

# Anterior Chamber Angle Imaging with Swept-Source Optical Coherence Tomography: An Investigation on Variability of Angle Measurement

Shu Liu, Marco Yu, Cong Ye, Dennis S. C. Lam, and Christopher Kai-shun Leung

**PURPOSE.** To evaluate the reproducibility of anterior chamber angle measurements obtained by swept-source optical coherence tomography (OCT) and to identify factors associated with its measurement variability.

**METHODS.** One eye from each of 30 healthy subjects was randomly selected for anterior segment OCT imaging (Casia SS-1000 OCT; Tomey, Nagoya, Japan) in three separate visits within a week. The angle opening distance (AOD), the trabecular iris space area (TISA), and the trabecular-iris angle (TIA) at the superior (90°), nasal (0°), inferior (270°), and temporal (180°) angles were measured. The intraobserver and interobserver reproducibility coefficient (RC) and intraclass correlation coefficient (ICC) were calculated. Generalized linear latent and mixed modeling was used to examine the association between the variance of angle measurements and each of the following: angle width, pupil diameter, pupil diameter variance, iris thickness, iris thickness variance, axial length, anterior chamber depth, scan location, scleral spur visibility, and age.

**RESULTS.** The intervisit, intraobserver RCs ranged between 0.140 mm and 0.252 mm for AOD, 0.050 mm<sup>2</sup> and 0.090 mm<sup>2</sup> for TISA, and 7.7° and 9.5° for TIA, and the interobserver RCs were between 0.103 mm and 0.187 mm, 0.049 mm<sup>2</sup> and 0.101 mm<sup>2</sup>, and 8.5° and 13.7°, respectively. The ICCs were all  $\geq 0.83$ . Increased iris thickness, increased iris thickness variance, angle measured at the superior and inferior quadrants, increased angle width, and long axial length were associated with increased variance of angle measurements.

**CONCLUSIONS.** Although the swept-source OCT had high reproducibility for angle measurement, differences in iris thickness, angle width, measurement location, and axial length may influence its variability. (*Invest Ophthalmol Vis Sci.* 2011;52:8598–8603) DOI:10.1167/iovs.11-7507

Evaluation and measurement of the anterior chamber angle is pertinent to risk assessment of angle closure. Investigating quantitative change in angle configuration after laser peripheral iridotomy or cataract extraction also depends on precise recording of the angle width.<sup>1–7</sup> The

Visante optical coherence tomography (OCT; Carl Zeiss Meditec, Dublin, CA) and the slit-lamp OCT (SL-OCT; Heidelberg Engineering GmbH, Dossenheim, Germany) are non-contact imaging devices that have been shown to be repeatable and reproducible for measurement of the angle.<sup>8–12</sup> Both instruments are time-domain OCT with a respective scan speed of 2000 A-scans and 200 A-scans per second. With a frame size of 256 A-scans and 215 A-scans, respectively, it takes 0.125 seconds for Visante OCT and 1.075 seconds for SL-OCT to capture a single cross-sectional image. The relatively slow scan rate limits the sampling density for both instruments and may increase the propensity for motion artifact for SL-OCT.

The Casia SS-1000 OCT (Tomey, Nagoya, Japan) is a Fourier-domain, swept-source OCT designed specifically for imaging the anterior segment. With a substantial improvement in scan speed (30,000 A-scans per second), the anterior chamber angles can be imaged in 128 cross-sections (each with 512 A-scans) 360° around the anterior segment in 2.4 seconds. The objectives of this study were to examine the intervisit reproducibility of the Casia SS-1000 OCT for measurement of the anterior chamber angle and identified factors accountable for its measurement variability.

## SUBJECTS AND METHODS

### Subjects

Thirty healthy subjects with no history of ocular disease were consecutively invited for anterior chamber angle imaging in three separate visits within a week. Only one eye from each subject was randomly selected in the analysis. None of the subjects had evidence of ocular disease, none had a history of intraocular surgery or laser procedure, and none were using topical medication that could have affected pupil size. One eye had a quadrant (the superior quadrant) showing a closed angle in the OCT image. The other quadrants were open, and there was no evidence of glaucoma or other ocular abnormalities. The study was conducted in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and was approved by the local clinical research ethics committee; informed consent was obtained from all subjects.

### Anterior Segment OCT Imaging

Instead of using a spectrometer, as in spectral-domain OCT, swept-source OCT uses a monochromatic, tunable, fast-scanning laser source and a photodetector to detect wavelength-resolved interference signals.<sup>13,14</sup> The Casia SS-1000 OCT (Tomey, Nagoya, Japan) is a commercially available swept-source OCT with a swept-source laser wavelength of 1310 nm.

The anterior chamber angle scan protocol was used to image the angle. It was composed of 128 radial scans, each 16 mm in length and

From the Department of Ophthalmology and Visual Sciences, The Chinese University of Hong Kong, Hong Kong, P. R. China.

Supported by Tomey and Carl Zeiss Meditec (CKL).

Submitted for publication March 5, 2011; revised July 26 and September 11, 2011; accepted September 11, 2011.

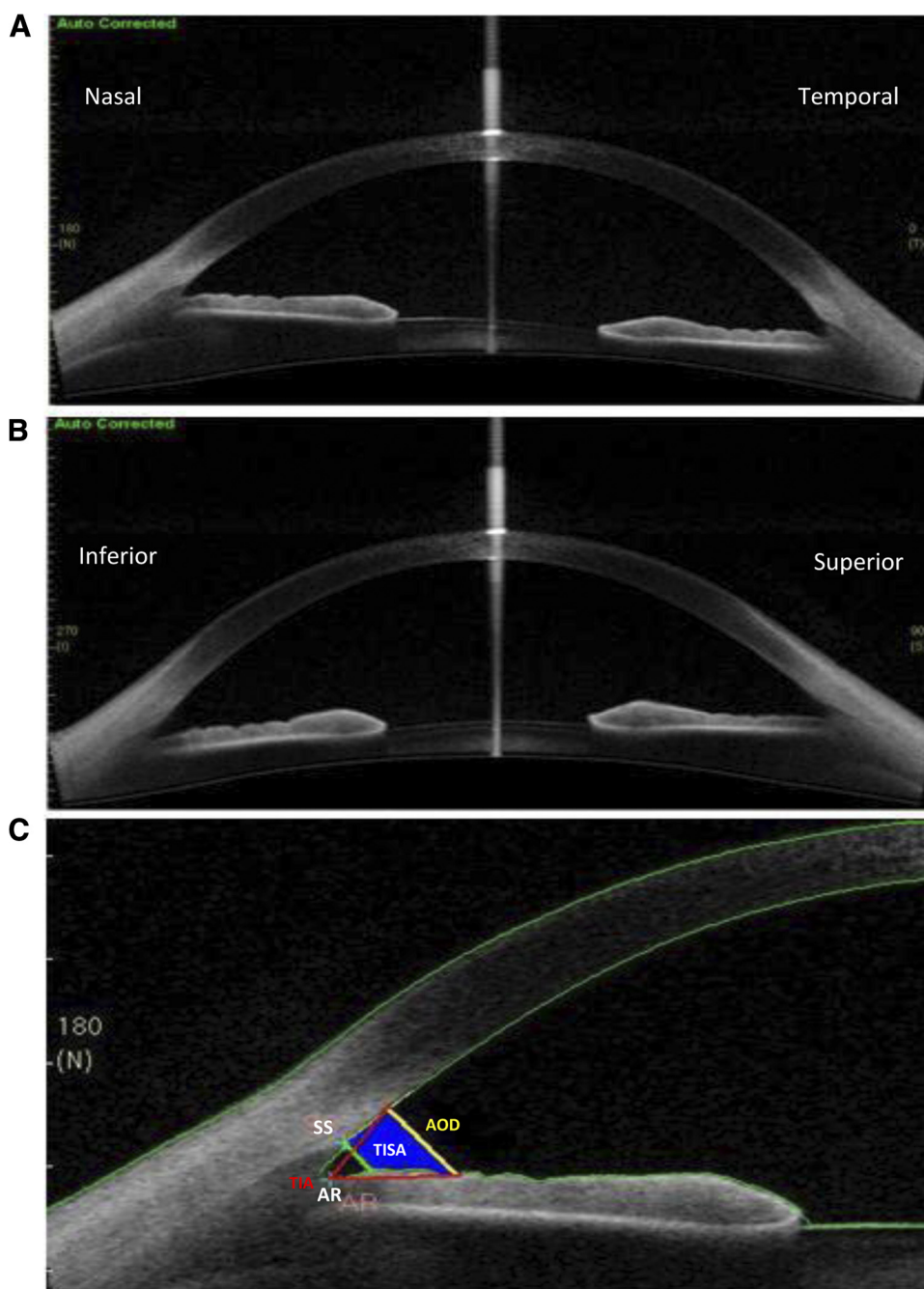
Disclosure: S. Liu, None; M. Yu, None; C. Ye, None; D.S.C. Lam, None; C.K. Leung, Tomey (F), Carl Zeiss Meditec (F, C, R)

Corresponding author: Christopher Kai-shun Leung, Department of Ophthalmology & Visual Sciences, The Chinese University of Hong Kong, Hong Kong Eye Hospital, 147K Argyle Street, Kowloon, Hong Kong; tlims00@hotmail.com.

6 mm in depth. During the scan, the participant was asked to fixate on an internal fixation target; the total scan duration was 2.4 seconds. To avoid lid artifact, participants were instructed to pull down the lower lid against the lower orbital rim to expose the lower limbus while the technician elevated the upper lid against the upper orbital rim to expose the upper limbus. All images obtained had no lid artifacts. Each eye was imaged in the dark (0.3 lux) in three separate visits (a total of three image series) within a week. The angle opening distance (AOD), trabecular iris space area (TISA), and trabecular-iris angle (TIA) were measured, by a single masked observer, once for the three image series (images of the horizontal and vertical meridians were measured in each image series) using the instrument software in a random order to determine intervisit and intraobserver variability and to identify factors associated with the variance of angle measurements. Another masked observer performed angle measurements using the image series obtained in the final visit to determine intravisit and interobserver variability.

### Measurement of Scleral Spur Visibility, Anterior Chamber Angle, Pupil Diameter, Anterior Chamber Depth, and Axial Length

The AOD, TISA, and TIA were automatically analyzed after the scleral spur and the angle recess were manually located (Fig. 1). The scleral spur is a scleral protrusion at the angle that can be identified in OCT images by following the boundary between longitudinal fibers of the ciliary muscle and the sclera until it reaches the anterior chamber. Its visibility is determined with reference to a scoring system devised in a previous study.<sup>15</sup> A scleral spur visibility score (SSVS) of 2 and 1 denoted a clearly and a moderately visible scleral spur, respectively. A SSVS of 0 indicated the scleral spur was not visible. Subjects were included in the analysis only when all angles from all three images had a SSVS of at least 1. Three subjects were excluded because the scleral spur was not detectable in at least one quadrant in any of the three scans taken per eye. AOD was calculated as the perpendicular distance



**FIGURE 1.** OCT images obtained from the Casia OCT at the horizontal (A) and vertical (B) meridians. AOD (long yellow line), TISA (blue), and TIA (angle bounded by the red lines) were automatically reported by the analysis software after the scleral spur (SS) and the angle recess (AR) were located manually.

measured from the trabecular meshwork at 500  $\mu\text{m}$  anterior to the scleral spur to the anterior iris surface.<sup>16</sup> TISA was an area bounded anteriorly by the AOD, posteriorly by a line drawn from the scleral spur perpendicular to the plane of the inner scleral wall to the opposing iris, superiorly by the inner corneoscleral wall, and inferiorly by the iris surface.<sup>17</sup> 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  $\mu\text{m}$  from the scleral spur and the point on the iris perpendicularly opposite.<sup>16</sup> Superior (90°), nasal (0°), inferior (270°), and temporal (180°) angles were measured. Pupil diameter was measured as iris tip-to-tip distance. Anterior chamber depth (ACD) was defined as the perpendicular distance from the corneal endothelium at the corneal apex to the anterior lens surface. Iris thickness was defined as the distance between the anterior and posterior iris surfaces at 500  $\mu\text{m}$  from the scleral spur. Pupil diameter, iris thickness, and ACD were measured from the OCT image. The horizontal meridian of each of the three image series of each eye was selected for measurement of pupil diameter and ACD. The average of three measurements was analyzed. Axial length was measured with an optical biometer (IOLMaster, version 3.0.1; Carl Zeiss Meditec, Dublin, CA). Iris and corneal boundaries were checked for all angle, iris, and ACD measurements. There were no segmentation errors in the analyzed images.

### Statistical Analysis

Statistical analysis was performed (Stata, version 10.1; StataCorp, College Station, TX). The intervisit RC and ICC were calculated. The RC is defined as  $1.96 \times \sqrt{2} \times \text{within-subject SD}$ .<sup>18</sup> The interpretation is that 95% of the difference between measurements obtained from two separate occasions would be less than the RC. ICC was interpreted as follows: <0.75 represents poor to moderate reliability, 0.75 to 0.90 represents good reliability, and >0.90 represents excellent reliability for clinical measures.<sup>19</sup> By setting the 95% confidence interval as 20% on either side of the estimate of within-subject standard deviation Sw

[ $n = 1.96^2 / (2 \times 0.2^2 \times (m-1))$ ],<sup>20</sup> where  $n$  is the number of subjects and  $m$  is the number of observations, it was estimated that a minimum of 25 subjects was required. Angle measurements at different quadrants were compared with Wilcoxon signed-rank tests at the 5% level of significance with Bonferroni adjustment. Generalized linear latent and mixed modeling was used to evaluate the effects of mean angle width, mean pupil diameter, variance of pupil diameter, iris thickness, variance of iris thickness, axial length, anterior chamber depth, SSVS, age, and scan location on the variances of AOD, TISA, and TIA. In brief, the angle variance (*varANGLE*) was regressed on the mean angle (*ANGLE*), mean pupil diameter (*PD*), variance of pupil diameter (*varPD*), mean iris thickness (*IT*), variance of iris thickness (*varIT*), axial length (*AL*), anterior chamber depth (*ACD*), SSVS, age (*AGE*), and the scan location (*TEMPORAL*, *SUPERIOR*, and *INFERIOR*), with random subject effect as the random intercept using uniform link function:

$$\begin{aligned} \text{varANGLE} = & \beta_0 + \beta_1 \times \text{ANGLE} + \beta_2 \times \text{PD} + \beta_3 \times \text{varPD} \\ & + \beta_4 \times \text{IT} + \beta_5 \times \text{varIT} + \beta_6 \times \text{AL} + \beta_7 \times \text{ACD} \\ & + \beta_8 \times \text{AGE} + \beta_9 \times \text{SSVS} + \beta_{10} \times \text{TEMPORAL} \\ & + \beta_{11} \times \text{SUPERIOR} + \beta_{12} \times \text{INFERIOR} + \eta_0 + \varepsilon \end{aligned}$$

where  $\beta_0 - \beta_9$  represent the fixed effects associated with the intercept, mean value of the angle measurement, pupil diameter, variance of pupil diameter, iris thickness, variance of iris thickness, axial length, anterior chamber depth, subject age, and scleral spur visibility score, respectively;  $\beta_{10} - \beta_{12}$  represents the fixed effects associated with the scan location (Three variables—TEMPORAL, SUPERIOR, INFERIOR—were used to denote the four scan locations. For example, temporal measurement was coded as *TEMPORAL* = 1, *SUPERIOR* = 0, *INFERIOR* = 0. Nasal measurement was coded as *TEMPORAL* = 0, *SUPERIOR* = 1, *INFERIOR* = 0).

TABLE 1. Average of Three Scans for Each Eye Was Used for Calculations

	P of Pairwise Comparison*				
	Mean $\pm$ SD	S	N	I	T
AOD 500, mm					
S	0.319 $\pm$ 0.212	—	0.000†	0.000†	0.000†
N	0.454 $\pm$ 0.230	0.000†	—	0.043	0.003†
I	0.491 $\pm$ 0.277	0.000†	0.043	—	0.319
T	0.507 $\pm$ 0.272	0.000†	0.003†	0.319	—
TISA 500, mm <sup>2</sup>					
S	0.100 $\pm$ 0.088	—	0.000†	0.000†	0.000†
N	0.155 $\pm$ 0.084	0.000†	—	0.734	0.280
I	0.153 $\pm$ 0.098	0.000†	0.734	—	0.382
T	0.160 $\pm$ 0.095	0.000†	0.280	0.382	—
TIA, deg					
S	25.3 $\pm$ 11.7	—	0.000†	0.001†	0.000†
N	32.9 $\pm$ 11.1	0.000†	—	0.104	0.079
I	31.1 $\pm$ 10.9	0.001†	0.104	—	0.003†
T	34.8 $\pm$ 11.0	0.000†	0.079	0.003†	—
IT 500, mm					
S	0.354 $\pm$ 0.055	—	0.086	0.047	0.002†
N	0.335 $\pm$ 0.051	0.086	—	0.001†	0.280
I	0.371 $\pm$ 0.075	0.047	0.001†	—	0.000†
T	0.323 $\pm$ 0.060	0.002†	0.280	0.000†	—
SSVS					
S	1.51 $\pm$ 0.45	—	0.000†	0.959	0.001†
N	1.96 $\pm$ 0.19	0.000†	—	0.000†	1.000
I	1.52 $\pm$ 0.45	0.959	0.000†	—	0.000†
T	1.94 $\pm$ 0.22	0.001†	1.000	0.000†	—

S, superior; N, nasal; I, inferior; T, temporal.

\* Measurements at different quadrants were compared with Wilcoxon signed-rank test at 5% level of significance with Bonferroni adjustment.

†  $P < 0.008$  was considered statistically significant.

**TABLE 2.** Intervisit/Intraobserver and Intravisit/Interobserver RC and ICC of Anterior Chamber Angle Measurements in All Quadrants

	RC (95% CI)		ICC (95% CI)	
	Intraobserver	Interobserver	Intraobserver	Interobserver
AOD 500, mm				
S	0.140 (0.115–0.165)	0.158 (0.118–0.198)	0.94 (0.90–0.97)	0.93 (0.85–0.97)
N	0.141 (0.116–0.166)	0.116 (0.087–0.145)	0.95 (0.91–0.98)	0.97 (0.94–0.99)
I	0.252 (0.207–0.297)	0.187 (0.140–0.235)	0.90 (0.83–0.95)	0.94 (0.88–0.97)
T	0.224 (0.184–0.265)	0.103 (0.077–0.129)	0.91 (0.85–0.96)	0.98 (0.96–0.99)
TISA 500, mm <sup>2</sup>				
S	0.074 (0.061–0.087)	0.083 (0.062–0.103)	0.91 (0.84–0.95)	0.90 (0.81–0.95)
N	0.050 (0.041–0.059)	0.049 (0.037–0.062)	0.95 (0.92–0.98)	0.96 (0.91–0.98)
I	0.090 (0.074–0.106)	0.101 (0.075–0.126)	0.90 (0.83–0.95)	0.86 (0.74–0.93)
T	0.086 (0.071–0.101)	0.051 (0.038–0.064)	0.90 (0.83–0.95)	0.96 (0.93–0.98)
TIA 500, deg				
S	7.7 (6.4–9.1)	13.3 (9.9–16.6)	0.94 (0.90–0.97)	0.88 (0.77–0.94)
N	8.9 (7.3–10.5)	13.7 (10.2–17.2)	0.92 (0.86–0.96)	0.83 (0.68–0.92)
I	9.5 (7.8–11.2)	13.4 (10.0–16.8)	0.91 (0.83–0.95)	0.87 (0.74–0.94)
T	8.2 (6.8–9.8)	8.5 (6.4–10.7)	0.93 (0.87–0.96)	0.94 (0.87–0.97)

RIOR = 0, INFERIOR = 0. The nasal quadrant was set as a reference location for comparison with other quadrants.);  $\eta_0$  represents the random subject effects associated with the intercept; and  $\varepsilon$  represents the residual. Insignificant factors were removed by backward selection after performing likelihood-ratio test at the 5% significance level. Comparisons of estimates among the quadrants were performed with the Wald test.  $P < 0.05$  was considered statistically significant.

## RESULTS

Mean age, axial length, pupil diameter, and anterior chamber depth were  $39.5 \pm 13.1$  (range, 24.0–69.0) years,  $24.3 \pm 1.7$  (range, 22.0–30.6) mm,  $4.77 \pm 0.88$  (range, 2.94–6.19) mm, and  $2.9 \pm 0.4$  (range, 2.4–3.7) mm, respectively. AOD, TISA, TIA, iris thickness (IT), and SSVS measurements in the superior, nasal, inferior, and temporal quadrants are shown in Table 1. AOD, TISA, and TIA ranged from 0.000 mm to 1.461 mm, 0.000 mm<sup>2</sup> to 0.497 mm<sup>2</sup>, and 0.0° to 61.9°, respectively. Angle measurements of the superior quadrant were significantly smaller than those measured in the other quadrants ( $P < 0.001$ ). The iris was thicker in the superior and inferior quadrants, whereas the SSVS was greater in the nasal and temporal quadrants (Table 1).

Intervisit, intraobserver RCs ranged between 0.140 mm and 0.252 mm for AOD, 0.050 mm<sup>2</sup> and 0.090 mm<sup>2</sup> for TISA, and 7.7° and 9.5° for TIA. Interobserver RCs ranged between 0.103 mm and 0.187 mm, 0.049 mm<sup>2</sup> and 0.101 mm<sup>2</sup>, and 8.5° and 13.7°, respectively (Table 2). In general, the RC was greatest (i.e., the highest measurement variability) at the inferior quadrant. The ICC for all parameters was  $\geq 0.83$ .

Generalized linear latent and mixed modeling was performed to identify factors (mean angle width, mean pupil diameter, variance of pupil diameter, mean iris thickness, variance of iris thickness, axial length, anterior chamber depth, SSVS, age, and scan location) responsible for the measurement variability of AOD, TISA, and TIA (Tables 3–5). Measurements obtained from the superior and inferior quadrants ( $P \leq 0.009$ ) were associated with increased variability of TISA. Greater mean angle width was associated with increased variability of AOD and TISA ( $P \leq 0.001$ ). TIA variance, in contrast, was not related to the mean angle width or the location of measurement. The only significant factor associated with the variance of TIA was the axial length ( $P < 0.001$ ), which was also significantly associated with the variance of AOD ( $P = 0.009$ ). Mean and variance of iris thickness were associated with the variance of AOD ( $P = 0.027$  and  $P = 0.005$ , respectively). Age, anterior chamber depth, pupil diameter, variance of pupil diameter, and scleral spur visibility were not related to the variance of angle measurements. Except for iris thickness in the model of AOD (power = 60%) and the temporal quadrant in the model of TISA (power = 14%), the statistical power of all the GLLAM models ranged between 74% and 100%, with an alpha = 5% (Tables 3–5).

## DISCUSSION

The swept-source OCT demonstrated low variability for measurement of the anterior chamber angle. The ICC of all angle parameters measured at different quadrants was  $\geq 0.83$ . Iris thickness, scan location, angle dimension, and axial length

**TABLE 3.** Factors Associated with the Variance of AOD Analyzed by a Generalized Linear Latent and Mixed Model

	Coefficient	Estimate	95% CI	P	Power (%)*
Mean AOD	$\beta_1$	$1.04 \times 10^{-2}$	$0.51 \times 10^{-2}$ to $1.56 \times 10^{-2}$	0.000	97
Mean IT	$\beta_4$	$9.77 \times 10^{-3}$	$1.13 \times 10^{-3}$ to $18.41 \times 10^{-3}$	0.027	60
IT variance	$\beta_5$	$9.24 \times 10^{-1}$	$2.73 \times 10^{-1}$ to $15.76 \times 10^{-1}$	0.005	79
Axial length	$\beta_6$	$6.29 \times 10^{-4}$	$1.57 \times 10^{-4}$ to $11.02 \times 10^{-4}$	0.009	74
Intercept	$\beta_0$	$-1.98 \times 10^{-2}$	$-3.04 \times 10^{-2}$ to $-0.91 \times 10^{-2}$	0.000	—

Pupil diameter, variance of pupil diameter, ACD, SSVS, age, and locations were removed by backward selection after performing likelihood-ratio test at 5% significance level.

\* Power calculation was performed based on a z-test.



**TABLE 4.** Factors Associated with the Variance of TISA Analyzed by a Generalized Linear Latent and Mixed Model

	Coefficient	Estimate	95% CI	P	Power (%) <sup>*</sup>
Mean TISA	$\beta_1$	$4.81 \times 10^{-3}$	$2.74 \times 10^{-3}$ to $6.87 \times 10^{-3}$	0.000	100
Superior†	$\beta_{11}$	$4.15 \times 10^{-4}$	$1.02 \times 10^{-4}$ to $7.29 \times 10^{-4}$	0.009	74
Inferior†	$\beta_{12}$	$4.65 \times 10^{-4}$	$1.32 \times 10^{-4}$ to $7.97 \times 10^{-4}$	0.006	78
Temporal	$\beta_9$	$1.49 \times 10^{-4}$	$-1.91 \times 10^{-4}$ to $4.89 \times 10^{-4}$	0.390	14
Intercept	$\beta_0$	$-7.7 \times 10^{-2}$	$-143.12 \times 10^{-2}$ to $127.73 \times 10^{-2}$	0.911	—

Pupil diameter, variance of pupil diameter, IT, variance of IT, axial length variance, ACD, SSVS, and age were removed by backward selection after performing likelihood-ratio test at 5% significance level.

<sup>\*</sup> Power calculation was performed based on a z-test.

† The nasal quadrant was set as a reference location for comparison with other quadrants. Significant differences were also observed between the nasal and superior and the nasal and inferior quadrants (Wald test,  $P = 0.009$  and  $P = 0.006$ , respectively).

were accountable to variance of angle measurements. High-speed imaging of the anterior segment with the swept-source OCT would be a reliable approach for the evaluation and measurement of the anterior chamber angle.

The reliability of angle measurements obtained with time-domain OCT has been previously investigated. In the study by Tan et al.,<sup>11</sup> the interobserver ICCs of AOD500, AOD750, TISA500, and TISA750 measured by the Visante OCT (Carl Zeiss Meditec) ranged between 0.978 and 0.988. Using the SL-OCT (Heidelberg Engineering), Muller et al.<sup>12</sup> reported that the interobserver ICC of the anterior chamber angle was 0.96. Although the ICCs reported by Radhakrishnan et al.<sup>10</sup> were generally smaller (0.31–0.73 for the inferior quadrant; 0.56–0.93 for the nasal and temporal quadrants), it is notable that they used a prototype device. The disparities in ICCs would be related to the differences in study populations, study design, instruments, and quadrants of assessment. We showed in a previous study that the intervisit RCs for AOD and TIA measured at the nasal angle in the dark by the Visante OCT were 0.177 mm and 9.4°, respectively (we analyzed only the nasal angle and measured AOD and TIA in this study).<sup>8</sup> These values closely resemble those reported in the present study using the Casia SS-1000 OCT (0.141 mm for AOD, 8.9° for TIA at the nasal angle).

AOD, TISA, and TIA are parameters measured with reference to the scleral spur.<sup>16,17</sup> They have different units ( $\mu\text{m}$ ,  $\mu\text{m}^2$ , and degree, respectively) and represent different dimensions (length, area, and angle) of the angle. For this reason, it is not surprising to find disparities in the comparisons of angle width (Table 1) and different factors accounting for measurement variability of AOD, TISA, and TIA (Tables 3–5). The most consistent observation in the comparison of angle width in different quadrants is that the superior angle was the smallest. This concurs with the earlier studies performed with gonioscopy and ultrasound biomicroscopy showing that the angle is narrower in the superior quadrant.<sup>21,22</sup> Although there were also significant differences between the temporal and inferior angles for TIA ( $P = 0.003$ ) and between the nasal and temporal

angles for AOD ( $P = 0.003$ ), the differences were fairly small (3.7° and 0.053 mm, respectively).

Given that the AOD is measured in distance, it is not surprising to find an association between the variance of iris thickness and the variance of AOD (Table 3). Although iris thickness measurements had no influence on the variances of TISA and TIA (Tables 4, 5), variation in anterior iris surface contour could influence the variability of TISA as one of the measurement boundaries of TISA is the anterior iris surface. In this study, angles measured at the superior and inferior quadrants were associated with increased TISA variance. Although this association might be related to the fact that the scleral spur tends to be less distinct at the superior and inferior quadrants (Table 1),<sup>15,23</sup> we did not find an association between scleral spur visibility score and any of the angle measurement variances. Without a validated approach to quantify the configuration of the anterior iris surface, it is uncertain whether there are greater variations in iris surface contour in the superior and inferior quadrants and whether such variations, if they exist, contribute to the increased variability of TISA.

Mean angle width was significantly associated with the variances of AOD and TISA, but not with the variance of TIA. Although a small shift in the identified scleral spur location may induce a substantive change in AOD and TISA, TIA measurement, by contrast, could be more accommodating (Fig. 2). Variations in AOD and TISA as a result of a shift in the identified scleral spur location would be greater in a wide-open angle than in a narrow angle.

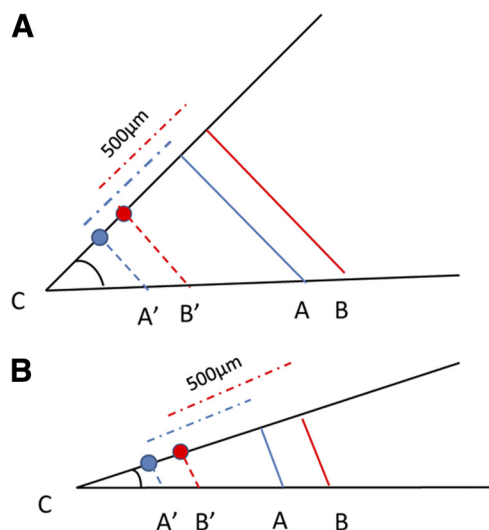
Because ACD and axial length are highly correlated variables, it was likely that one of them would be removed after model fitting. In the GLLAM models, ACD was removed by backward selection, and axial length was found to be significantly associated with AOD and TIA variances. It is unclear why a longer axial length was associated with an increased variance of AOD and TIA. It has been shown that eyes with a longer axial length had greater ciliary body and ciliary muscle thicknesses.<sup>24,25</sup> The ciliary body is a dynamic structure, and the increase in ciliary body and ciliary muscle thicknesses

**TABLE 5.** Factors Associated with the Variance of TIA Analyzed by a Generalized Linear Latent and Mixed Model

	Coefficient	Estimate	95% CI	P	Power (%) <sup>*</sup>
Axial length	$\beta_6$	3.11	2.09 to 4.13	0.000	100
Intercept	$\beta_0$	$-6.62 \times 10$	$-9.07 \times 10$ to $-4.17 \times 10$	0.000	—

Trabecular iris angle width, pupil diameter, variance of pupil diameter, IT, variance of IT, ACD, SSVS, age, and locations were removed by backward selection after performing likelihood-ratio test at 5% significance level.

<sup>\*</sup> Power calculation was performed based on a z-test.



**FIGURE 2.** Schematics demonstrating how a shift in locating the scleral spur (blue dot to red dot) changes the measurement of AOD (line A to line B) and TISA (area bounded by line A' and line A to area bounded by line B' and line B). The angle measurement (TIA, angle C), by contrast, is not affected. The differences in AOD (line B – line A) and TISA (area B'B – area A'A) as a result of a change in the location of scleral spur are greater in a wide-open angle (A) than in a narrow angle (B).

might impose additional variations in measurement of the angle. Limited by scleral scattering, it is not feasible to visualize the ciliary body in full with the swept-source OCT, and its dimensions were not measured in this study.

To our knowledge, this is the first study showing that the new swept-source OCT provides reproducible measurement of AOD, TISA, and TIA at different meridians, suggesting that it is useful for measuring the angle for risk assessment of angle closure and for evaluating longitudinal changes before and after therapeutic intervention in patients with angle closure. Identifying factors responsible for angle measurement variability would be important for interpreting the reproducibility of various angle parameters. The finding of an association between the angle width and the variances of AOD and TISA, but not the variance of TIA, might indicate that TIA could be a more reliable indicator to follow the longitudinal changes of the angle. Prospective analysis would be needed to validate this hypothesis.

## References

- Ang GS, Wells AP. Changes in Caucasian eyes after laser peripheral iridotomy: an anterior segment optical coherence tomography study. *Clin Exp Ophthalmol*. 2010;38:778–785.
- See JL, Chew PT, Smith SD, et al. Changes in anterior segment morphology in response to illumination and after laser iridotomy in Asian eyes: an anterior segment OCT study. *Br J Ophthalmol*. 2007;91:1485–1489.
- Memarzadeh F, Li Y, Chopra V, et al. Anterior segment optical coherence tomography for imaging the anterior chamber after laser peripheral iridotomy. *Am J Ophthalmol*. 2007;143:877–879.
- Memarzadeh F, Tang M, Li Y, et al. Optical coherence tomography assessment of angle anatomy changes after cataract surgery. *Am J Ophthalmol*. 2007;144:464–465.
- Nolan WP, See JL, Aung T, et al. Changes in angle configuration after phacoemulsification measured by anterior segment optical coherence tomography. *J Glaucoma*. 2008;17:455–459.
- Kucumen RB, Yenerel NM, Gorgun E, et al. Anterior segment optical coherence tomography measurement of anterior chamber depth and angle changes after phacoemulsification and intraocular lens implantation. *J Cataract Refract Surg*. 2008;34:1694–1698.
- Tai MC, Chien KH, Lu DW, et al. Angle changes before and after cataract surgery assessed by Fourier-domain anterior segment optical coherence tomography. *J Cataract Refract Surg*. 2010;36:1758–1762.
- Li H, Leung CK, Cheung CY, et al. Repeatability and reproducibility of anterior chamber angle measurement with anterior segment optical coherence tomography. *Br J Ophthalmol*. 2007;91:1490–1492.
- Leung CK, Li H, Weinreb RN, Liu J, et al. Anterior chamber angle measurement with anterior segment optical coherence tomography: a comparison between slit lamp OCT and Visante OCT. *Invest Ophthalmol Vis Sci*. 2008;49:3469–3474.
- Radhakrishnan S, See J, Smith SD, et al. Reproducibility of anterior chamber angle measurements obtained with anterior segment optical coherence tomography. *Invest Ophthalmol Vis Sci*. 2007;48:3683–3688.
- Tan AN, Sauren LD, de Brabander J, et al. Reproducibility of anterior chamber angle measurements with anterior segment optical coherence tomography. *Invest Ophthalmol Vis Sci*. 2011;52:2095–2099.
- Müller M, Dahmen G, Pörksen E, et al. Anterior chamber angle measurement with optical coherence tomography: intraobserver and interobserver variability. *J Cataract Refract Surg*. 2006;32:1803–1808.
- Yun S, Tearney G, de Boer J, et al. High-speed optical frequency-domain imaging. *Opt Express*. 2003;11:2953–2963.
- Yasuno Y, Madjarova VD, Makita S, et al. Three-dimensional and high-speed swept-source optical coherence tomography for in vivo investigation of human anterior eye segments. *Opt Express*. 2005;13:10652–10664.
- Liu S, Li H, Dorairaj S, et al. Assessment of scleral spur visibility with anterior segment optical coherence tomography. *J Glaucoma*. 2010;19:132–135.
- Pavlin CJ, Harasiewicz K, Foster FS. Ultrasound biomicroscopy of anterior segment structures in normal and glaucomatous eyes. *Am J Ophthalmol*. 1992;113:381–389.
- Radhakrishnan S, Goldsmith J, Huang D, et al. Comparison of optical coherence tomography and ultrasound biomicroscopy for detection of narrow anterior chamber angles. *Arch Ophthalmol*. 2005;123:1053–1059.
- British Standards Institution. *Precision of Test Methods, 1: Guide for the Determination and Reproducibility for a Standard Test Method* (BS 597, part 1). London: BSI; 1975.
- Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice*. Norwalk, CT: Appleton & Lange; 1993:505–528.
- Bland JM. How can I decide the sample size for a repeatability study? <http://www-users.york.ac.uk/~mb55/meas/sizerep.htm>. Accessed August 28, 2011.
- Phillips CI. Closed-angle glaucoma: significance of sectorial variations in angle depth. *Br J Ophthalmol*. 1956;40:136–143.
- Dorairaj SK, Tello C, Liebmann JM, et al. Narrow angles and angle closure: anatomic reasons for earlier closure of the superior portion of the iridocorneal angle. *Arch Ophthalmol*. 2007;125:734–739.
- Sakata LM, Lavanya R, Friedman DS, et al. Assessment of the scleral spur in anterior segment optical coherence tomography images. *Arch Ophthalmol*. 2008;126:181–185.
- Muftuoglu O, Hosai BM, Zilelioglu G. Ciliary body thickness in unilateral high axial myopia. *Eye (Lond)*. 2009;23:1176–1181.
- Oliveira C, Tello C, Liebmann JM, et al. Ciliary body thickness increases with increasing axial myopia. *Am J Ophthalmol*. 2005;140:324–325.