Assessment of the Scleral Spur in Anterior Segment Optical Coherence Tomography Images

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Objective: To assess visibility of the scleral spur in anterior segment optical coherence tomography (AS-OCT) images.

Methods: This cross-sectional observational study included 502 participants aged 50 years or older who had no previous ophthalmic problems and were recruited from a community clinic in Singapore. All participants underwent gonioscopy and AS-OCT (Visante; Carl Zeiss Meditec, Dublin, California). Scleral spur location was assessed in AS-OCT images by 2 examiners with glaucoma subspecialty training and was defined as the point where there was an inward protrusion of the sclera with a change in curvature of its inner surface.

Results: Scleral spur location could be determined in 72% of the images of the right eye. Its location on AS-OCT images was less detectable in quadrants with a closed angle on gonioscopy and also in images obtained in the superior and inferior compared with the nasal and temporal quadrants (64%, 67%, 75%, and 80%, respectively; P < .001).

Conclusions: The inability to detect the scleral spur may hamper quantitative analysis of anterior chamber angle parameters that are dependent on the location of this anatomical structure, particularly in the superior and inferior quadrants. New parameters independent of the scleral spur may be useful for detecting eyes at risk of angle closure.

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Anterior segment optical coherence tomography (AS-OCT) is a new technology for imaging the anterior segment of the eye. It is capable of obtaining real-time images of the anterior chamber angle and represents a rapid, noncontact method for the detection of eyes at risk of angle closure. As with ultrasound biomicroscopy, the evaluation of the anterior chamber angle in AS-OCT depends on determining the location of the scleral spur, which anatomically represents the junction between the inner wall of the trabecular meshwork and the sclera. The scleral spur in anterior segment imaging is marked by a prominent inner extension of the sclera (its thickest part) and represents an anatomical landmark for the trabecular meshwork, which is located approximately 250 to 500 µm anterior to the scleral spur along the angle wall. The aim of this study was to evaluate the visibility of the scleral spur in AS-OCT images and to assess the effect of this on the assessment of angle closure.

Study participants were in a subset of consecutive participants of a larger study conducted to evaluate the performance of new imaging devices in screening for angle closure. Those included in the larger study were aged older than 50 years and were attending a community polyclinic in Singapore, for nonophthalmic reasons from January to July 2006. Informed consent was obtained from all participants. The study had the approval of the institutional review board of the Singapore Eye Research Institute and adhered to the tenets of the Declaration of Helsinki.

After being asked about his or her medical and ophthalmic history, each participant underwent the following examinations on the same day: visual acuity, AS-OCT (Visante; Carl Zeiss Meditec, Dublin, California), anterior chamber depth and axial length measurements (IOL-Master, Carl Zeiss Meditec), slit-lamp biomicroscopy, Goldmann applanation tonometry, and gonioscopy. Participants were excluded if they had a history of intraocular surgery or penetrating trauma in either eye, anterior segment laser treatment, or glaucoma.

Gonioscopy was performed in the dark in all participants by a single examiner masked to AS-OCT findings. A 1-mm light beam was...
reduced to a very narrow slit, which was offset horizontally for assessing superior and inferior angles and vertically for nasal and temporal angles. Nonindentation gonioscopy was performed using a Goldmann 2-mirror lens at high magnification (×16) with the eye in the primary position of gaze. Care was taken to keep the light from falling on the pupil and to avoid accidental indentation during examination. The anterior chamber angle width in each quadrant was determined using the Scheie grading system, which is based on the angle structures visible during the examination. Slight tilting of the gonioscope lens was permitted in an attempt to gain a view over the convexity of the iris; the results obtained with this technique were used in the analysis. Dynamic gonioscopy with a Sussman 4-mirror lens was also performed. The results of this dynamic examination were not used in the analysis of our study.

ANTERIOR SEGMENT OPTICAL COHERENCE TOMOGRAPHY

Details of AS-OCT technology have been described previously. Briefly, this technology permits image acquisition at a rate of 8 frames/s (2000 A-scans/s) with a transverse resolution of 60 µm and an axial resolution of 10 to 20 µm. Furthermore, the use of wide-field scanning optics (16 mm) and deep axial scan range (8 mm) permit the AS-OCT to image the entire anterior chamber in a single frame. After acquisition, the scanned images are processed by a customized “dewarping” software, which compensates for the index of refraction transition at the air-tear interface and the different group indices in air, cornea, and aqueous to correct the images’ physical dimensions.

Participants were examined in the sitting position by a single masked examiner (H.T.A.) before any procedure that involved contact with the eye. Anterior segment optical coherence tomography images of the anterior chamber angle were obtained in dark conditions using the standard anterior segment single-scan protocol. To obtain the best quality image, the examiner adjusted the saturation and noise and optimized the polarization for each scan during the examination. Three AS-OCT images of the anterior chamber angle of each eye were obtained: 1 scanning the angle at the 3- and 9-o’clock positions, 1 scanning the angle at the 12-o’clock position, and 1 scanning the angle at the 6-o’clock position.

Anterior segment optical coherence tomography image files were exported to a personal computer and were evaluated using Microsoft Office Picture Manager software (Microsoft Corp, Redmond, Washington). Adjustments of the images’ contrast and brightness were performed to facilitate image evaluation in an attempt to improve the detection of the scleral spur.

MAIN OUTCOMES VARIABLES

Scleral spur visibility in each of the 4 quadrants of the eye was assessed in AS-OCT images of both eyes by 2 examiners with glaucoma subspecialty training who were masked to other tests results (L.M.S. and T.A. working together). The examiners tried to locate the scleral spur on each AS-OCT image. The scleral spur was defined as the point where there was a change in curvature of the inner surface of the angle wall, often appearing as an inward protrusion of the sclera (Figure 1).

The anterior chamber angle in a particular quadrant was classified as closed on gonioscopy if the posterior trabecular meshwork could not be seen (Scheie grade III or IV) during nonindentation gonioscopy. A closed anterior chamber angle on AS-OCT was defined by the presence of any contact anterior to the scleral spur between the iris and angle wall.

The intraobserver reproducibility in detecting the scleral spur in AS-OCT images was assessed in a random subset of 33 eyes (132 quadrants). Images of the 4 quadrants of the eye were assessed in 2 sessions separated by a 1-week interval. A single examiner (L.M.S.), masked to the other test results, graded each quadrant in a dichotomous classification: detectable or undetectable scleral spur. In addition, a second analysis aimed to evaluate the reproducibility of determining the exact scleral spur location in the same 132 AS-OCT images. Its location was plotted in the AS-OCT images using ImageJ software (NIH Image; National Institutes of Health, Bethesda, Maryland). A single examiner (L.M.S.) obtained the x and y coordinates of the scleral spur location in 2 sessions separated by a 1-week interval. The distance between the scleral spur (in each particular quadrant) was assessed in 78 quadrants, as the examiner could not define its exact location in 54 quadrants.

STATISTICAL ANALYSIS

Parametric and nonparametric tests were used to compare continuous variables according to data distribution. The χ2 test was used to compare categorical data. Logistic regression analysis was used to assess the factors related to the detectability of the scleral spur on AS-OCT images. For the logistic analysis, only 1 quadrant of 1 eye per participant was randomly selected for analysis. The intraobserver reproducibility in determining the presence of a detectable scleral spur was assessed using χ statistics. P < .05 was considered statistically significant. Statistical analyses were performed using JMP5 (SAS Institute Inc, Cary, North Carolina) and MedCalc (MedCalc, Mariakerke, Belgium) software.

RESULTS

A total of 504 consecutive participants were included in this study, of whom 274 (54.6%) were women. Most participants were Chinese (463 [92%]), the rest being Malay (9 [2%]), Indian (20 [4%]), and other races (12 [2%]). The mean (SD) age was 61.3 (7.6 [range, 51-93]) years. The mean (SD) anterior chamber depth of the participants’ right eyes was 3.12 (0.36) mm. Mean (SD) axial length was 23.71 (3.25) mm.

Anterior segment optical coherence tomography images of all 4 quadrants could be obtained in 502 patients; it was not possible to obtain superior scans in both eyes of 2 patients. The location of the scleral spur on AS-OCT images could be determined in 1439 of 2008 (71.7%) quadrants of the right eye and in 1415 of 2008 (70.5%) quadrants of the left eye (P = .44). In a quadrant-by-quadrant comparison, the frequency of images with a detectable scleral spur in each of the quadrants of the right eye was not significantly different from the corresponding quadrants of the left eye (Table 1). Further analyses are for the right eye only.
The visibility of the scleral spur was significantly lower in the superior quadrant compared with the temporal and nasal quadrants (P<.001) and in the inferior compared with the temporal and nasal quadrants (P=.01). Most of the cases in which the scleral spur could not be detected occurred in images in which the internal surface of the sclera formed a smooth continuous line, with no internal protrusion of the sclera or change in its curvature) or in images with suboptimal quality. Less frequently, the scleral spur was difficult to identify owing to an atypical contour of the inner corneoscleral wall (Figure 2).

In the analysis by eye, the scleral spur location could not be determined in at least 1 quadrant of 334 of 502 (66.5%) eyes. In most of these eyes (52%), the scleral spur could not be detected in just 1 of the 4 quadrants; but in 4% of these eyes, its location was undetectable in all 4 quadrants. The superior and inferior anterior chamber angles were the locations with the highest rates of undetectable scleral spur for eyes in which the scleral spur was not detectable in 1 or 2 quadrants (Table 2).

Logistic regression showed that superior and inferior quadrants as well as quadrants with angle closure (diagnosed on gonioscopy) were more likely to have an undetectable scleral spur on AS-OCT images (Table 3). Although the identification of the scleral spur location was not possible in 569 of 2008 right-eye quadrants imaged by AS-OCT, it was still possible to grade the anterior chamber angle status as open or closed in 490 of 569 (86%) of these images (Table 4). Figure 3 shows examples of quadrants imaged by AS-OCT that were graded as open or closed even though the scleral spur location could not be determined.

The intraobserver agreement in detecting the scleral spur (132 quadrants) was moderate to substantial in all 33 eyes of the random subset (κ=0.65; 95% confidence interval).
interval, 0.52-0.78). In the assessment of the reproducibility of the exact scleral spur location, the distance between the scleral spur localized in the same image across 2 sessions was within 10 µm in 83% of the 78 quadrants assessed and within 20 µm in 90% (median difference, 4 [range 0-69] µm). Fifty-four quadrants were excluded from this analysis, as the exact location of the scleral spur was considered undetectable.

Scleral spur location represents an important anatomical landmark in imaging the anterior chamber angle, as it is a reference point for the relative position of the trabecular meshwork. The scleral spur is also used as a landmark for quantitative measurements of the anterior chamber angle; parameters such as the angle-opening distance, angle re-

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**Table 4. Ability to Grade Anterior Chamber Angle (ACA) Status by Quadrant and Scleral Spur Detectability**

<table>
<thead>
<tr>
<th>Quadrant</th>
<th>No. of Images</th>
<th>Gradable</th>
<th>Not Gradable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detectable scleral spur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>322</td>
<td>316 (98.1)</td>
<td>6 (1.9)</td>
</tr>
<tr>
<td>Inferior</td>
<td>338</td>
<td>337 (99.7)</td>
<td>1 (0.3)</td>
</tr>
<tr>
<td>Nasal</td>
<td>375</td>
<td>372 (99.2)</td>
<td>3 (0.8)</td>
</tr>
<tr>
<td>Temporal</td>
<td>404</td>
<td>404 (100)</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1439</td>
<td>1429 (99.3)</td>
<td>10 (0.7)</td>
</tr>
<tr>
<td>Undetectable scleral spur</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior</td>
<td>180</td>
<td>156 (86.7)</td>
<td>24 (13.3)</td>
</tr>
<tr>
<td>Inferior</td>
<td>164</td>
<td>134 (81.7)</td>
<td>30 (18.3)</td>
</tr>
<tr>
<td>Nasal</td>
<td>127</td>
<td>109 (85.8)</td>
<td>18 (14.2)</td>
</tr>
<tr>
<td>Temporal</td>
<td>98</td>
<td>91 (92.9)</td>
<td>7 (7.1)</td>
</tr>
<tr>
<td>Total</td>
<td>569</td>
<td>490 (86.1)</td>
<td>79 (13.9)</td>
</tr>
</tbody>
</table>

**Figure 3. Anterior segment optical coherence tomography images in which the anterior chamber angle could be graded as open or closed, though the location of the scleral spur could not be determined. A, An open anterior chamber angle with a wide open angle. B, A clearly closed anterior chamber angle.**

Scleral spur location represents an important anatomical landmark in imaging the anterior chamber angle, as it is a reference point for the relative position of the trabecular meshwork. The scleral spur is also used as a landmark for quantitative measurements of the anterior chamber angle; parameters such as the angle-opening distance, angle re-

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**COMMENT**

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While the interpretation of anterior chamber angle images obtained with ultrasound biomicroscopy is also dependent on the identification of the scleral spur, no study has directly addressed this issue. In a previous study that compared ultrasound biomicroscopy with a prototypical version of the AS-OCT, the authors stated that scleral spurs were more distinct in AS-OCT images, though no further information was provided. In our previous study, when the anterior chamber angle was imaged using a prototypical AS-OCT device, the visibility of the scleral spur seemed better than in images obtained with the Visante AS-OCT. This information is clinically relevant because software algorithms for quantitative measurements of the anterior chamber angle rely entirely on the scleral spur as the principal angle landmark. Difficulty in determining scleral spur location in AS-OCT imaging could adversely affect the accuracy and performance of future imaging programs that aim to automatically detect this anatomical structure.

The rates of detection were better in AS-OCT images obtained in the nasal quadrant and worse in those obtained in the superior and inferior quadrants compared with images taken in the temporal quadrant. In addition, detection was worse in images obtained in quadrants with narrow anterior chamber angles. Although logistic regression analysis is a mere attempt to measure the percentage of variance explained by the model, the $R^2$ value of 0.05 observed in this study suggests that other factors may be accounting for the limited detection of the scleral spur on AS-OCT, such as technical difficulties in imaging the superior and inferior quadrants (imaging artifacts from eyelids and/or manipulation of the eyelids), anatomical variations between participants and/or the quadrants of the eye, relatively low lateral resolution of the AS-OCT, and other factors related to image acquisition or imaging processing (eg, optical correction factors). The worse visibility of the scleral spur in narrow anterior chamber angles may also be because of the proximity of 2 high-reflectivity structures on AS-OCT imaging: the trabecular meshwork and peripheral iris. However, the scleral spur location could not be determined in many AS-OCT images with an open anterior chamber angle (251 quadrants). Notably, manipulation of the image contrast and/or brightness could not improve visibility in most of the images.

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images of a single anterior chamber angle at a time. While it is possible that the visibility of the scleral spur may be better with this high-resolution scan, the images obtained with this scan are not corrected for the different indices of refraction of the air, cornea, and aqueous humor (ie, not “dewarped”) and so were not used in this study.

The intraobserver reproducibility in determining the presence of a detectable scleral spur in this study was substantial. Its exact location could not be determined in 41% of the quadrants included in the reproducibility analysis; however, among the remaining quadrants where it was considered detectable, the distance between scleral spur locations (determined in 2 independent sessions) was within 10 µm in 83% of the quadrants. It is important to note that the effect of the variability of the scleral spur location in measuring anterior chamber angle parameters (such as angle-opening distance) was not evaluated here; it will be the subject of future studies.

Although the location of the scleral spur could not be determined in 30% of AS-OCT images, the presence or absence of angle closure could still be assessed qualitatively in more than 90% of eyes evaluated. Some eyes had deep and open angles with the iris base clearly going into the ciliary body. In these cases, the examiners who graded the AS-OCT images understood that scleral spur location was not necessary for diagnosis of an open angle. Similarly, some angles seemed clearly closed, as they showed a large area of iris contact to the angle wall anterior to the insertion of the iris. Only 10% of images could not be classified by the examiners owing to lack of visualization of the scleral spur. It is important to consider that the results of the open/closed status of the anterior chamber angle in images with an undetectable scleral spur (489 images) were based exclusively on the judgment of the examiners, and the gonioscopic findings cannot validate our AS-OCT grading, as the agreement between the 2 techniques is not good (in both eyes with undetectable and detectable scleral spurs). This may be because of particularities in the methods of assessing and interpreting the anterior chamber angle configuration that may prevent appropriate comparisons between the 2 techniques; these issues were addressed in previous publications. Nevertheless, the findings of this study suggest that qualitative assessment of angle closure may be more useful than quantitative evaluation, at least when considering the current Visante AS-OCT device.

Our study has important limitations. The qualitative assessment of the scleral spur was performed by 2 glaucoma specialists who have particular interest in angle closure and are experienced in assessing AS-OCT images. It is likely that the number of images in which the scleral spur location cannot be detected may be higher in clinical practice, especially if imaging is performed by inexperienced technicians or if the images are qualitatively assessed by observers with less expertise. Similarly, while the intraobserver reproducibility in determining the scleral spur was substantial, as was the reproducibility of the exact location of this structure, this was again assessed by a glaucoma specialist. Last, although the location of the scleral spur on AS-OCT imaging was determined qualitatively as an inward prominent extension of the sclera with a change in curvature of the inner (posterior) surface of the sclera, there was no reference standard to confirm where this structure is actually located in the eye.

In summary, our study showed that almost 90% of the Visante AS-OCT images could be qualitatively graded by 2 glaucoma specialists (working together) as having either an open or closed anterior chamber angle, though the location of the scleral spur could not be determined in approximately 30% of images. This problem of determining the scleral spur location may hamper quantitative evaluation of anterior chamber angle parameters and the determination of eyes at risk for closure. New anterior chamber angle parameters for assessing angle closure that are independent of locating the scleral spur may improve the performance of AS-OCT imaging in detecting eyes at risk of angle closure.

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