA, trabecular–iris angle.

Table 2 Intersession reproducibility: measurements obtained from three separate visits

	Overall mean (SD)	Sw (95% CI)	CVw (%) (95% CI)	Precision (95% CI)	ICC (95% CI)
AOD in light	787 μm (267)	79 μm (63–93)	10.0 (8.1–12.0)	155 μm (124–185)	0.91 (0.84–0.96)
TIA in light	49.8° (10.3)	3.5° (2.8–4.2)	7.0 (5.6–8.4)	6.8° (5.5–8.2)	0.89 (0.79–0.94)
AOD in dark	643 μm (272)	64 μm (51–76)	9.9 (7.9–11.8)	124 μm (100–149)	0.95 (0.90–0.97)
TIA in dark	43.4° (11.7)	3.4° (2.7–4.0)	7.8 (6.3–9.3)	6.6° (5.3–7.9)	0.92 (0.84–0.96)

AOD, angle opening distance; CVw, within-subject coefficient of variation; ICC, intraclass correlation coefficient; Sw, within-subject standard deviation; TIA, trabecular–iris angle.

Since the objective of this study was to study the variability of the anterior segment OCT in measuring the anterior chamber angle, we focused only on the nasal angle for analysis. Although no significant difference in AOD among superior, nasal, inferior and temporal quadrants, in either the light or the dark, was found in a previous UBM study,[6] other studies have shown regional differences in angle width.[9 10] It would be interesting to observe the potential variability of angle width by measuring the angles at the other quadrants. While it is mentioned in the operating manual that the wavelength of the visual aiming beam is 845 nm, there are no data available in the literature or from the company indicating the level of light intensity of the internal fixation target and to what extent the luminance of the internal fixation light affects pupillary response. It is uncertain if images captured in the dark by the anterior segment OCT could reflect the ''true'' pupil size in darkness. It is also difficult to measure the exact light intensity at the position of the scanned eye where the forehead is in contact with the Visante unit. Nevertheless, we were able to demonstrate there was a significant difference in pupil size in the two different lighting conditions suggesting there was enough illumination difference. While variability secondary to scan position and pupillary response could be minimised with the imaging system, identifying the anatomic landmarks for angle measurements remains a subjective interpretation which could potentially introduce measurement errors. In this study, an experienced technician was responsible for taking the images in different sessions and a well-trained observer measured all the images. With this arrangement, interobserver differences could have been eliminated.

A major limitation in the current imaging system is the lack of a reliable interface for angle measurement. Only simple angle tool and calipers are available for image analysis in the Visante anterior segment OCT. In this study, all the images were exported to a custom-made program for AOD and TIA measurement to minimise errors secondary to caliper manipulation. Another limitation is that all the volunteers included were relatively young, demonstrated clear visibility of the scleral spur and had open angle. Repeatability and reproducibility would be expected to decrease in eyes with a less distinct boundary of the scleral spur in the OCT images.

In summary, the anterior segment OCT can provide objective and quantitative measurement of the anterior chamber angle with good repeatability and reproducibility. Enhancement in the angle measurement interface in the Visante OCT is warranted to improve its measurement capability.

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