# Anterior chamber depth measurements using Scheimpflug imaging and optical coherence tomography: Repeatability, reproducibility, and agreement

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**PURPOSE:** To determine the repeatability, reproducibility, and agreement of anterior chamber depth (ACD) measurements obtained with 3 Scheimpflug cameras and an anterior segment optical coherence tomography (AS-OCT) device.

**SETTING:** Eye Hospital of Wenzhou Medical University, Zhejiang, China.

**DESIGN:** Observational cross-sectional study.

**METHODS:** Two observers took 3 consecutive measurements in healthy right eyes using each device to assess intraoperator repeatability. The mean values obtained at different sessions by the first operator were used to determine the intersession reproducibility. Three consecutive measurements obtained by the first operator at the first session were averaged and used to assess agreement.

**RESULTS:** The ACD measurements obtained by 2 observers in 71 eyes were highly repeatable using the 4 devices, with a test–retest repeatability of 0.04 to 0.07 mm for intraoperator repeatability. The interoperator and intersession reproducibility of ACD measurements were high, and the test–retest repeatability ranges of interoperator and intersession reproducibility were 0.06 to 0.07 mm and 0.05 to 0.08 mm, respectively. The ACD measurements of the 4 systems were sorted from the thickest to the thinnest (Galilei G2 > Visante > Sirius > Pentacam). The differences in the measurements were statistically significant except between the ACD measurements obtained by the Sirius device and the Visante device. However, good agreement with narrow 95% limits of agreement was found between these devices.

**CONCLUSIONS:** The 4 devices provided high intraoperator repeatability and interoperator and intersession reproducibility for ACD measurements. Good agreement in ACD measurements was found between the devices in healthy eyes.

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Anterior chamber depth (ACD) refers to the distance between the corneal epithelium and the anterior lens capsule.[1] Reliable ACD measurement is important in clinical practice and research settings. Accurate ACD measurement plays a critical role in the detection of angle-closure glaucoma[2–4] and in the selection of candidates for phakic intraocular lens (IOL) implantation.[5,6] This measurement is also necessary when calculating the IOL power using certain formulas[7,8] and for

converting the toric IOL cylinder from the IOL to the corneal plane.[9,10]

Ultrasound (US) biometry is widely used to measure ACD and is most commonly applied with the applanation technique.[11–14] However, applanation biometry requires direct corneal contact, which may lead to false results as a result of indentation of the cornea.[15] Furthermore, the measurement also depends on the precise skills of the operator to place the probe

on the center of the cornea precisely.[13] Like any other contact methods, applanation US biometry may also cause discomfort to patients or even lead to damage of the corneal epithelium.[16] To overcome these disadvantages, many noncontact technologies for ACD measurement have been developed; these include Scheimpflug imaging and anterior segment optical coherence tomography (AS-OCT).

Previous studies[17–20] have shown that the ACD can be reliably measured by several noncontact devices. These include the Pentacam rotating Scheimpflug camera (Oculus Optikgeräte GmbH), the Sirius rotating single Scheimpflug camera combined with a Placido disk corneal topographer (Costruzione Strumenti Oftalmici), the Galilei dual Scheimpflug camera combined with a Placido disk corneal topographer (Ziemer Ophthalmic Systems AG), and the AS-OCT based Visante device (Carl Zeiss Meditec AG). However, the repeatability and reproducibility of ACD measurements using all 4 systems have not been rigorously assessed under the same conditions in a single study. Most previous studies compared the repeatability and reproducibility of corneal measurements of a few instruments only.[21,22]

Our aim was to comprehensively assess the intraoperator repeatability, interoperator and intersession reproducibility, and agreement of ACD measurements using the Pentacam (Scheimpflug device), Sirius (Scheimpflug–Placido device 1), Galilei G2 (Scheimpflug–Placido device 2), and Visante (AS-OCT device).

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## SUBJECTS AND METHODS

The study was performed at the Eye Hospital of Wenzhou Medical University, Zhejiang, China, in accordance with the principles stated in the Declaration of Helsinki. The Office of Research Ethical Committee, Wenzhou Medical University, approved the study. All participants provided written informed consent after receiving an explantation of the nature of the study.

All eyes had a complete ophthalmic examination that included visual acuity testing with refraction, slitlamp microscopy, noncontact tonometry, corneal topography (Topolyzer, Wavelight Technologie AG), and ophthalmoscopy. The exclusion criteria included recent use of contact lenses (rigid contact lenses within 4 weeks and soft contact lenses within 2 weeks of study enrollment), poor corrected distance visual acuity (worse than 20/20), high intraocular pressure (higher than 21 mm Hg), high corneal astigmatism (higher than 2.0 diopters), active ocular pathology, and a history of ophthalmic surgery.

### Sample Size

Sample-size calculation was performed a priori using PS: Power and Sample Size Calculation software.[A] Based on the results in a recent study of ACD measurements obtained using different devices,[19] the standard deviation of the differences in ACD between devices was 0.06 mm. Using a 2-sided level of significance ($\alpha$) of 0.01 and a power ($\beta$) of 99%, the sample-size calculation indicated that a minimum of 38 subjects would be required to detect a mean difference of 0.05 mm.

### Instruments

The Pentacam device is based on a single rotating Scheimpflug camera (180 degrees) that provides a 3-dimensional scan of the anterior segment of the eye. The Scheimpflug camera rotates around the optical axis of the eye and captures 25 slit images of the anterior segment within 2 seconds.

The Sirius device combines a rotating Scheimpflug camera and a small-angle Placido disk topographer with 22 rings. A complete scan acquires a series of 25 Scheimpflug images (meridians) and 1 Placido top-view image.

The Galilei G2 device combines a dual Scheimpflug camera and a Placido disk to analyze the anterior segment of the eye. The dual Scheimpflug camera captures slit images from opposite sides of the illuminated slit, and the data obtained from the corresponding opposite slit images are averaged. Moreover, the dual camera simultaneously tracks decentration resulting from eye movements.

The Visante AS-OCT, a time-domain system, uses a noncontact low-coherence interferometer to obtain cross-sectional images of the anterior segment at a high resolution (approximately 18.0 μm axially and approximately 60.0 μm horizontally). The light source is a 1310 nm superluminescent light-emitting diode. In the present study, the anterior chamber single-scan mode was used during scanning at a speed of 4000 axial scans/s. The depth and width of the scanning field were 6.0 mm and 16.0 mm, respectively. By moving the scanning spot laterally across the eye, the system obtains multiple A-scans and aligns them to construct 2-dimensional images similar to a US B-scan. A single image frame has 500 axial scans per image. When the corneal reflex, a vertical white line along the center of the cornea, is visible,

the image is captured. The ACD was obtained using the on-screen calibrated caliper function, which measures the distance from the corneal epithelium to the anterior lens capsule.

### Measurement Technique

Measurements were obtained randomly by 2 observers (P.C., H.Y.J) who were skilled at using the 4 instruments. The observers were masked to the results of the previous measurements obtained with each device. For each subject, the ACD in the undilated right eye was measured between 10 AM and 5 PM to minimize the effects of diurnal variation on the anterior segment shape.[23] All measurements with each instrument were performed in a dim room according to the manufacturer's guidelines. The sequence of the measurements using the 4 devices was randomly chosen to avoid methodological bias. Medcalc statistical software (version 10.0.1.0, Medcalc Software bvba) was used to generate a predetermined random-sample program.

All subjects were positioned using a headrest and instructed to fixate on an internal target on the center of the camera without blinking during the scans. When using the instruments providing automatic measurements (ie, the 3 Scheimpflug systems), only the scans with an examination quality specification of OK were retained for analysis; data from substandard scans were discarded, and the scans were repeated. Subjects were asked to blink once completely just before the scan was initiated to allow an optically smooth tear film to spread over the cornea. After each measurement, the subject was asked to sit back and the system was realigned for the next measurement.

The 2 observers took 3 sequential measurements in each eye with each device. The 3 standard measurements obtained by each operator using each device were used to assess the intraoperator repeatability. To determine the interoperator reproducibility, the values of 3 successive measurements were averaged to obtain the mean value and the differences between the mean values obtained by the 2 observers were compared. The same measurements were repeated by the same operator using the same protocol at the second session, which was scheduled 1 day to 1 week later at almost the same time of day as the first session. The mean values obtained at different time points by the first operator were compared to determine the intersession reproducibility of each device. In addition, the mean values of the 3 measurements obtained by the first operator in the first session were used to assess the agreement between ACD measurements obtained using the 4 devices.

### Statistical Analysis

Statistical analysis was performed using the SPSS for Windows software (version 17, SPSS, Inc.) and Excel software (Microsoft Corp.). A $P$ value less than 0.05 was considered statistically significant. The distributions of the datasets were checked for normality using the Kolmogorov-Smirnov test. The results indicated that the data were normally distributed ($P > .05$).

To determine the intraoperator repeatability of each device, parameters such as the within-subject standard deviation ($S_w$), test–retest repeatability, within-subject coefficient of variation (CoV), and intraclass correlation coefficient (ICC) were calculated for the 3 repeated measurements obtained by the first operator and the second operator. The test–retest repeatability was defined as 2.77 $S_w$, which

represents an interval within which 95% of the differences between measurements are expected to lie. The CoV was calculated as the ratio of the $S_w$ to the overall mean. A lower CoV is associated with higher repeatability. The closer the ICC is to 1, the better the measurement consistency. To assess the interoperator reproducibility, the mean of the 3 readings from each operator was first calculated for each device, after which the interoperator $S_w$, 2.77 $S_w$, CoV, and ICC were calculated. To assess the intersession reproducibility, the mean of the 3 readings from 2 sessions taken by the same first operator was calculated for each device, after which the intersession $S_w$, 2.77 $S_w$, CoV and ICC were calculated.

For multiple comparisons between the ACD measurements, the repeated-measures analysis of variance with Bonferroni post hoc comparison was used. Agreement between the 4 devices was assessed using the Bland-Altman plot analysis. In this method that uses graphs, the differences in ACD measurements between the 2 devices were plotted against the means of the 2 devices. The difference in measurements between the 2 devices is displayed on the $y$-axis, whereas the mean measurement value is plotted on the $x$-axis. The 95% limits of agreement (LoA) were calculated as the mean difference in measurements obtained from the 2 devices $\pm$ 1.96 SD.[23]

## RESULTS

This study enrolled 71 right eyes of 71 subjects. The mean age of the 34 men and 37 women was 35.56 years $\pm$ 9.81 (SD) (range 19 to 55 years). The mean spherical equivalent refraction was $-3.95 \pm 2.39$ D (range 0.75 to $-11.75$ D).

### Intraoperator Repeatability

The ACD measurements obtained by the 2 observers were highly repeatable for all 4 devices (Table 1). The test–retest of both observers ranged from 0.04 to 0.07 mm. The CoV was lower than 0.8% and the ICC was higher than 0.98 in all cases.

### Interoperator and Intersession Reproducibility

The interoperator reproducibility and intersession reproducibility of the ACD measurements were high with all 4 devices (Tables 2 and 3). The test–retest range of interoperator reproducibility was 0.06 to 0.07 mm, and that of intersession reproducibility was 0.05 to 0.08 mm. The CoV was always lower than 0.8%, and the ICC was higher than 0.98.

### Comparison and Agreement

The ACD measurements obtained from the 4 systems were sorted from the thickest to the thinnest (Scheimpflug–Placido 2 > AS-OCT > Scheimpflug–Placido 1 > Scheimpflug) (Table 4). According to the Bonferroni post hoc test, the differences in all measurements between the 4 systems were statistically significant (all $P < .001$) except for the difference between the ACD measurements obtained using the

**Table 1.** Intraobserver repeatability of ACD measurements by device.

| Device/Observer | Mean ± SD (mm) | $S_w$ (mm) | TRT (mm) | CoV (%) | ICC |
|---|---|---|---|---|---|
| Scheimpflug | | | | | |
|   Observer 1 | 3.72 ± 0.22 | 0.03 | 0.07 | 0.71 | 0.986 |
|   Observer 2 | 3.71 ± 0.22 | 0.02 | 0.07 | 0.65 | 0.988 |
| Scheimpflug–Placido 1 | | | | | |
|   Observer 1 | 3.76 ± 0.22 | 0.02 | 0.05 | 0.47 | 0.994 |
|   Observer 2 | 3.75 ± 0.23 | 0.02 | 0.06 | 0.57 | 0.991 |
| Scheimpflug–Placido 2 | | | | | |
|   Observer 1 | 3.83 ± 0.22 | 0.02 | 0.06 | 0.60 | 0.989 |
|   Observer 2 | 3.82 ± 0.23 | 0.02 | 0.06 | 0.57 | 0.991 |
| AS-OCT | | | | | |
|   Observer 1 | 3.76 ± 0.21 | 0.02 | 0.05 | 0.46 | 0.993 |
|   Observer 2 | 3.75 ± 0.22 | 0.01 | 0.04 | 0.35 | 0.996 |

AS-OCT = anterior segment optical coherence tomography; CoV = within-subject coefficient of variation; ICC = intraclass correlation coefficient; $S_w$ = within-subject standard deviation; TRT = test–retest repeatability (2.77 $S_w$)

**Table 2.** Interobserver reproducibility of ACD measurements by device.

| Device | $S_w$ (mm) | TRT (mm) | CoV (%) | ICC |
|---|---|---|---|---|
| Scheimpflug | 0.02 | 0.06 | 0.54 | 0.992 |
| Scheimpflug–Placido 1 | 0.02 | 0.07 | 0.64 | 0.988 |
| Scheimpflug–Placido 2 | 0.03 | 0.07 | 0.66 | 0.987 |
| AS-OCT | 0.02 | 0.06 | 0.54 | 0.991 |

AS-OCT = anterior segment optical coherence tomography; CoV = within-subject coefficient of variation; ICC = intraclass correlation coefficient; $S_w$ = within-subject standard deviation; test–retest repeatability (2.77 $S_w$)

Scheimpflug–Placido device 1 and the AS-OCT device. The 95% LoA values for each paired comparison of the 4 devices were narrow, which implied good agreement between them (Figures 1 to 6). The closest agreement of ACD measurements was between the Scheimpflug–Placido device 1 and the AS-OCT device, with 95% LoA of −0.09 to 0.09 mm.

## DISCUSSION

Accurate measurement of ACD is important because of the theoretical and practical applications in different fields of ophthalmology. For example, precise ACD measurements are crucial in selecting patients for phakic IOL implantation,[5,6] calculating IOL power according to certain formulas,[7,8] calculating the corneal equivalent cylinder of toric IOLs,[9] and

**Table 3.** Intersession reproducibility of ACD measurements by device.

| Device | $S_w$ (mm) | TRT (mm) | CoV (%) | ICC |
|---|---|---|---|---|
| Scheimpflug | 0.03 | 0.08 | 0.78 | 0.983 |
| Scheimpflug–Placido 1 | 0.02 | 0.07 | 0.64 | 0.988 |
| Scheimpflug–Placido 2 | 0.02 | 0.07 | 0.61 | 0.989 |
| AS-OCT | 0.02 | 0.05 | 0.49 | 0.993 |

AS-OCT = anterior segment optical coherence tomography; CoV = within-subject coefficient of variation; ICC = intraclass correlation coefficient; $S_w$ = within-subject standard deviation; test–retest repeatability (2.77 $S_w$)

analyzing the anterior segment in eyes with glaucoma.[2,3,24]

To our knowledge, ours is the first study to comprehensively assess the intraobserver repeatability, interobserver reproducibility, and intersession reproducibility of ACD measurements in the same sample of subjects using 4 of the latest-generation instruments (Pentacam, Sirius, Galilei G2, Visante AS-OCT). In the study, these devices provided highly precise ACD measurements with good agreement between the 4 devices.

The repeatability and reproducibility of the ACD measurements obtained by the Scheimpflug imaging systems and AS-OCT device has been reported in part in previous studies. However, none of these studies compared ACD measurements by all 4 devices at the same time under identical conditions using a large enough sample. For example, studies have reported that the Pentacam device offered good intraobserver repeatability[25,26] and interobserver reproducibility for ACD measurements.[26] In another study by Chen et al.,[19] excellent intraobserver repeatability was shown for ACD measurements using the Sirius system, with a repeatability limit of 0.02 mm. Dinc et al.[25] and Nemeth et al.[27] also found that this imaging device had good intraobserver repeatability for ACD measurements. The interobserver reproducibility of ACD measurements using the Visante device was also found to be good.[27] With regard to ACD measurements, the interobserver reproducibility and intersession reproducibility using the Sirius device and the intersession reproducibility using the Pentacam device and the Visante device have not been previously assessed. In addition, no study has evaluated the intraobserver repeatability and the interobserver and intersession reproducibility of ACD measurements using the Galilei G2 device.

Our study provides information lacking in the existing literature and comprehensively evaluated the intraobserver repeatability and the interobserver and intersession reproducibility of ACD measurements using the 4 devices. The repeatability and reproducibility

**Table 4.** Mean differences in ACD measurements and corresponding results of Bonferroni post hoc comparison and 95% LoA by device.

| Device Pairing | Mean Difference (mm) ± SD | P Value | 95% LoA (mm) |
|---|---|---|---|
| Scheimpflug − Scheimpflug–Placido 1 | −0.04 ± 0.04 | <.001 | −0.12, 0.04 |
| Scheimpflug − Scheimpflug–Placido 2 | −0.11 ± 0.04 | <.001 | −0.19, −0.03 |
| Scheimpflug − AS-OCT | −0.04 ± 0.05 | <.001 | −0.14, 0.06 |
| Scheimpflug–Placido 1 − Scheimpflug–Placido 2 | −0.07 ± 0.04 | <.001 | −0.15, 0.01 |
| Scheimpflug–Placido 1 − AS-OCT | 0.00 ± 0.05 | 1.000 | −0.09, 0.09 |
| Scheimpflug–Placido 2 − AS-OCT | 0.07 ± 0.05 | <.001 | −0.02, 0.16 |

AS-OCT = anterior segment optical coherence tomography; LoA = limits of agreement

of the semiautomated measurement mode of the Visante device was as good as those of the automated Scheimpflug devices. The results in our study are consistent with those in previous studies and show that the 4 devices provided high intraobserver repeatability (test–retest: 0.04 to 0.07 mm) and high interobserver and intersession reproducibility (test–retest: 0.06 to 0.07 mm and 0.05 to 0.08 mm, respectively) for ACD measurements.

Overall, we found the ACD measurements obtained by the 4 devices were in good agreement, indicating that the devices can be used interchangeably in most clinical situations. The highest agreement was between the Sirius device and Visante device. The Galilei G2 device provided slightly higher and the Pentacam device provided slightly lower values than the other instruments; however, this difference in measurements (although statistically significant) cannot be considered clinically important.

Other studies have compared ACD measurements acquired using different Scheimpflug imaging systems, and the results in most cases are similar to those in the present study. Salouti et al.[21] found good agreement between ACD measurements (95% LoA from −0.11 to 0.12 mm) acquired by the Pentacam HR device and the Galilei device and state that the 2 devices can be regarded as interchangeable. We agree that the statistically significant overestimation by the Galilei G2 device compared with the Pentacam device (approximately 0.1 mm) is not clinically relevant and that the 2 instruments can be considered interchangeable.

The ACD measurements acquired by the Pentacam device and Sirius device can be used interchangeably in healthy subjects, notwithstanding the statistically significant overestimation by the latter device. In this case, the mean difference between the measurements was 0.04 mm, which is a clinically negligible value, and the 95% LoA were quite narrow.

None of the previous studies compared the ACD measurements acquired using the Sirius device with those using the Galilei device. In our study, the mean ACD measurements obtained using the Sirius device were lower than those obtained by the Galilei G2 device. However, the 95% LoA between the 2 devices
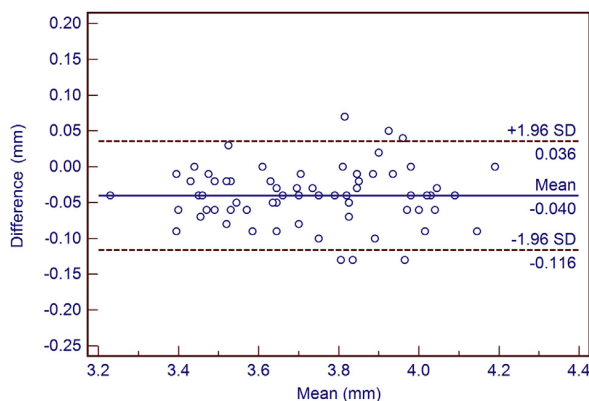


**Figure 1.** Bland-Altman plots showing the agreement of the ACD measurements taken with the Scheimpflug device and Scheimpflug–Placido device 1. The solid line indicates the mean difference (bias), and the dotted lines indicate 95% LoA.
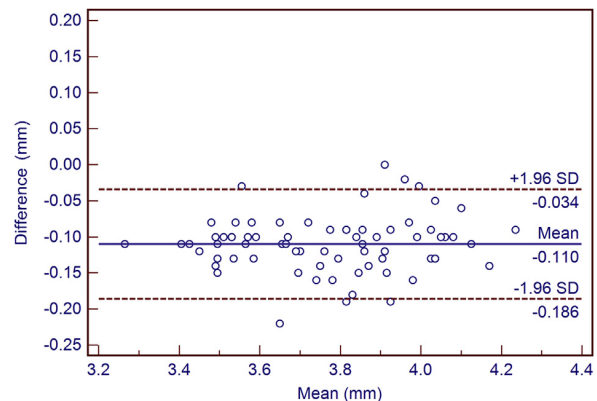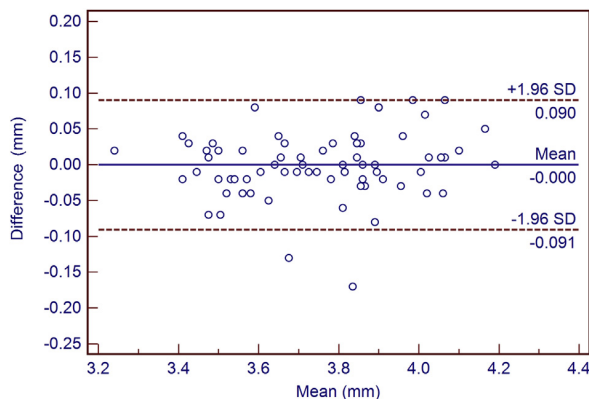


**Figure 2.** Bland-Altman plots showing the agreement of the ACD measurements taken with the Scheimpflug device and Scheimpflug–Placido device 2. The solid line indicates the mean difference (bias), and the dotted lines indicate 95% LoA.
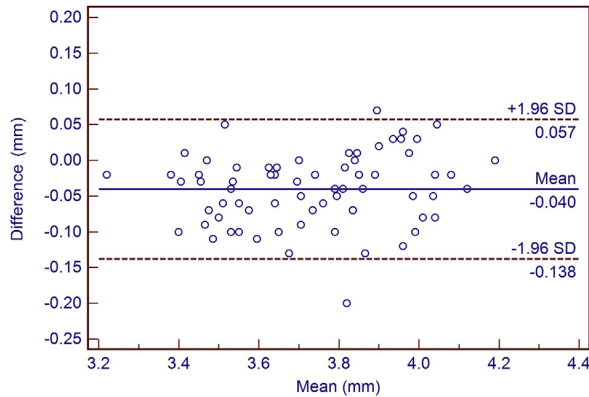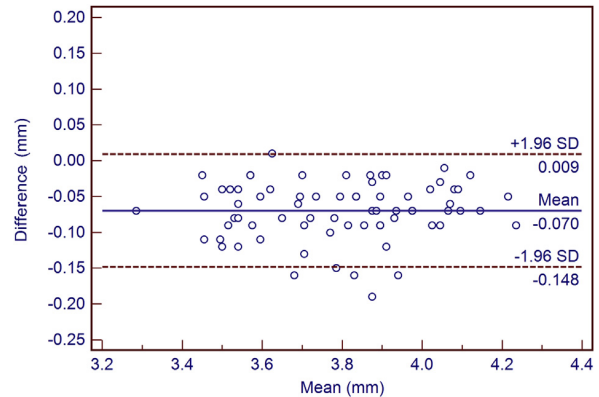
**Figure 3.** Bland-Altman plots showing the agreement of the ACD measurements taken with the Scheimpflug device and Visante OCT. The solid line indicates the mean difference (bias), and the dotted lines indicate 95% LoA.



**Figure 4.** Bland-Altman plots showing the agreement of the ACD measurements taken with the Scheimpflug–Placido device 1 and Scheimpflug–Placido device 2. The solid line indicates the mean difference (bias), and the dotted lines indicate 95% LoA.

were narrow (−0.15 to 0.01 mm for ACD), which indicated that the agreement between the measurements was good and that the 2 devices can be used interchangeably.

We also found good agreement of the ACD measurements taken using the Visante device and those taken using the 3 Scheimpflug imaging devices. Consistent with our results, Dinc et al.[25] found that the Visante AS-OCT and Pentacam ACD measurements were comparable (95% LoA, −0.019 to 0.056 mm). Our study also found that the mean ACD measurements from the Visante AS-OCT were greater than those from the Pentacam device. However, the agreement between the 2 devices was good for ACD measurements, which implies their interchangeability in a clinical setting. The discrepancy between the Visante and Pentacam readings might be the result of several factors. First, the quality of the ocular media
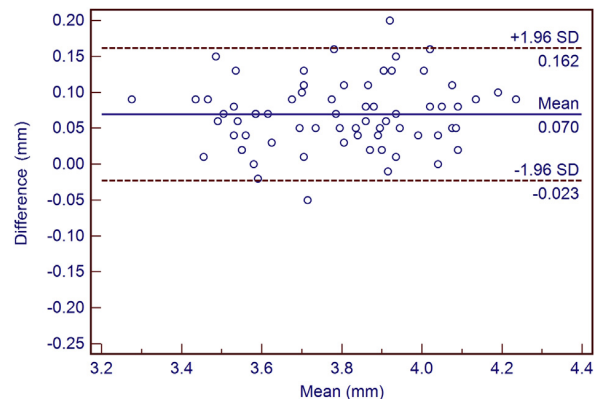
affects the measurements obtained by the Pentacam device because of the interfering signals reflected on the iris.[7] In contrast, data from the Visante device are less dependent on the optical clarity of the anterior segment because the anterior chamber can be directly visualized during the ACD measurements.[25,28,29] Second, the Visante ACD measurements are manually obtained by locating the corneal epithelium and the anterior lens surface with a caliper, whereas the Pentacam device automatically measures the ACD.[22] Third, accommodation can be better controlled during the Visante measurements by balancing the spherical ametropia with the positive and negative lenses in the instrument.[22]

Agreement of the ACD measurements between the Visante AS-OCT device and the Sirius device as well as between the Visante device and the Galilei G2 device has not been previously assessed. In our study,



**Figure 5.** Bland-Altman plots showing the agreement of the ACD measurements taken with the Scheimpflug–Placido device 1 and AS-OCT device. The solid line indicates the mean difference (bias), and the dotted lines indicate 95% LoA.



**Figure 6.** Bland-Altman plots showing the agreement of the ACD measurements taken with the Scheimpflug–Placido device 2 and AS-OCT device. The solid line indicates the mean difference (bias), and the dotted lines indicate 95% LoA.

the Visante device significantly underestimated the ACD measurements compared with the Galilei G2 device, whereas the difference with respect to the Sirius device was small and not statistically significant. Similar to the comparison between the Visante device and the Pentacam device, the discrepancy between the Visante measurements and the Sirius measurements and between the Visante measurements and the Galilei G2 measurements can be attributed to similar factors, such as the effect of the poor quality of the ocular media on Visante measurements compared with that of the Sirius and Galilei G2 devices. However, the Bland-Altman plots suggest that in 95% of eyes, the differences in measurements between the 3 devices were small. Thus, we conclude that these devices have good concordance and can be used interchangeably to measure ACD.

Our study has several limitations. First, we restricted enrollment to normal eyes of healthy subjects. Our next step is to assess the repeatability, reproducibility, and agreement of ACD measurements in pseudophakic subjects, which is currently underway. Second, we did not compare the results of the 4 devices with those of US biometry. Previous studies have compared US biometry and Pentacam,[30] ultrasound biomicroscopy and Visante ACD measurements[31] and found good agreement between the 3 techniques in phakic eyes, whereas significant differences were found in pseudophakic eyes.[14] To date, no study has assessed the agreement of ACD measurements between US techniques and 2 of the Scheimpflug devices (Sirius and Galilei), and this might be the subject of a future project.

In conclusion, ACD measurements obtained with the 4 devices had high intraobserver repeatability and high interobserver and intersession reproducibility. In addition, although statistically significant differences were found in these measurements between the 4 systems, the differences cannot be considered clinically significant because of the high level of agreement. Thus, the 4 devices can be considered interchangeable for the ACD measurement in normal healthy eyes.

**WHAT WAS KNOWN**
- Reliable ACD measurement is important in clinical practice and research settings.

**WHAT THIS PAPER ADDS**
- The 4 devices provided high repeatability and reproducibility of ACD measurements, with good agreement between the devices. The closest agreement of ACD measurements was between the Sirius device and the Visante device.

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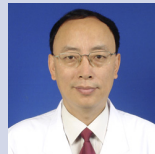
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