Comparison of Slitlamp Optical Coherence Tomography and Scanning Peripheral Anterior Chamber Depth Analyzer to Evaluate Angle Closure in Asian Eyes

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Objective: To evaluate the effectiveness of slitlamp optical coherence tomography (SL-OCT) and Scanning Peripheral Anterior Chamber depth analyzer (SPAC) in detecting angle closure, using gonioscopy as the reference standard.

Methods: A total of 153 subjects underwent gonioscopy, SL-OCT, and SPAC. The anterior chamber angle (ACA) was classified as closed on gonioscopy if the posterior trabecular meshwork could not be seen; with SL-OCT, closure was determined by contact between the iris and angle wall anterior to the scleral spur; and with SPAC by a numerical grade of 5 or fewer and/or a categorical grade of suspect or potential.

Results: A closed ACA was identified in 51 eyes with gonioscopy, 86 eyes with SL-OCT, and 61 eyes with SPAC (gonioscopy vs SL-OCT, P < .001; gonioscopy vs SPAC, P = .10; SL-OCT vs SPAC, P < .001; McNemar test). Of the 51 eyes with a closed ACA on gonioscopy, SL-OCT detected a closed ACA in 43, whereas SPAC identified 41 (P = .79). An open angle in all 4 quadrants was observed in 102 eyes with gonioscopy, but SL-OCT and SPAC identified 43 and 20 of these eyes, respectively, as having angle closure. The overall sensitivity and specificity for SL-OCT were 84% and 58% vs 80% and 80% for SPAC.

Conclusion: Using gonioscopy as the reference, SL-OCT and SPAC showed good sensitivity for detecting eyes at risk of angle closure.


GLAUCOMA IS A IMPORTANT cause of blindness and an increasing economic burden on health care systems worldwide. The prevalence of glaucoma across Asia has been estimated to range from 2% to 5% in persons 50 years or older.1 Primary angle-closure glaucoma is an important form of the disease and more visually debilitating than primary open-angle glaucoma in population surveys conducted in Singapore, Mongolia, India, and China.2-5 The identification of eyes at risk of angle closure may reduce the morbidity of this disease because early treatment may halt the process and, hence, reduce the risk of developing primary angle-closure glaucoma.

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Previous studies have evaluated various screening methods for angle closure that assess the central and peripheral anterior chamber depth (ACD).6-8 Scanning peripheral ACD analyzer (SPAC) (model SM-70; Takagi Seiko Co, Nagano, Japan)10 and anterior segment optical coherence tomography (AS-OCT)11-14 are new noncontact devices that enable evaluation of the peripheral ACD and anterior chamber angle (ACA), respectively. The SPAC grading correlates well with limbal ACD assessed using the modified van Herick system.15 In addition, AS-OCT allows dynamic imaging of the ACA, and previous studies have been performed to evaluate the use of the Visante-OCT (Carl Zeiss Meditec, Dublin, California) in detecting angle closure.16,17 Both SPAC and AS-OCT can be performed quickly and are easily tolerated by patients.

The aim of this study was to evaluate the effectiveness of a new AS-OCT method, slitlamp optical coherence tomography (SL-OCT) (Heidelberg Engineering, Heidelberg, Germany) in detecting angle closure, using gonioscopy as the reference standard. We also compared the performance of this instrument with SPAC.
This prospective hospital-based comparative study was conducted with the approval of the ethics review board and performed in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from every participant.

Consecutive patients who fulfilled study eligibility criteria were recruited from a glaucoma clinic at a Singapore hospital from January 1 to July 31, 2007. Patients who had undergone any prior intraocular procedures or had any penetrating eye injuries and corneal disorders, such as corneal endothelial dystrophy, pterygium, or a corneal scar, that may preclude satisfactory imaging were excluded from the study. Patients who had undergone laser iridotomy were not excluded. A comprehensive ophthalmic examination was performed on the day of recruitment and included visual acuity examination, slitlamp biomicroscopy, Goldmann application tonometry, gonioscopy, and fundus examination followed by imaging with the SPAC and SL-OCT.

**METHODS**

**GONIOSCOPY**

Gonioscopy was performed in the dark by one of us with glaucoma subspecialty training (H.T.W.) who was masked to findings from SPAC and SL-OCT. Static and dynamic gonioscopy was performed using the Sussman 4-mirror lens under high magnification (×16) with the eye in primary gaze position. During gonioscopic examination, care was taken to avoid any light falling onto the pupil and any accidental indentation on the globe. The ACA in each quadrant was graded using the Scheie grading system, which is based on the anatomical structures observed during nonindentation gonioscopy (grade I, visible ciliary body; grade II, visible scleral spur; grade III, visible anterior trabecular meshwork; grade IV, angle structures not visible). The ACA was considered closed in that quadrant if the posterior trabecular meshwork could not be seen in the primary position without indentation (Scheie grade 3 or 4).

**SCANNING PERIPHERAL ANTERIOR CHAMBER DEPTH ANALYZER**

The SPAC imaging was performed by one of us (H.T.A.) who was masked to gonioscopic and clinical findings. Study participants were required to place their chin and forehead against the headrest of the slitlamp and remain fixated on the red light-emitting diode in front while the examiner aligned the reflection of the red light with the pupil center. In SPAC, optical methods are used to measure the peripheral ACD, and the ACD is scanned from the optical axis to the temporal limbus at a rate of 12 mm/s. The instrument acquired 21 images at 0.4-mm intervals with a magnification of 0.4. Three measurements were automatically performed at each point, and the mean of the ACD values was used for analysis. These measurements were compared with those in a normative database included with the device (derived from a sample of Japanese subjects), and SPAC software provides numerical and categorical grades to classify the ACD. The numerical scale ranged from 1 to 12, with 12 representing the deepest ACD. The categorical grading indicates the risk for angle closure: S, suspect angle closure; P, potential angle closure; and no suffix (for normal results).

**SLITLAMP OPTICAL COHERENCE TOMOGRAPHY**

The SL-OCT was performed by one of us (H.T.A.) who was masked to gonioscopic and clinical findings. All participants were required to place their chin and forehead against the headrest of the slitlamp while the beam was positioned onto the area of interest. Of note, a low-intensity narrow light beam from the slitlamp was kept on during SL-OCT scan acquisition to facilitate gross adjustment of the scanning beam location because that beam scans the eye’s structures along the same line of the slitlamp light beam.

The SL-OCT is incorporated into a slitlamp microscope, with a scanner unit attached to the slitlamp’s illumination system. Using coherence interferometry technology with a 1310-nm laser, the SL-OCT enables dynamic imaging of the anterior segment, with an image acquisition rate of 200 A-scans per second, using 670 points per A-scan, to a depth of 7 mm. The SL-OCT images are composed horizontally of 200 A-scans over 15 mm. These images are then rescaled to the actual scale, where the horizontal data are stretched to more than twice their size to represent the actual anterior chamber dimensions. The final SL-OCT image has a maximum transverse resolution of 75 µm and an axial resolution of 10 to 25 µm.

Image acquisition with the SL-OCT required imaging of the entire cross-section of the anterior segment in 1 single-image frame. Moving the upper and lower eyelids away was necessary to image the ACA at the 12- and 6-o’clock positions, and care was taken to avoid inadvertent pressure on the globe. Two scans of the ACA of each eye were obtained: one at the 3- and 9-o’clock meridian and another at the 12- and 6-o’clock meridian.

The ACA status in each of the 4 quadrants of the eye was assessed by one of us with glaucoma subspecialty training (L.M.S.) who was masked to other test results. The ACA was considered closed on SL-OCT imaging if there was contact between the iris and angle wall anterior to the scleral spur in that quadrant.

**RESULTS**

A total of 188 participants (188 eyes) were recruited for the study. Their mean (SD) age was 63.3 (10.5) years (range, 37-99 years), and 57.0% were women. Most were Chinese (162 [86.2%]) and the rest were Malay (8 [4.3%]), Indian (12 [6.4%]), and other races (6 [3.2%]). The mean (SD) Scheie grade was 1.92 (0.96).

Fourteen participants (7.5%) were excluded from the analysis because of failure in obtaining SL-OCT images...
(the examiner was unable to move the eyelids out of the way in 12 [6.4%], and motion artifacts during imaging in 2 [1.1%] resulted in poor image quality). Another 21 participants (11.2%) were also excluded because their SL-OCT images could not be graded owing to poor definition of the scleral spur. Therefore, further analysis was only conducted for 153 participants (81.4%) with satisfactory SL-OCT and SPAC assessments. Of note, there were no significant differences in the mean age, sex, race distribution, and number of gonioscopically closed quadrants for excluded vs included cases (P=.44). Of 153 included participants, 102 (66.7%) had an open ACA in all 4 quadrants of the eye on gonioscopic examination, whereas 51 (33.3%), all of whom had previously undergone laser iridotomy, had at least 1 closed-quadrant ACA.

ANALYSIS BY EYE

Overall, angle closure in 1 or more quadrants was detected by gonioscopy in 51 eyes and by SL-OCT in 86 eyes; SPAC identified 61 eyes at risk of angle closure (numerical grade <5 and/or categorical grade S or P). Therefore, SL-OCT identified significantly more eyes with angle closure than gonioscopy or SPAC (gonioscopy vs SL-OCT, P<.001; SL-OCT vs SPAC, P<.001; gonioscopy vs SPAC, P=.10). Of 51 eyes identified by gonioscopy as having a closed ACA in at least 1 quadrant, SL-OCT identified 43 (84%) and SPAC identified 41 (80%) (P=.79) (Table 1).

Of 102 eyes with an open ACA in all 4 quadrants on gonioscopic evaluation, SL-OCT detected a closed ACA in at least 1 quadrant in 43 (42.2%), whereas SPAC identified 20 (19.6%) at risk for angle closure. Table 2 shows the area under the receiver operating characteristic curve, sensitivity, and specificity values for SL-OCT and SPAC. Using the definition of angle closure as an eye with 1 quadrant of closed ACA on gonioscopic evaluation as the reference standard, the overall sensitivity and specificity for SL-OCT was 84% and 58% vs 80% and 80% for SPAC. With a definition of 2 quadrants of closed ACA, the overall sensitivity and specificity for SL-OCT was 65% and 72% vs 83% and 78% for SPAC.

ANALYSIS BY QUADRANT

Overall, SL-OCT detected more closed ACA quadrants than gonioscopy (P=.006) (Table 3), particularly in the superior, inferior, and temporal quadrants (superior and inferior quadrants, P<.001; temporal quadrant, P=.003). There was no difference in the proportion of closed nasal quadrants detected using gonioscopy vs SL-OCT.

Intraobserver agreement for qualitatively grading the SL-OCT images of 83 randomly selected eyes by the examiner (L.M.S.) was substantial (κ, 0.71 [95% confidence interval, 0.63-0.79]). No comparisons were made with the SPAC because it does not analyze the anterior segment in a quadrant-by-quadrant fashion.

COMMENT

To our knowledge, this is the first study to evaluate the use of SL-OCT for angle imaging and to compare this device with SPAC, another noncontact instrument for angle-closure detection. We found interesting differences between SL-OCT, SPAC, and gonioscopy in the assessment of angle closure. Both SL-OCT and SPAC detected most of the eyes with a closed ACA in at least 1 quadrant on gonioscopy. However, SL-OCT identified more eyes as having angle closure compared with gonioscopy and SPAC. In fact, SL-OCT detected a closed ACA in at least 1 quadrant in 30 eyes that were determined to be open by gonioscopy and SPAC. It is important to note that SL-OCT actually produces images of all 4 quadrants of the ACA, and these images must be interpreted by an examiner, whereas SPAC evaluates the peripheral ACD of the temporal quadrant only and uses a normative database to interpret the results of each examination.

Previous studies have shown that AS-OCT imaging performed with Visante-OCT also detected more closed ACAs than gonioscopy, particularly in the superior and inferior quadrants. The discrepancies between gonioscopy and AS-OCT may be owing to differences in the methods of assessing and interpreting the ACA configuration with each technique, including the influence of visible light on the pupil during gonioscopy (AS-OCT is performed in the dark), inadvertent indentation during gonioscopy, and the level of irido-angle contact required to define a closed ACA on AS-OCT imaging. Of interest, a low-intensity narrow slit of light from the slit-lamp was kept on during image acquisition with SL-OCT to facilitate the positioning of the scan beam at the apex of the cornea, as suggested in the SL-OCT manual. In spite of this, SL-OCT imaging still detected more closed ACAs than gonioscopy in this study.

Compared with the SL-OCT, our study showed that the SPAC had a similar sensitivity but a higher specificity (80% vs 55%) in detecting eyes with angle closure using the definition of 1 quadrant of closed ACA on gonioscopy. When the definition was 2 quadrants of closed ACA, SPAC performed better than SL-OCT, with an overall sensitivity and specificity of 83% and 78% for

Table 1. Detecting Angle Closure Using SPAC and SL-OCT (153 Eyes)

<table>
<thead>
<tr>
<th>Quadrant Number</th>
<th>Gonioscopy</th>
<th>SL-OCT</th>
<th>SPAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Quadrants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td>82</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Closed</td>
<td>20</td>
<td>41</td>
<td>38</td>
</tr>
<tr>
<td>No. of Quadrants Closed</td>
<td>59</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Abbreviations: SL-OCT, slitlamp optical coherence tomography; SPAC, Scanning Peripheral Anterior Chamber depth analyzer.

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participants were excluded, mainly because of the poor
ficity of SL-OCT were worse.

closed ACA on gonioscopy) did not markedly change
specificity would be desirable to reduce the number of
false-positive cases and, thus, improve the cost-
effectiveness of the screening method. Of interest, using
a stricter definition of angle closure (ie, 2 quadrants of
angle closure; SL-OCT, slitlamp optical coherence tomography; SPAC, Scanning Peripheral Anterior Chamber depth analyzer.

Table 3. Quadrant-by-Quadrant Comparison of Gonioscopy and SL-OCT

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>Closed on Gonioscopy</th>
<th>Closed on SL-OCT</th>
<th>P Valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (n=612)</td>
<td>158 (25.8)</td>
<td>195 (31.9)</td>
<td>.006</td>
</tr>
<tr>
<td>Superior (n=153)</td>
<td>46 (30.1)</td>
<td>70 (45.8)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Inferior (n=153)</td>
<td>39 (25.5)</td>
<td>71 (46.4)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Nasal (n=153)</td>
<td>37 (24.2)</td>
<td>37 (24.2)</td>
<td>.88</td>
</tr>
<tr>
<td>Temporal (n=153)</td>
<td>36 (23.5)</td>
<td>17 (11.1)</td>
<td>.003</td>
</tr>
</tbody>
</table>

Abbreviation: SL-OCT, slitlamp optical coherence tomography.

In conclusion, there were differences in angle-
closure detection between SL-OCT and SPAC compared
with gonioscopy. In particular, more persons were
found to have closed angles with SL-OCT than with
gonioscopy. Although SPAC and SL-OCT devices have
high sensitivity in detecting eyes with angle closure,
these methods may have limited use in population-
based screening programs because of their low specific-
ity. Longitudinal prospective studies may help clarify
the clinical value of each instrument’s findings and
determine whether eyes classified as closed by SL-OCT
and SPAC, but not gonioscopy, are at risk of developing
angle-closure glaucoma.

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