High-Definition Optical Coherence Tomography Imaging of the Iridocorneal Angle of the Eye

Hon-Tym Wong, FRCS(Ed); Marcus C. Lim, MRCS(Ed); Lisandro M. Sakata, MD, PhD; Han T. Aung, MBBS; Nishani Amerasinghe, MRCOphth; David S. Friedman, MD, MPH, PhD; Tin Aung, MBBS, FRCS(Ed), PhD

Objective: To assess the ability of high-definition optical coherence tomography (HD-OCT) to image the anterior chamber angle.

Methods: Forty-five consecutive subjects with phakic eyes underwent gonioscopy and anterior chamber angle imaging with HD-OCT adapted with a 60-diopter aspheric lens mounted over the imaging aperture. The patients’ fixation was directed to the side using an external fixation light, and scans were taken of the temporal and nasal quadrants. The visibility of angle structures was assessed and the diagnosis of angle closure using HD-OCT was compared with that of gonioscopy.

Results: The majority of subjects were Chinese (91.1%) and female (62.2%). Cross-sectional HD-OCT allowed in vivo visualization of the scleral spur in 71 of 90 quadrants (78.9%) and the termination of the Descemet membrane (Schwalbe line) in 84 of 90 quadrants (93.3%). It was possible to image the trabecular meshwork in 56 quadrants (62.2%). Angle closure was observed in 17 eyes with gonioscopy and 12 eyes with HD-OCT (P=.12, McNemar test). The 2 modalities showed good agreement for angle closure diagnosis by quadrant (κ=0.65).

Conclusion: The adapted HD-OCT provided magnified views of the anterior chamber angle and allowed visualization of the Schwalbe line and trabecular meshwork in most eyes.


Anterior segment optical coherence tomography (AS-OCT) uses a 1310-nm diode laser to obtain real-time images of the anterior chamber angle.1-4 Recent studies have shown that AS-OCT tends to confirm gonioscopic angle closure in most patients but also detects more closed angles than gonioscopy.5,6 This discrepancy in findings between gonioscopy and AS-OCT may be due to the different anatomical landmarks and levels of irido-angle contact used to define a closed angle. On AS-OCT images, it is not possible to determine the location of the trabecular meshwork, and the presence of any contact between the iris and the angle wall anterior to the scleral spur is graded as angle closure.7 However, if this apposition did not reach the level of the posterior trabecular meshwork, the quadrant would be considered open on gonioscopy. Scleral spur determination is impossible in approximately 20% to 30% of AS-OCT images. This could be because of low lateral resolution of AS-OCT images, image artifacts from eyelids or other structures, anatomical variations in eyes, and technical difficulties in imaging some quadrants.7 This inability to detect the scleral spur may limit the accuracy and usefulness of angle imaging, especially for quantitative analysis of the angle that uses the scleral spur as an anatomical landmark for measurements.8,9

High-definition OCT (HD-OCT) has been recently introduced for imaging the retina.10-13 High-definition OCT uses a scanning rate 50 to 60 times faster than current time-domain OCT devices,12,13 and with an axial resolution of 3 to 5 μm, the higher resolution of HD-OCT allows the identification of retinal layers and enhanced visualization of the macula and optic nerve head.10,11 A prototype HD-OCT device was also recently used as a noninvasive corneal imaging modality that was capable of in vivo differentiation of corneal layers and demonstration of pathologic abnormalities in the cornea.14

The aim of this study was to evaluate a modification of a commercially available HD-OCT device (Cirrus-OCT; Carl Zeiss Meditec, Dublin, California) adapted for imaging the anterior chamber angle.
imaging; however, those who had previously undergone laser any cornea opacities or abnormalities that precluded angle tory of previous intraocular surgery or penetrating trauma or ment imaging (see later). Eyes were excluded if there was a his-day: slitlamp biomicroscopy, gonioscopy, and anterior seg-

In this hospital-based study, consecutive consenting subjects were recruited from a glaucoma clinic at a Singapore hospital. Informed consent was obtained from all participants, and the study had the approval of the hospital’s institutional review board and adhered to the tenets of the Declaration of Helsinki.

After an interview about medical and ophthalmic history, each subject underwent the following examinations on the same day: slitlamp biomicroscopy, gonioscopy, and anterior segment imaging (see later). Eyes were excluded if there was a history of previous intraocular surgery or penetrating trauma or any cornea opacities or abnormalities that precluded angle imaging; however, those who had previously undergone laser iridotomy were not excluded.

**GONIOSCOPY**

Gonioscopy was performed in the dark in all cases by a single examiner with glaucoma fellowship training (H.T.W.) who was masked to OCT findings. Static and dynamic gonioscopy was performed using a Sussman 4-mirror lens, at high magnification \((\times 16)\), with the eye in the primary position of gaze. A 1-mm light beam was reduced to a very narrow slit, and care was taken to avoid light falling on the pupil and accidental indentation during examination. Slight tilting of the gonioscopy lens was permitted in an attempt to gain a view over the convexity of the iris. The angle in each quadrant was graded using the Scheie grading system, which is based on the anatomical structures observed during gonioscopy (grade I=visible ciliary body, grade II=visible scleral spur, grade III=visible anterior trabecular meshwork, grade IV=angle structures not visible).

On gonioscopy, an angle quadrant was considered “closed” if the posterior trabecular meshwork could not be seen in the primary position without indentation (Scheie grade III or IV).

**HD-OCT IMAGE ACQUISITION**

Seated subjects were examined by a single examiner (H.T.A.) masked to other test results. A 60-dioptr (D) aspheric lens (Volk Optical, Mentor, Ohio) was mounted over the HD-OCT (Cirrus-OCT) imaging aperture, with the same distance from the Volk lens to the instrument’s entrance pupil as one would normally use between this lens and the patient’s entrance pupil during fundus examination. The magnification of the 60-D lens increases the transverse scan range of the HD-OCT from 6 mm to 7.2 mm. The HD-OCT instrument was set for full myopic correction, retracting the HD-OCT imaging aperture and Volk lens so as to allow room for the patient at the same working distance as in the usual configuration for retinal scanning. For angle imaging, the patient’s fixation was directed to the side of the instrument, using an external fixation light so that the irido-
corneal angle was centered in the instrument’s field of view. Two scans of the angle of each eye were obtained with HD-OCT in the dark: one image scanning the angle at the 3-o’clock position and the other at the 9-o’clock position, representing the temporal and nasal quadrants of each eye. The superior and inferior quadrants were not scanned because of technical difficulties in scan acquisition caused by the eyelids.

In a subset of the last 31 consecutive patients, anterior segment imaging of the nasal and temporal quadrants was also performed under the same illumination conditions using a commercially available AS-OCT device (Visante; Carl Zeiss Meditec).

**IMAGE ANALYSIS**

All HD-OCT and AS-OCT scans were analyzed separately by an examiner with glaucoma subspecialty training (T.A.) masked to other test results. For HD-OCT images in which the trabecular meshwork was visible, angle closure in a quadrant was diagnosed if there was contact between the iris and the trabecular meshwork. For images in which trabecular meshwork was not delineated, angle closure was diagnosed if there was any contact between the iris and angle wall anterior to the scleral spur. For the comparison between HD-OCT and AS-OCT, the angle was considered “closed” on AS-OCT and HD-OCT imaging if any contact between the iris and angle wall anterior to the scleral spur was noted.

The intraobserver reproducibility for the assessment of angle closure in HD-OCT images was assessed in a random subset of 20 subjects (20 eyes, 40 quadrants). Images of the quadrants of the eye were graded for angle closure in 2 sessions separated by an interval of 1 week by a single examiner (T.A.) masked to other results.

**STATISTICAL ANALYSIS**

One eye per patient was selected for analysis; this was the right eye if both eyes fulfilled the inclusion criteria. Parametric and nonparametric tests were used to compare continuous variables according to data distribution. The \( \chi^2 \) or Fisher exact test was used to compare categorical data. The McNemar test was used to compare differences in distribution of a categorical variable between 2 dependent samples. The \( \kappa \) statistic was used to assess the agreement between categorical variables. Statistical significance was set at \( P < .05 \) and statistical analysis was performed using SPSS (version 11.5; SPSS Inc, Chicago, Illinois).

**RESULTS**

The mean (SD) age of the 45 participants was 62.5 (9.1) years and the majority of subjects were female (62.2%) and Chinese (91.1%).

Cross-sectional HD-OCT allowed in vivo visualization of the scleral spur in 71 of 90 quadrants (78.9%) and the termination of the Descemet membrane (Schwalbe line) in 84 of 90 quadrants (93.3%) (Figure 1). There was no difference in the visibility of the scleral spur \((P > .99, \text{ McNemar test})\) and Schwalbe line \((P > .99, \text{ McNemar test})\) between nasal and temporal quadrants. It was possible to image the trabecular meshwork in 36
quadrants (62.2%; 23 nasal and 33 temporal quadrants) (Figure 1). This structure was represented as a triangular dark area between the scleral spur and the Schwalbe line (Figure 1). The angle could not be graded as open or closed in 3 quadrants (3.3%) because of limited visualization of the angle structures.

A closed angle in either quadrant was observed in 17 eyes (37.8%) with gonioscopy and 12 eyes (26.7%) with HD-OCT ($P = .12, \text{ McNemar test}$) (Figure 2). The 2 modalities showed good agreement ($\kappa = 0.65$) for angle closure diagnosis by quadrant. Identical results were obtained when considering all 4 quadrants for gonioscopy, as all eyes with a closed angle in any quadrant had either the nasal or temporal quadrant also closed. One eye was identified as closed by HD-OCT in the 28 eyes that were open both nasally and temporally by gonioscopy. The intraobserver reproducibility for the assessment of angle closure in HD-OCT images was very good ($\kappa = 0.81; 95\% \text{ confidence interval [CI], 0.60-1.00}$).

Thirty-one subjects underwent imaging with both HD-OCT and AS-OCT. The Venn diagram (Figure 3) shows the agreement between gonioscopy, HD-OCT, and AS-OCT in detecting eyes with angle closure. Angle closure in a nasal or temporal quadrant was observed in 11, 10, and 8 eyes with gonioscopy, HD-OCT, and AS-OCT, respectively (gonioscopy vs AS-OCT, $P = .38$; AS-OCT vs HD-OCT, $P = .69$). Anterior segment OCT identified 8 of 11 eyes while HD-OCT identified 7 of 11 eyes diagnosed with angle closure on gonioscopy ($P > .99$, Fisher exact test). Once again, identical results were obtained when considering all 4 quadrants for gonioscopy, as all eyes with a closed angle in any quadrant had either the nasal or temporal quadrant also closed.

An open angle in all quadrants was found in 20 eyes on gonioscopy. Of these, 2 eyes and 1 eye were identified as closed by AS-OCT and HD-SD-OCT, respectively.

Using gonioscopy as the reference standard, the specificity of AS-OCT was 88.9% (95% CI, 80.1%-97.7%) and HD-OCT, 96.4% (95% CI, 91.0%-100.0%), while the sensitivity of AS-OCT and HD-OCT were 71.4% (95% CI, 58.8%-84.1%) and 64.7% (95% CI, 50.7%-78.7%), respectively.

Modification of a commercially available HD-OCT device with the use of a 60-D lens enabled high-resolution imaging of the anterior chamber angle. In addition to the scleral spur, we were able to identify a new imaging landmark for the angle, namely the termination of the endothelium/Descemet membrane at the Schwalbe line. Grading an angle as open or closed based on apposition of the iris to the area between these landmarks (where the trabecular meshwork lies) would thus be possible. Furthermore, the association of partial trabecular meshwork closure and intraocular pressure could be investigated. This is a distinct advantage over AS-OCT imaging of the angle, in which only the scleral spurs is visible (though only in about 70%-80% of images) and angle closure is diagnosed based on the presence of any contact between the iris and the angle wall anterior to the scleral spur.

It was possible in some eyes to identify what seems to be the trabecular meshwork (Figure 1). This is an exciting observation as it would allow even more accurate phenotyping of the angle status by the presence of direct iris apposition to the trabecular meshwork in real time and in a noncontact fashion. In 1 case, we were also able to identify peripheral anterior synechiae in the angle (Figure 4). Although the resolution of the HD-OCT was sufficiently high for identification of these structures, penetration of HD-OCT was limited and it was not possible to image the ciliary body. Thus, it would not be possible to evaluate underlying mechanisms for angle closure such as plateau iris, where a large ciliary body and/or anteriorly rotated ciliary processes have been shown to hold the peripheral iris in apposition to the trabecular meshwork. Also, the depth and width of view provided by HD-OCT precluded imaging of the entire angle up to the iris root, and the images obtained may thus be unfamiliar to most ophthalmologists who expect to view the angle in its entirety, such as in images produced by AS-OCT. We believe, however, that imaging iris–trabecular meshwork contact is the most crucial feature in diagnosing angle closure and so we may not actually need to see the entire angle.

Overall, the agreement in detecting a closed angle quadrant using HD-OCT and gonioscopy was good, with a $\kappa$
of 0.65. However, when we compared the gonioscopy findings with those of HD-OCT, we found that the rate of angle closure diagnosis was lower using HD-OCT, with some eyes graded as open on HD-OCT but closed on gonioscopy. This difference could in part be explained by the presence of a gap between the cornea and sclera such that the iris does not seem to be in apposition with the angle. Another possibility is that HD-OCT images using our jury-rigged device are likely distorted since they are not dewarped or corrected for the index of refraction transition at the air-tear interface and the different group indexes in air, cornea, and aqueous. An example of an eye in which there was disagreement between HD-OCT and gonioscopy is seen in Figure 5, where there appears to be a gap between the iris and angle wall (arrow); however, the quadrant was graded as closed on gonioscopy.

When HD-OCT was compared with AS-OCT and gonioscopy, we found that AS-OCT detected 2 eyes as having closed angles that were found to be open on gonioscopy and HD-OCT. The higher rate of angle closure diagnosis by AS-OCT compared with gonioscopy has been found in previous studies.

Our study had some limitations. For angle imaging using the HD-OCT, the patient’s fixation was directed outside the instrument using an external fixation light so that the iridocorneal angle was centered in the instrument’s field of view. This external fixation could not be completely standardized and thus the images may not have been centered alike in all cases. As noted earlier, the images obtained with this adapted device are not dewarped, limiting the accuracy of angle findings somewhat. For AS-OCT, we used the normal imaging mode and not the high-resolution mode, which may have better visualization of angle structures. Finally, the use of a single observer could result in a systematic bias of the gonioscopy findings (and the OCT analysis).
In summary, we found that HD-OCT provided images of the anterior chamber angle with higher resolution than the current AS-OCT device. Despite the fact that the anterior chamber angle images were acquired by an adapted HD-OCT device, it was possible to identify a new anatomical landmark for anterior chamber angle evaluation, the Schwalbe line, which is the anterior boundary of the trabecular meshwork, as well as the trabecular meshwork itself. There are still limitations with this method, including the inability to clearly identify all the angle structures in every eye. With further optimization, HD-OCT has the potential to produce more precise determination of iris–posterior trabecular meshwork contact and thus represents a promising imaging method for the detection of eyes at risk of angle closure. More studies are under way to evaluate the use of HD-OCT in angle imaging, including ways to obtain a 3-dimensional image of the angle.

Submitted for Publication: May 21, 2008; final revision received July 10, 2008; accepted July 17, 2008.

Correspondence: Tin Aung, MBBS, FRCSEd, PhD, Singapore National Eye Center, 11 Third Hospital Ave, Singapore 168751 (tin11@pacific.net.sg).

Author Contributions: Drs Wong and Lim contributed equally to the work and are joint first authors.

Financial Disclosures: Dr Wong has received financial support and honoraria for travel to conferences from Carl Zeiss Meditec and Heidelberg Engineering. Dr Friedman has received an instrument loan and has been a consultant for Carl Zeiss Meditec. Dr T. Aung has received grant funding as well as financial support and honoraria for travel to conferences from Carl Zeiss Meditec.