Anterior Chamber Angle Measurement with Anterior Segment Optical Coherence Tomography: A Comparison between Slit Lamp OCT and Visante OCT

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Purpose. To compare anterior chamber angle measurements obtained from two anterior segment optical coherence tomography (OCT) instruments and to evaluate their agreements and interobserver reproducibility.

Methods. Forty-nine eyes from 49 healthy normal subjects were studied. The anterior chamber angle was imaged with the Visante anterior segment OCT (Carl Zeiss Meditec, Dublin, CA) and the slit lamp OCT (SLOCT, Heidelberg Engineering, GmbH, Dossenheim, Germany) on one randomly selected eye in each subject and measured by two independent observers. The angle-opening distance (AOD 500), the trabecular–iris angle (TIA 500), and the trabecular–iris space area (TISA 500) at the nasal and temporal angles were measured. The agreements between SLOCT and Visante OCT measurements and the interobserver reproducibility were evaluated.

Results. The mean nasal/temporal anterior chamber angles measured by Visante OCT and SLOCT were 527 ± 249/572 ± 275 μm (AOD), 0.180 ± 0.091/0.193 ± 0.102 mm^2 (TISA), and 38.1 ± 12.3/39.6 ± 13.2° (TIA); and 534 ± 234/628 ± 254 μm (AOD), 0.191 ± 0.089/0.217 ± 0.093 mm^2 (TISA), and 37.8 ± 10.1/40.6 ± 10.7° (TIA), respectively. No significant difference was found between Visante OCT and SLOCT measurements except the temporal TISA (P = 0.034). The interobserver coefficient of variation ranged between 4.4% and 7.8% for Visante OCT and 4.9% and 7.0% for SLOCT. The spans of 95% limits of agreement of the nasal/temporal angle measurements between Visante OCT and SLOCT were 437/531 mm^2, 0.174/0.186 mm^2, and 25.3/28.0° for AOD, TISA, and TIA, respectively.

Conclusions. Although Visante OCT and SLOCT demonstrate high interobserver reproducibility for anterior chamber angle measurements, their agreement was poor. (*Invest Ophthalmol Vis Sci.* 2008;49:3469–3474) DOI:10.1167/iovs.07-1477

Evaluation of the anterior chamber angle is imperative for determining the risk of angle closure. Although gonioscopy provides semiquantitative assessment of the angle width, precise measurement of the angle is only possible with ultrasound biomicroscopy (UBM) or anterior segment optical coherence tomography (OCT). Two systems of anterior segment OCT have been recently introduced for imaging the anterior segment: the slit lamp OCT (SLOCT; Heidelberg Engineering, GmbH, Dossenheim, Germany) and the Visante OCT (Carl Zeiss Meditec, Dublin, CA). Both anterior segment OCT instruments were designed based on low coherence interferometry, with a superluminescent diode with a wavelength of 1310 nm. In contrast to UBM, anterior segment OCT allows noncontact imaging of the anterior chamber angle at specific meridians in a sitting position. Without the need to position a scanning probe at a close distance to the globe, better control of eye accommodation and pupil size is attainable with anterior segment OCT.

Anterior chamber angle measurements with SLOCT and Visante OCT have recently been demonstrated to be reproducible.[1–3] However, it remains uncertain whether the angle measurements obtained by the two anterior segment OCT instruments are comparable. Differences in the instrumentation, scan speed, and scan resolution between SLOCT and Visante OCT may lead to measurement disparity. Since the scleral spur is the reference landmark for anterior chamber angle measurement, images with sharper delineation of the scleral spur would allow more consistent measurement of the angle and thus have higher measurement reproducibility. The purpose of this study was to evaluate the agreement and the interobserver reproducibility of anterior chamber angle measurements obtained with the two anterior segment optical coherence tomographers.

Methods

Subjects

Forty-nine healthy, normal volunteers were invited for anterior chamber angle imaging. All volunteers had visual acuity of at least 20/40 with no evidence of ocular disease. Gonioscopy was performed with a Goldmann two-mirror lens with a short and narrow beam width of minimum possible illumination in a darkened room. Caution was exercised to avoid having the slit beam light fall on the pupil. Schaffer's grading system was used to describe the angle width. Subjects with evidence of peripheral anterior synechiae on indentation, history of use of any topical or systemic medication that could affect the drainage angle or pupillary reflex, history of any previous intraocular surgery, laser trabeculoplasty, laser iridoplasty, or laser iridotomy were excluded from the study. When both eyes of the same subject were eligible, one eye was randomly selected. The study was conducted in accordance with the ethical standards stated in the 1964 Declaration of

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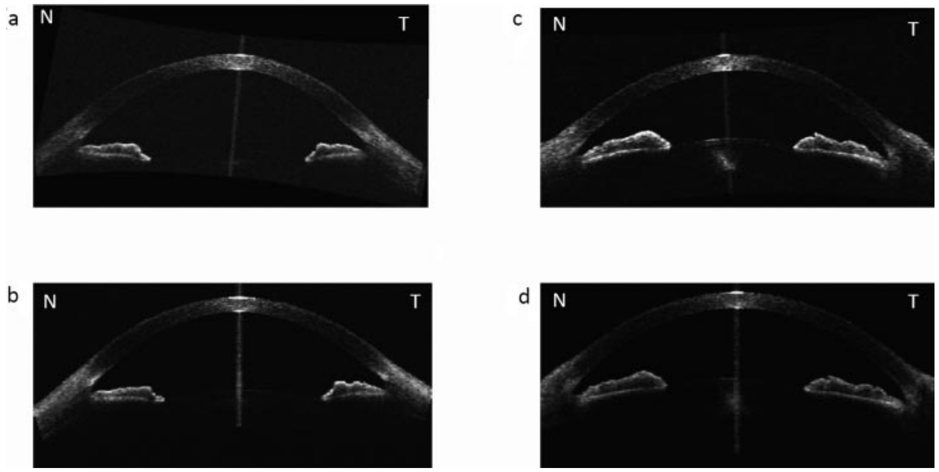

FIGURE 1. Examples of distinct (*left*) and indistinct (*right*) appearance of the scleral spur in the anterior segment OCT images. *Left*: the nasal (N) and temporal (T) angles showed clear visibility of the scleral spur in the SLOCT (**a**) and Visante OCT (**b**) images. *Right*: the location of the scleral spur was uncertain at the temporal angle in the SLOCT (**c**) and Visante OCT (**d**) images. The temporal angle of this eye was excluded in the analysis.

Helsinki and approved by the Clinical Research Ethics Committee (Kowloon Central/East) with informed consent obtained.

Anterior Segment OCT Imaging

The SLOCT and the Visante OCT are noncontact, high-resolution tomographic and biomicroscopic devices designed for anterior segment imaging and measurement. Analogous to an ultrasound B-scan, the anterior segment OCT acquires multiple A-scans and creates a two-dimensional image from them. For Visante OCT, the subjects were positioned with a head rest. To acquire images of the unaccommodated eye, the focus of an internal-fixation target was adjusted with reference to the subject's refraction. A real-time charge-coupled device displaying the position of the scan and the position of the eye was available to enable scan alignment. OCT scans were acquired with the protocol anterior segment single 0° to 180° (8 mm deep by 16 mm wide, with 256 A-scans per line). The scan line was manually adjusted to bisect the pupil. For SLOCT, subjects were positioned in a slit lamp, and the scan alignment was achieved with slit lamp illumination (red free) and an external fixation located on the side arm of the SLOCT. After the slit-lamp illumination was turned off, a horizontal scan line (7 mm deep by 15 mm wide, with 215 A-scan per scan line) bisecting the pupil was selected for the imaging. The captured OCT image in the monitor screen was used as a guide, to ensure that there was no eye movement during the imaging (any eye movement would result in a distorted image). Imaging with both devices was performed with all room lights switched off. Each eye was measured at least three times in the dark by SLOCT and Visante OCT. One image from each instrument with clear visibility of the scleral spur was independently measured by two observers (CKSL, HL). Anterior chamber angles with unclear scleral spurs were excluded in the analysis. All the images obtained had clear visibility of iris recess apex. Examples of SLOCT and Visante OCT anterior chamber angle images are shown in Figure 1.

Measurements of the Angle Opening Distance (AOD), Trabecular-Iris Angle (TIA), Trabecular-Iris Space Area (TISA), and Pupil Diameter

Although Visante OCT can measure the AOD and TIA with the caliper tool provided in the analysis software, we specifically designed a computer program to measure the angle (MatLab ver. 6.5; The MathWorks, Natick, MA), to minimize the measurement errors that can occur with the manipulation of calipers.[2] The program automatically calculated the AOD 500, TISA 500, and TIA 500 when the apex of iris recess and the scleral spur were manually located. For images obtained with SLOCT, its built-in analysis software allows automatic measurements of the angle parameters after selecting the locations of the scleral spur and apex of iris recess manually.

The AOD 500 was calculated as the perpendicular distance measured from the trabecular meshwork at 500-μm anterior to the scleral spur to the anterior iris surface.[4] The TISA 500 is an area bounded anteriorly by the AOD 500; 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.[5] This parameter was used instead of the angle recess area (ARA 500) because it has been proposed the ARA may be less sensitive in identifying narrow angles in eyes with deep angle recesses.[5] TIA 500 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.[4] The nasal and temporal angles were measured in this

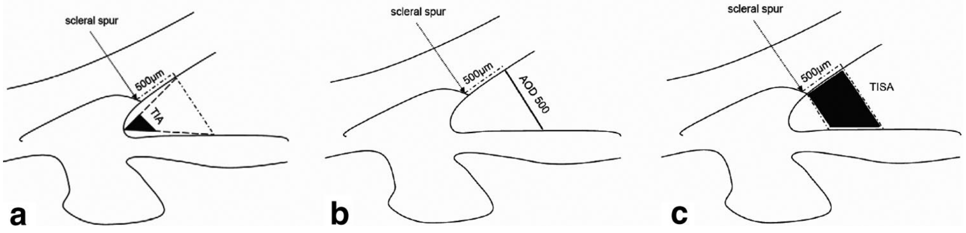

FIGURE 2. Measurement of the TIA 500 (**a**), AOD 500 (**b**), and TISA 500 (**c**).

Table 1. Interobserver Reproducibility of SLOCT Anterior Chamber Angle Measurements

	n	Overall Mean (SD)	Sw (95% CI)	Reproducibility (95% CI)	CVw, % (95% CI)	ICC (95% CI)
Nasal AOD 500 (μm)	48	534 (234)	26 (21–30)	73 (58–87)	4.9 (3.9–5.9)	0.99 (0.98–0.99)
Nasal TISA 500 (mm^2)	48	0.191 (0.089)	0.011 (0.009–0.014)	0.032 (0.025–0.038)	6.0 (4.8–7.2)	0.98 (0.97–0.99)
Nasal TIA 500 (degrees)	48	37.8 (10.1)	2.2 (1.7–2.6)	6.0 (4.8–7.3)	5.8 (4.6–6.9)	0.96 (0.92–0.97)
Temporal AOD 500 (μm)	42	628 (254)	43 (34–53)	120 (94–146)	6.9 (5.4–8.4)	0.97 (0.95–0.98)
Temporal TISA 500 (mm^2)	42	0.217 (0.093)	0.015 (0.012–0.018)	0.042 (0.033–0.051)	7.0 (5.5–8.5)	0.97 (0.95–0.99)
Temporal TIA 500 (degrees)	42	40.6 (10.7)	2.3 (1.8–2.7)	6.2 (4.9–7.6)	5.5 (4.4–6.7)	0.95 (0.92–0.98)

study. Pupil diameter was calculated as iris tip-to-tip distance. An illustration of the TIA 500, AOD 500, and TISA 500 measurements is shown in Figure 2.

Statistical Analysis

Statistical analyses were performed with commercial software (SPSS, ver. 15.0; SPSS Inc., Chicago, IL). Anterior chamber angle measurements obtained from the two observers in each image were averaged in the analyses of paired comparisons (SLOCT versus Visante OCT) and agreements. Based on a previous study of anterior segment OCT, the mean anterior chamber angle of healthy normal eyes was 35.9 ± 5.7°.[3] With the level of significance (α) set at 0.05 and the power (β) at 80%, a sample size calculation indicated that, for the statistical test to detect a mean difference of 3.6° between the groups, a minimum of 40 subjects would be necessary to give 80% power at a 5%, two-sided significance level. Measurements of SLOCT and Visante OCT were compared with paired *t*-tests, and their agreements were evaluated with Bland-Altman plots.[6] The associations between the differences in angle measurements and the difference in pupil diameter measured by SLOCT and Visante OCT were expressed as Pearson correlation coefficients. Measurements obtained independently from the two observers were used to calculate interobserver reproducibility (2.77 × within-subject SD [Sw]), coefficient of variation (CVw: 100 × Sw/overall mean), and intraclass correlation coefficient (ICC). $P < 0.05$ was considered statistically significant.

Results

The mean ± SD age of the 49 subjects was 34.5 ± 11.6 years with average spherical equivalent of −3.3 ± 3.5 D. The mean gonioscopy grades were 3.71 ± 0.46 and 3.46 ± 0.54 for nasal and temporal angles, respectively. For SLOCT, 48 nasal and 42 temporal angles were included in the analysis, and for Visante OCT, 48 nasal and 47 temporal angles were included (Fig. 1, see Methods).

The average nasal and temporal AOD, TISA, and TIA measured by SLOCT and Visante OCT are presented in Tables 1 and 2. The mean nasal/temporal anterior chamber angles measured by Visante OCT and SLOCT were 527 ± 249/572 ± 275 μm (AOD), 0.180 ± 0.091/0.193 ± 0.102 mm^2 (TISA), and 38.1 ± 12.3/39.6 ± 13.2° (TIA), and 534 ± 234/628 ± 254 μm (AOD), 0.191 ± 0.089/0.217±0.093 mm^2 (TISA), 37.8 ±10.1/40.6 ± 10.7° (TIA), respectively. There was no significant difference in the angle measurements between SLOCT and Visante OCT except the temporal TISA ($P = 0.034$; Table 3). The pupil diameter measured by SLOCT and Visante OCT were comparable (5.29 mm versus 5.22 mm, 95% CI of mean difference = −0.1 to 0.24 mm, $P = 0.421$). There was no correlation between differences in the angle measurements and difference in pupil diameter (all with $P \geq 0.118$, Table 3). The spans of 95% limits of agreement of the nasal/temporal angle measurements between SLOCT and Visante OCT were 437/531 μm, 0.174/0.186 mm^2, and 25.3/28.0 ° for AOD, TISA, and TIA, respectively (Figs. 3, 4, 5).

Both anterior segment OCTs demonstrated excellent interobserver reproducibility (Tables 1, 2). The coefficient of variation ranged between 4.9% and 7.0% for SLOCT and between 4.4% and 7.8% for Visante OCT. The values of intraclass correlation were at or above 0.95 for all the anterior chamber angle parameters.

Discussion

In this study, excellent interobserver reproducibility for anterior chamber angle measurements was observed for both Visante OCT and SLOCT. The poor agreements between Visante OCT and SLOCT indicate that angle measurements obtained from these instruments cannot be used interchangeably.

The slit lamp OCT was initially designed at the University of Lübeck by Hoerauf et al.[7] The initial SLOCT operated at a wavelength of 830 nm. A modified version with a superluminescent diode at 1310 nm was subsequently described[8] and is now commercially available as the SLOCT (Heidelberg Engineering, GmbH, Dossenheim, Germany) and Visante OCT (Carl Zeiss Meditec, Dublin, CA). Anterior chamber angle measurements with anterior segment OCT have recently been demonstrated to be reproducible. In the study by Li et al.[2] using Visante OCT, the intrasession/intersession intraclass correlation for AOD and TIA measured in the dark were 0.98/0.95 and 0.97/0.92, respectively. With the prototype anterior segment OCT developed by Carl Zeiss Meditec, Radhakrishnan et al.[1] showed the intraclass correlations were between 0.67 and 0.90 for short term measurements (in a single visit) and 0.56 and

Table 2. Interobserver Reproducibility of Visante OCT Anterior Chamber Angle Measurements

	n	Overall Mean (SD)	Sw (95% CI)	Reproducibility (95% CI)	CVw, % (95% CI)	ICC (95% CI)
Nasal AOD (μm)	48	527 (249)	24 (19–28)	66 (53–79)	4.5 (3.6–5.4)	0.99 (0.99–1.0)
Nasal TISA (mm^2)	48	0.180 (0.091)	0.011 (0.009–0.014)	0.031 (0.025–0.038)	6.3 (5.0–7.5)	0.99 (0.98–0.99)
Nasal TIA (degree)	48	38.1 (12.3)	1.7 (1.4–2.0)	4.7 (3.8–5.6)	4.4 (3.6–5.3)	0.98 (0.97–0.99)
Temporal AOD (μm)	47	572 (275)	32 (25–39)	89 (70–108)	5.6 (4.4–6.8)	0.99 (0.98–0.99)
Temporal TISA (mm^2)	47	0.193 (0.102)	0.015 (0.012–0.018)	0.042 (0.032–0.051)	7.8 (6.1–9.4)	0.98 (0.97–0.99)
Temporal TIA (degree)	47	39.6 (13.2)	2.2 (1.8–2.7)	6.2 (4.9–7.5)	5.7 (4.5–6.9)	0.97 (0.95–0.98)

Table 3. Pair-wise Comparisons of Anterior Chamber Angle Measurements between Visante OCT and SLOCT

	n	Mean difference (*P*)	Correlation Coefficient *r* (*P*)
Nasal AOD 500 (μm)	48	7.3 (0.651)	−0.026 (0.863)
Nasal TISA 500 (mm^2)	48	0.011 (0.089)	−0.046 (0.756)
Nasal TIA 500 (degree)	48	−0.4 (0.694)	−0.009 (0.118)
Temporal AOD 500 (μm)	42	34.6 (0.106)	−0.172 (0.275)
Temporal TISA 500 (mm^2)	42	0.016 (0.034)	−0.131 (0.408)
Temporal TIA 500 (degree)	42	−0.1 (0.933)	−0.012 (0.939)

The associations between the differences and the difference in pupil diameters are expressed as Pearson correlation coefficients.

0.93 for long-term measurements (median of 3 weeks). Muller et al.[3] also reported high intraclass correlations (0.93–0.97 for AOD, 0.91–0.94 for TIA) for SLOCT angle measurements. Although high reproducibility for anterior chamber angle measurements was observed, we found that SLOCT and Visante OCT had poor agreement (Figs. 3, 4, 5). For example, the difference between SLOCT and Visante OCT measurements of TIA would be within 28° in 95% of observations. The poor agreement is not likely to be related to the difference in pupil size, because there was no correlation between differences in

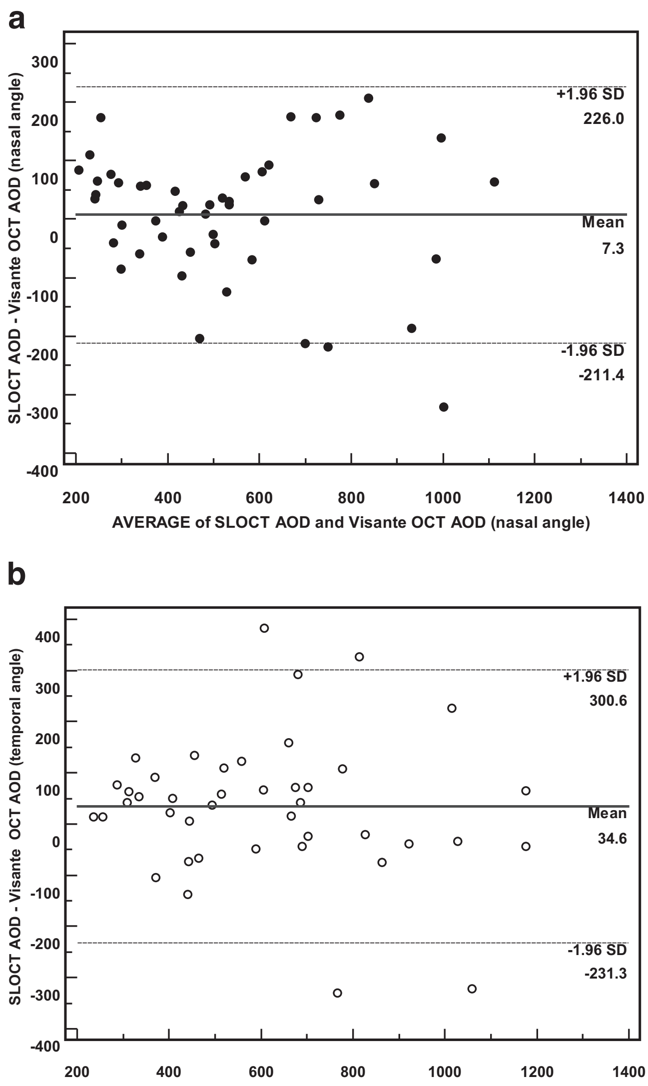

Figure 3. Bland-Altman plots of difference in AOD 500 μm between SLOCT and Visante OCT against the average of the two of the nasal (**a**) and temporal (**b**) angles.

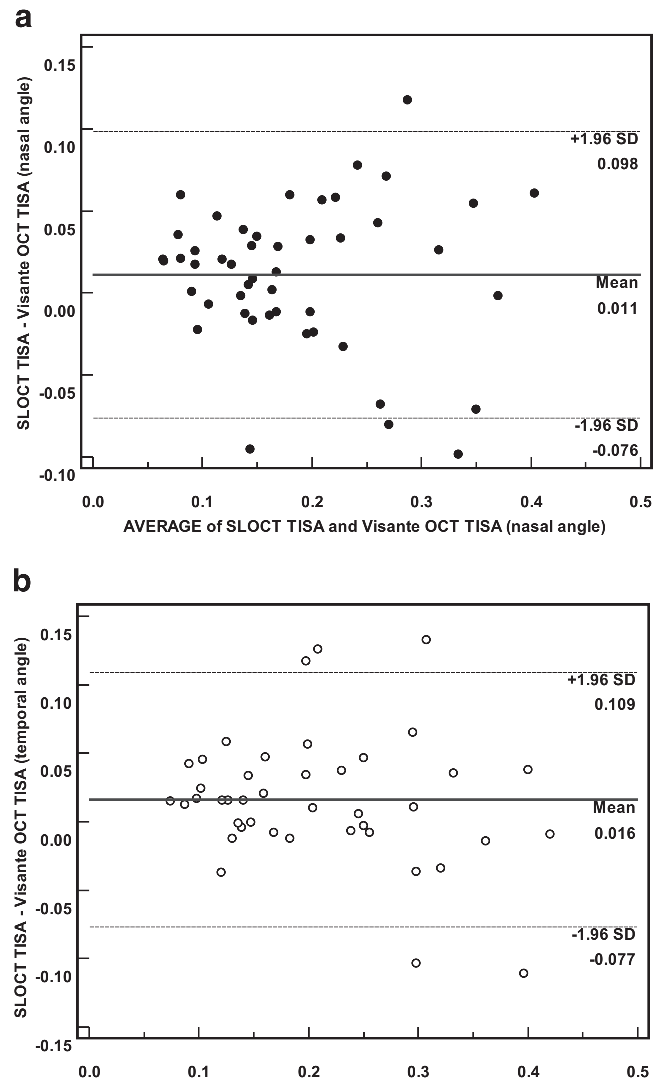

Figure 4. Bland-Altman plots of the TISA 500 mm^2 difference between SLOCT and Visante OCT against the average of the two of the nasal (**a**) and temporal (**b**) angles.

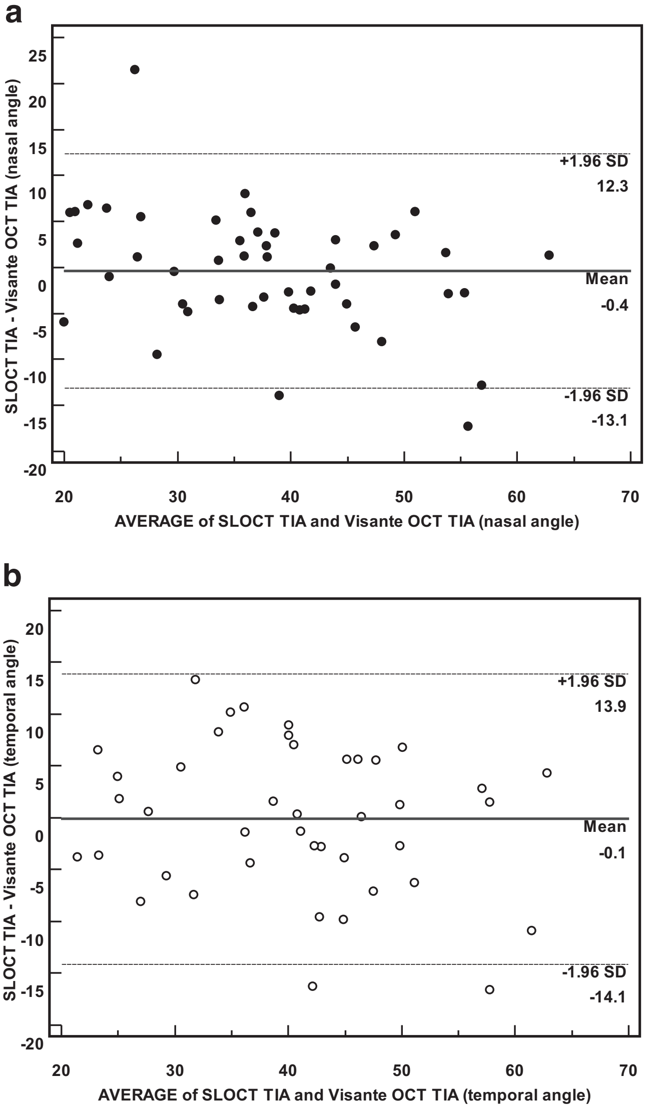

FIGURE 5. Bland Altman plots of the TIA 500° difference between SLOCT and Visante OCT against the average of the two of the nasal (**a**) and temporal (**b**) angles.

angle measurements and difference in pupil size measured by the two instruments (all with $P \geq 0.118$). Although it is unavoidable to have minimal illumination from the screen display, the finding that the pupil size measured by SLOCT and Visante OCT was comparable indicates that the difference of illumination during imaging was minimal. It is plausible, however, that the poor agreement could be attributable to the differences in the choice of refractive indexes in the calculation of anterior segment dimensions, algorithms for image dewarping, the state of accommodation, and the exact scan locations. The corneal refractive index adopted by SLOCT is 1.376, which is derived from the model of Gullstrand of the human eye for visible light, whereas a group index of 1.389 was used in Visante OCT.[9] The different refractive indexes may lead to different corneal thickness and anterior chamber angle measurements. Because of the scan geometry of the scan probe and the refraction at smooth surfaces of the eye, algorithms for dewarping are incorporated in the analysis software of Visante OCT and SLOCT to correct for image misalignment. It is uncertain whether these algorithms have equivalent adjustment. The use of internal fixation in Visante OCT and external fixation in SLOCT probably would have resulted in a different state of accommodation during the imaging. For each diopter increase in accommodation, the anterior pole of the lens moves forward by an average of 30 μm.[10] Change in lens position is probably linked with change in the angle width. Finally, since the scan position was based on subjective alignment of a scan line bisecting the pupil, there may be differences in the exact scan location. Because we lack a standard reference for comparison, it is not yet certain which anterior segment OCT provides more accurate estimation of the angle width.

In this study, a customized computer program was used to measure the angle width of Visante OCT images, with angle measurement obtained with the built-in software in SLOCT. We did not use the customized computer program to measure SLOCT images, because image composition including brightness, contrast, saturation, and polarization levels is intrinsically different between Visante OCT and SLOCT. Different sets of program routines and parameters are needed to adjust for the differences in image composition. This aspect of image analysis is difficult to standardize and precludes a head-to-head comparison using the same program.

Reliable documentation of the angle dimensions is also dependent on precise localization of the scleral spur. Previous UBM studies failed to attain repeatable measurements of the angle.[11,12] In the study by Urbak et al.,[11] who used the same UBM images for measurement, the intraobserver coefficient of variation for AOD was up to 16.97%, with significant differences ($P < 0.001$) found between observers. Measurement reproducibility was affected by subjective interpretation of visualized anatomic landmarks, which is directly related to image resolution. With higher-resolution images, lower interobserver coefficients of variation (range, 4.9%–7.8%) for angle measurements were achieved in anterior segment OCT. It is notable that Visante OCT and SLOCT are different in scanning speed (1 frame/second for SLOCT; 8 frames/second for Visante OCT) and scan resolution (axial resolution, <25 μm; transverse resolution, 20–100 μm for SLOCT; axial resolution up to 18 μm; transverse resolution, 60 μm for Visante OCT). Nevertheless, both instruments demonstrated excellent interobserver reproducibility, suggesting that images obtained provide sharp delineation of the scleral spur and are equally reliable for imaging and measuring the angle.

In this study, we analyzed only the nasal and temporal angles, because they are more accessible than the superior and inferior angles. Lid manipulation is always necessary for superior and inferior angle imaging and may lead to inadvertent change in angle configuration. Although no significant difference in angle width among superior, nasal, inferior, and temporal quadrants, in either the light or the dark, was found in a previous UBM study,[13] it would be interesting to investigate the potential measurement variability at the other quadrants. Our study is also limited by the fact that most of the subjects had open angles. The measurement agreements and interobserver reproducibility could be different in eyes with narrow angles.

In summary, both Visante OCT and SLOCT can reliably measure the anterior chamber angle with excellent interobserver reproducibility. Nevertheless, their agreement was poor. In addition to standardizing the background light intensity and accommodation of the eye, clinicians should also be aware of the potential differences in the instruments for imaging and measuring the anterior chamber angle.

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