Comparison of anterior segment measurements with rotating Scheimpflug photography and partial coherence reflectometry

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PURPOSE: To compare central corneal thickness (CCT), anterior chamber depth (ACD), and keratometry (K) readings measured using optical low-coherence reflectometry (OLCR) biometry and high-resolution rotating Scheimpflug photography.

SETTING: Eye Hospital of Wenzhou Medical College, Wenzhou, China.

DESIGN: Comparative case series.

METHODS: The CCT, ACD endothelium to lens, ACD epithelium to lens, and K (mean; in flattest meridian; in steepest meridian) were measured 5 times using the LenStar/Biograph OLCR biometer and 3 times with the Pentacam Scheimpflug system in eyes of healthy volunteers. Concordance was evaluated using paired *t* tests, the Pearson correlation, and Bland-Altman analyses.

RESULTS: The CCT, ACD endothelium to lens, and ACD epithelium to lens measured with the Scheimpflug system were slightly, albeit significantly, higher than with the OLCR biometer ($P<.05$); the respective 95% limits of agreement (LoA) were -8.2 μm to 15.7 μm, -0.11 to 0.15 mm, and -0.13 to 0.17 mm. However, the Scheimpflug system gave significantly flatter readings for K in the flattest meridian (95% LoA, -0.54 to 0.32 diopters [D]), K in the steepest meridian (95% LoA, -0.63 to 0.45 D), and mean K (95% LoA, -0.53 to 0.33 D) ($P<.001$). The CCT, ACD, and K readings were all highly correlated between the 2 devices ($r>0.95$, $P<.001$).

CONCLUSIONS: The CCT and ACD measurements with the OLCR biometer and Scheimpflug system can be used interchangeably in healthy young subjects. However, for K measurements, these devices have wide LoA so may not be interchangeable under certain clinical circumstances.

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Accurate and precise determination of ocular biometric parameters is fundamental to many clinical and research applications in ophthalmology. The assessment of central corneal thickness (CCT) is important for treatment planning and postoperative management in corneal refractive surgery,[1] collagen crosslinking (CXL), and intrastromal ring placement.[2] In corneal refractive surgery, overestimation of CCT may lead to overablation, particularly in eyes with high myopia or borderline corneal thickness or those requiring enhancement surgery. This increases the risk for iatrogenic keratectasia.[1,3] Similarly, in CXL, it is crucial to ensure that the thinnest point of the deepithelialized cornea is at least 400 μm to avoid endothelial damage.[2]

The demand for accurate and repeatable measurements of corneal refractive power and anterior chamber depth (ACD) has increased greatly with the development of aphakic and refractive phakic intraocular lens (IOL) implantation.[4,5] Errors in measuring corneal refractive power and ACD can lead to significant postoperative refractive errors and result in unsatisfactory visual outcomes. Anterior chamber depth has also become an important parameter for other purposes in ophthalmology, including determining the risk for angle closure,[6] assessing changes in the anterior eye segment during accommodation and pseudophakic accommodation,[7,8] and evaluating and predicting endothelial cell damage after iris-fixated phakic IOL implantation.[9]

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Many types of instruments are available to measure these anterior segment parameters. Of the commercially available, only those based on scanning-slit optical pachymetry (Orbscan, Bausch & Lomb), single rotating Scheimpflug photography (Pentacam, Oculus, Inc.),[10] and dual rotating Scheimpflug–Placido hybrid photography system (Galilei, Ziemer Group AG) offer precise, noncontact, and user-independent measurement of these ocular biometric parameters in a single system that does not require realignment.[11]

The Pentacam system uses the Scheimpflug principle to acquire and generate entire cross-sectional reconstructions of the anterior segment. Complete corneal pachymetry, topographic maps of the anterior and posterior corneal surfaces, and anterior chamber analysis are taken from a single scan, which is acquired in 2 seconds. Recently, a new optical low-coherence reflectometry (OLCR) ocular biometry device, the LenStar LS900 (Haag-Streit AG)/Allegro Biograph (WaveLight AG), became available. A single noncontact measurement simultaneously provides up to 9 biometric assessments of the patient's eye, including CCT, ACD (lens position), lens thickness, axial length (AL), retinal thickness, keratometry (K), white-to-white (WTW) distance, pupillometry, and eccentricity of the visual optical line. The OLCR biometer includes internationally established IOL power calculation formulas and is equipped for the next generation of formulas.[12–14] Previous studies show that both modalities provide reliable intraobserver and interobserver measurements of CCT, K, and ACD.[12–14] However, it is not known whether the values obtained with the devices are comparable and can be used interchangeably.

Therefore, the current study was performed to evaluate and compare CCT, K, and ACD measurements using the single rotating Scheimpflug photography device and the OLCR ocular biometer in normal eyes.

SUBJECTS AND METHODS

This prospective study adhered to the tenets of the Declaration of Helsinki and was approved by the Research Review Board at Wenzhou Medical College. All subjects provided informed consent after receiving an explanation of the nature and purpose of the study. All subjects had good corrected distance visual acuity (20/25 or better) to allow adequate fixation. Subjects with a history of corneal abnormalities, contact lens use, active ocular pathology, or previous ocular surgery other than refractive error correction were excluded.

Measurement Technique

One eye of each subject was selected and was measured sequentially, first with the rotating Scheimpflug system and then with the OLCR biometer. Right eyes were chosen from the first group of subjects and left eyes from the second group. One experienced examiner performed all measurements but was unaware of the results obtained with each modality. All measurements were performed without pupil dilation.

Subjects were positioned with a headrest and instructed to fixate on an internal fixation within each device. They were asked to blink completely just before each measurement to spread an optically smooth tear film over the cornea. After each acquisition, the device was moved backward and realigned for the next scan. In each case, the entire scanning procedure was completed in fewer than 15 minutes with the goal of avoiding the effects of diurnal variation in corneal shape and thickness.[15]

The Pentacam high-resolution system used in this study is slightly different from the original version. The optical design of the new version uses a high-resolution, 1.45 mega pixel camera. The camera captures 138 000 data points in fewer than 2 seconds. Images of the anterior segment of the eye are acquired using a 475 nm wavelength blue light–emitting diode (LED) and a Scheimpflug camera; the LED and camera rotate together around the optical axis of the eye. The examiner in this study used the automatic release mode to reduce operator-dependent variables. Only scans with an "examination quality specification" of "OK" were chosen for analysis. Scans that were substandard because of blinking or eye movements were discarded and repeated. The system determines pachymetry at the apex center of the cornea; in this study, the K and ACD measurements were used for analysis.[10] Three valid measurement readings were taken. Each measurement consisted of 25 consecutive scans in a single shot; the measurements were averaged for comparisons between the 2 devices. Corneal power values from axial curvature (sagittal) maps in the central 3.0 mm were used for all data acquisition because axial power has become the standard in this technique.[16,17] The Scheimpflug system provides K values along the flattest meridian K as well as the K value and orientation axis of the steepest meridian. A mean K was calculated using the mean of the flattest meridian K and the steepest meridian K.

The LenStar/Biograph biometer uses an OLCR technique with a superluminescent diode laser at a wavelength of 820 nm. The exposure power at the pupil is less than 0.6 mW for measurements of AL, CCT, ACD, lens thickness, and retinal thickness. The optical path–length measurements are aligned on patient's visual optical line. The OLCR biometer also uses LED for K, WTW distance, and pupillometry assessments. The scan beam wavelength is 950 nm, and the exposure power at pupil is less than 0.2 mW. Corneal radius of curvature

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measurements are produced based on image analysis of a mire of constant size reflected off the anterior surface of the cornea. The biometric device obtains flattest meridian K and steepest meridian K values by analyzing the position of 32 projected light reflections at 2 rings with a diameter of 1.65 mm and 2.30 mm. Keratometry is obtained by converting the measured radius into diopters (D) using the standard 1.3375 refractive index, which corresponds to that used for the Scheimpflug system. Five valid measurement readings were taken. Each measurement consisted of 16 consecutive scans in a single shot; the average was used for analysis, as recommended by the manufacturer.

For calculating ACD, both systems measure the distance from the corneal endothelium to the anterior lens capsule, which in this study was defined as the ACD endothelium to lens, and measure the distance from the corneal epithelium to the anterior lens capsule, which was defined as the ACD epithelium to lens (ACD endothelium to lens + CCT). Differences in the 2 ACD parameters between the 2 devices were compared.

Statistical Analysis

All data were entered into an Excel spreadsheet (Microsoft Corp.) and transferred to SPSS software (version 13.0, SPSS, Inc.) for statistical analysis. A P value less than 0.05 was considered statistically significant. Normality of all data distributions was confirmed by the Kolmogorov-Smirnov test ($P > .05$), and parametric statistical tests were used for data analyses. The results are expressed as the mean ± SD. Paired t tests were applied to compare the difference in measurement values between the 2 devices. Pearson correlation coefficients and linear regression were computed to assess the relationship between variables. The agreement between the 2 methods was also assessed using Bland-Altman plot analysis.[18] In this analysis, bias was defined as a significant difference in the means of the 2 methods; 95% limits of agreement (LoA) were calculated as the mean difference ±1.96 SD.

RESULTS

One hundred eight eyes (54 right, 54 left) of 108 subjects (58 men, 50 women) were included in the study. The mean age of the subjects was 22.8 ± 3.5 years (range 18 to 32 years). The mean manifest spherical equivalent refraction was −4.74 ± 2.55 diopters (D) (range −0.50 to −11.375 D). One or 2 substandard Scheimpflug scans occurred in 10% of eyes due to blinking or eye movements.

Table 1 shows the mean CCT, K, and ACD values measured by the 2 devices. Table 2 shows the mean difference, SD, 95% LoA, and correlation coefficients for comparisons of the devices. The CCT, ACD endothelium-to-lens, and ACD epithelium-to-lens measurements taken with the Scheimpflug system were statistically significantly higher than those taken with the OLCR biometer ($P < .05$). However, the Scheimpflug system significantly underestimated the flattest meridian K, steepest meridian K, and mean K values compared with the OLCR biometer ($P < .001$).

Table 1. Mean CCT, ACD, and K readings.

Parameter	Mean ± SD OLCR Biometer	Mean ± SD Scheimpflug Device
CCT (μm)	534.28 ± 31.36	538.00 ± 29.93
ACD (mm)		
Endothelium to lens	3.23 ± 0.24	3.24 ± 0.25
Epithelial to lens	3.76 ± 0.24	3.78 ± 0.25
K value (D)		
Flat	42.77 ± 1.37	42.66 ± 1.40
Steep	43.90 ± 1.63	43.82 ± 1.62
Mean	43.34 ± 1.46	43.24 ± 1.48

ACD = anterior chamber depth; CCT = central corneal thickness; K = keratometry

All comparisons showed highly significant correlations. The Pearson correlation coefficients were more than 0.95 ($P < .001$) (Figure 1). For CCT measurements, linear regression analysis yielded the following relationship: $CCT_{OLCR} = -18.96 + 1.03 \times CCT_{Scheimpflug}$ coefficient of determination (r^2) = 0.963. For ACD measurements, linear regression analysis yielded the following relationship: ACD endothelium to $lens_{OLCR} = 0.32 + 0.91 \times$ ACD endothelium to $lens_{Scheimpflug}$ $r^2 = 0.932$ and ACD epithelium to $lens_{OLCR} = 0.32 + 0.91 \times$ ACD epithelium to $lens_{Scheimpflug}$ $r^2 = 0.928$. For K measurements, linear regression analysis yielded the following relationship: flattest meridian $K_{OLCR} = 1.43 + 0.97 \times$ flattest meridian $K_{Scheimpflug}$, $r^2 = 0.975$, steepest meridian $K_{OLCR} = 0.63 + 0.99 \times$ steepest meridian $K_{Scheimpflug}$ $r^2 = 0.971$ and mean $K_{OLCR} = 0.99 + 0.98 \times$ mean $K_{Scheimpflug}$ $r^2 = 0.978$.

The Bland-Altman plots showed that the mean differences between the 2 devices were not significantly different from zero for the comparison of all parameters (Figure 2). In terms of the agreement between the 2 devices, the CCT and ACD measurements showed a narrow 95% LoA, which implies good agreement. However, the 95% LoA were broad for K values, which implies moderate agreement.

DISCUSSION

Accurate quantitative measurements of CCT, ACD, and K provide valuable information for ophthalmologists. Such measurements are important for preoperative assessment, surgical planning, and follow-up in corneal refractive surgery and aphakic and refractive phakic IOL implantation. At present, contact ultrasound (US) is the most widely used method to measure axial intraocular distances in the anterior segment, such as CCT and ACD. This method is also regarded as the standard for measuring such parameters.[19–21] However, contact US has several limitations, including moderate

Table 2. The mean difference in parameters between devices and statistical findings.

Parameter	Mean Difference ± SD	95% LoA	*P* Value	Pearson Correlation *r* Value	Pearson Correlation *P* Value*
CCT (µm)	3.72 ± 6.10	−8.2 to 15.7	<.001	0.981	<.001
ACD (mm)					
Endothelium to lens	0.02 ± 0.07	−0.11 to 0.15	.011	0.966	<.001
Epithelium to lens	0.02 ± 0.07	−0.11 to 0.15	.004	0.963	<.001
K value (D)					
Flat	−0.11 ± 0.22	−0.54 to 0.32	<.001	0.988	<.001
Steep	−0.09 ± 0.28	−0.63 to 0.45	.001	0.986	<.001
Mean	−0.10 ± 0.22	−0.53 to 0.33	<.001	0.989	<.001

ACD = anterior chamber depth; CCT = central corneal thickness; K = keratometry; LoA = limits of agreement
*2 tailed

resolution and precision (approximately 200 µm and 150 µm, respectively), examiner dependence, patient discomfort, and a small risk for corneal infection.[20,22] Therefore, noncontact devices represent a desirable alternative.

In the present study, 2 noncontact optical devices—the Pentacam rotating Scheimpflug system and the LenStar/Biograph OLCR biometer—were assessed for concordance of anterior segment measurements. Although excellent intraobserver and interobserver reliability has been reported for the 2 instruments individually, before this study it was unknown whether the values obtained with each device are comparable and therefore can be used interchangeably.[12–14,19,22–27] To our knowledge, this is the first controlled study of the agreement in anterior segment biometry between the 2 systems. Our data show high agreement on all measurements, albeit better for CCT and ACD than for K.

Previous studies found that OLCR pachymetry agreed well with US pachymetry for CCT values.[22,28] Spadea et al.[22] compared preoperative and postoperative CCT measurements by US pachymetry and OLCR pachymetry in eyes having photorefractive keratectomy and found refractive surgery had a much smaller effect on the agreement between the 2 devices, with respective 95% LoA of 16.9 µm and 22.4 µm.[22] The reason for the differences may be the nonconsistent measurement point, different US settings, or different group refractive indices.[28,29] Spadea et al.[22] proposed that OLCR and ultrasonic pachymetry CCT measurements can be used interchangeably in normal eyes and in planning refractive surgery procedures. Barkana et al.[23] compared Scheimpflug and OLCR pachymetry CCT measurements and found a good correlation (correlation coefficient 0.96) between the devices, with a mean difference of 1.7 µm. More recently, Cruysberg et al.[14] reported significantly higher CCT measurements with the LenStar/Biograph biometer than with Visante anterior segment optical coherence tomography (Carl Zeiss Meditec AG) in normal eyes. The Bland-Altman plots suggested that in 95% of cases, the difference in measurements between the 2 devices ranged from 24.1 to −1.9 µm. In the present study, there was fairly good agreement between the 2 devices in CCT values, with narrow 95% LoA (range −8.2 to 15.7 µm). This is comparable to the reliability of most devices in current clinical use. For example, the respective 95% LoA of CCT measurements using the Pentacam system, Orbscan system, OLCR pachymeter are reported to be −10.2 to 11.9 µm, −12.0 to 14.0 µm, and −11.3 to 6.5 µm.[22–24] The discrepancies are small and not clinically significant; therefore, the measurements with these devices can be used interchangeably for most practical purposes.

In the present study, we evaluated the agreement between the Pentacam Scheimpflug system and LenStar/Biograph OLCR biometer measurements of 2 ACD modes (ACD endothelium to lens and ACD epithelium to lens). To our knowledge, no previous study has done this. Both devices provide accurate and reliable ACD measurement from the anterior and posterior surfaces of the cornea to the anterior surface of the crystalline lens.[12–14] In addition, the 2 ACD modes have different calculation methods. The ACD epithelium to lens mode is inclusive of ACD endothelium to lens and corneal thickness; therefore, the accuracy of ACD epithelium to lens is dependent on both parameters. This may lead to differences in agreement across devices using these modes. Moreover, this allowed us to perform a comprehensive comparison with results in previous studies that used different measurement modes. In our study, the values for both ACD modes were comparable between the 2 devices, with the same equivalent difference (0.02 mm) and narrow 95%

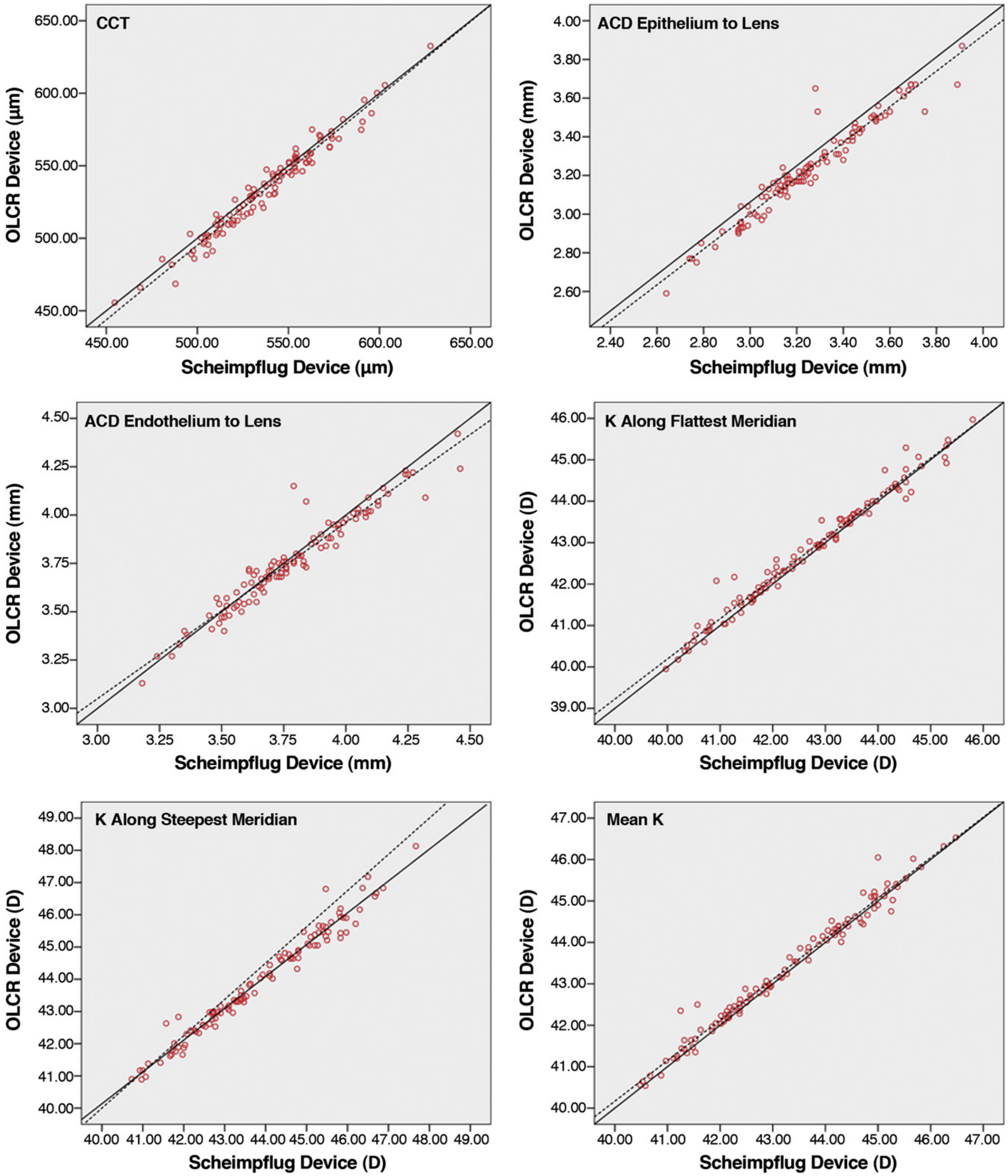

Figure 1. Scatterplots showing the parameters measured by Scheimpflug photography against OLCR biometry (ACD = anterior chamber depth; CCT = central corneal thickness; K = keratometry).

LoA. The mean difference in CCT readings between the Scheimpflug system and the OLCR biometer was 1.9% of the mean difference in the ACD reading. Our result agrees with findings in recent studies comparing ACD epithelium to lens measurements between devices. Cruysberg et al.,[14] Buckhurst et al.,[13] and Holzer et al.[12] evaluated the same 2 devices and found the LenStar/Biograph OLCR biometer gave deeper measurements

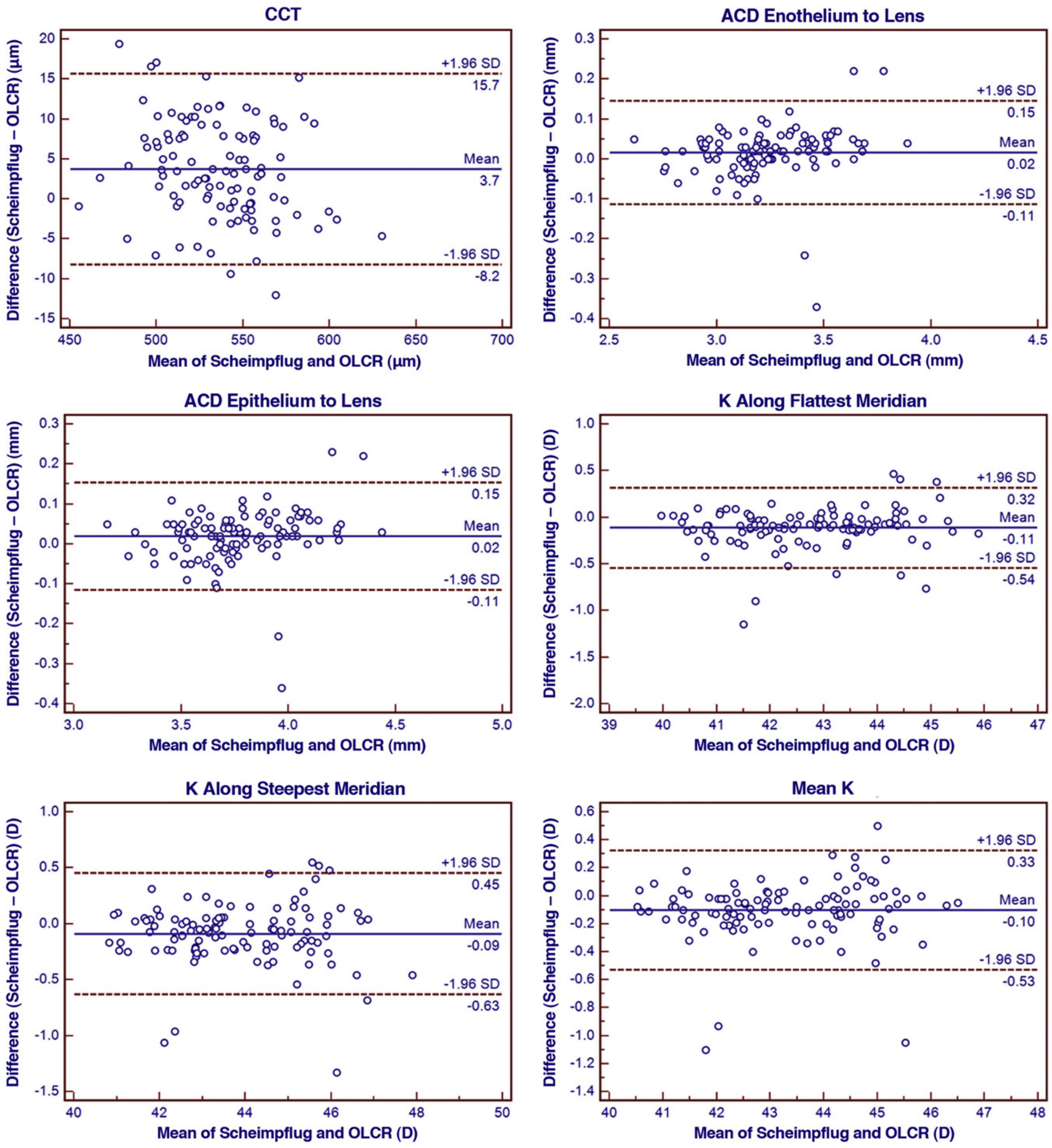

Figure 2. Bland-Altman plots of agreement between Scheimpflug photography against OLCR biometry measurements. The solid line indicates the mean difference (bias). The upper and lower lines represent the 95% LoA (ACD = anterior chamber depth; CCT = central corneal thickness; K = keratometry).

than the IOLMaster device by 0.05 mm, 0.10 mm, and 0.16 mm, respectively. Similarly, previous studies[20,21] report that measurements of ACD epithelium to lens taken with the Pentacam system were 0.05 to 0.11 mm deeper than those taken by the IOLMaster system.[20,21] The difference between these modalities seems too small to be clinically significant.

In our study, the corneal power readings were systematically steeper along the flattest meridian and steepest meridian, as were the mean K readings, with the OLCR biometer than with the Scheimpflug system. This is in accordance with findings in previous studies, which found that the IOLMaster device gave K readings comparable to those of the LenStar/Biograph biometer but steeper than those with the Pentacam system, the Galilei dual rotating Scheimpflug–Placido hybrid, the Orbscan scanning-slit optical pachymeter, a videokeratoscope, and manual and automated keratometers.[25,26] The reason for the difference is probably the different measurement zones of the anterior central cornea. The central corneal curvature is steeper than the peripheral curvature. The IOLMaster and LenStar/Biograph devices obtain the K value using 6 reflective light spots arranged in a 2.30 mm diameter hexagonal and 32 reflective light spots arranged in 2 diameter rings of 1.65 mm and 2.30 mm, respectively, which is smaller than with the other keratometers.[13,25] These differences might also be affected by the number of sampling points, reconstruction algorithms incorporated by each system, variations in corneal curvature along the meridian, eye microsaccade, and the tear film.[27] Although the magnitudes of the mean differences between both devices in K were small and unlikely to be clinically significant, the Bland-Altman analysis showed only a moderate LoA. The LenStar/Biograph biometer could be expected to measure as much as 0.45 D above to 0.63 D below the Pentacam system for K, which is not acceptable for the 2 instruments to be used interchangeably. For example, the sensitivity of the IOL power calculation to a K measurement error is 0.8 to 1.3 D/D error for children and adults.[30]

Although our sample size is large, a potential limitation of our study is that the population comprised only young, healthy persons with normal corneas. Further research is necessary to determine the accuracy and reliability of anterior segment measurements with the Pentacam system and the LenStar/Biograph biometer in elderly patients; in eyes after refractive surgery; and in cases of corneal disease, cataract, and pseudophakia.

In conclusion, our data suggest both the LenStar/Biograph biometer and the Pentacam system have good concordance and can be used interchangeably to measure the CCT and ACD. However, caution must be used in regard to K measurements because the devices have a wide LoA; therefore, the measurements may not be interchangeable.

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