Comparison of Optical Low-coherence Interferometry and Scheimpflug Imaging Combined with Partial Coherence Interferometry Biometers in Cataract Patients

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Research article

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Abstract

Background: To evaluate the agreement between the biometers measured by optical low-coherence interferometry (OLCI, Aladdin) and those measured by Scheimpflug imaging combined with partial coherence interferometry (Scheimpflug-PCI, Pentacam AXL) in cataract patients.

Methods: The axial length (AL), corneal power (keratometry, K), anterior chamber depth (ACD), and corneal astigmatism were measured with the two devices in patients with cataracts. The difference and correlation were evaluated with a paired t-test (p) and Pearson's correlation coefficient (r), respectively.

Results: One hundred sixty-four eyes of 95 patients were analyzed. The mean AL taken by OLCI was longer with excellent correlation (OLCI 23.25 mm, Scheimpflug-PCI 23.23 mm, $p = < 0.0001$, $r = 0.9990$). OLCI measured the ACD 0.08 mm shallower than Scheimpflug-PCI ($p = 0.0003$, $r = 0.7386$). The difference was statistically significant for flat K ($p = 0.0428$). The mean K and steep K were not significantly different. Vector analysis showed no statistically significant difference in the magnitude of astigmatism and the oblique vector between the two devices ($p = 0.1441$ and $p = 0.4147$, respectively). Only the cardinal vector was different ($p = 0.0087$).

Conclusions: Although OCLI and Scheimpflug-PCI showed strong correlations for AL, K, ACD, and corneal astigmatism in cataract patients, there were small but statistically significant differences in the AL, ACD, flat K, and cardinal vector. The two devices are not interchangeable for calculating intraocular lens power.

Background

Cataract surgery is one of the most frequent surgeries in ophthalmology. With the development of surgical techniques and the design of intraocular lenses (IOLs), the refractive outcome of cataract surgeries has improved greatly. Measuring the biometric data, including corneal curvature, anterior chamber depth (ACD), and axial length (AL) of the eye is very important for the calculation of IOL power.[1,2] In 1999, the IOLMaster (Carl Zeiss Meditec, Germany), based on partial coherence interferometry (PCI), was introduced. It measured the anterior corneal curvature using the reflection of six light spots projected hexagonally on the cornea with an approximate 2.3 mm radius pattern.[3] It also measured the ACD, lens thickness, vitreous length, and AL by analyzing the light reflected from the tissue interfaces without direct contact.[3] It was used widely for IOL power calculation and considered the gold standard except for in eyes with dense media opacity.[4,5]

Since 2009, other kinds of optical biometry devices have been introduced. The Lenstar LS 900 (Haag-Streit AG, Switzerland) using optical low-coherence reflectometry provided precise and valid biometry and IOL power calculation in cataract patients comparable to those obtained by PCI.[6] The Aladdin instrument (VISIA imaging and Topcon EU, Italy), based on optical low-coherence interferometry (OLCI) was released in 2012. The AL and corneal astigmatism measured by OLCI showed good agreement and correlation with those by PCI, but keratometry (K) and ACD acquired by the two instruments were statistically different.[7]

The Pentacam instrument uses a rotating Scheimpflug camera to analyze the anterior segment of the eye. The Pentacam AXL (Oculus Optikgeräte GmbH, Germany), based on Scheimpflug imaging combined with partial coherence interferometry (Scheimpflug-PCI), is composed of two functional units, a rotating Scheimpflug camera device and optical biometry based on PCI for AL measurements. When the biometric parameters were compared by Pentacam AXL and PCI, although there was an excellent agreement with the ACD,[8] there were significant differences in corneal curvature and the AL.[9]

In clinical settings, each type of biometry devices has its own advantage. OLCI showed a better measurement success rate in dense or posterior subcapsular cataracts than PCI.[10] Scheimpflug-PCI is commonly used for acquiring corneal topography to analyze corneal disease, such as keratoconus and preoperative screening, prior to refractive surgeries. Previous studies have reported the comparison of anterior segment parameters or AL measurements between a rotating Scheimpflug camera system and PCI.[8,9,11] Sabatino and colleagues published a comparative analysis of optical biometers measured by OLCI and PCI.[12] However, current literature has not evaluated the correlation and agreement of the results obtained with OLCI and Scheimpflug-PCI in cataract eyes.

The aim of this study was to compare the results of measurements of corneal curvature, ACD, and AL obtained with OLCI to those acquired with Scheimpflug-PCI in cataract patients. In addition, the vector analysis of corneal astigmatism was performed and compared between the two devices.

Method

This retrospective comparative study was performed at Sheikh Khalifa Specialty Hospital, United Arab Emirates. We analyzed the data of cataract patients who underwent preoperative measurements with OLCI and Scheimpflug-PCI between 2017 and 2019. The study protocol was approved by the Institutional Review Board and the Independent Ethics Committee (MOHAP/DXB-REC/NDD/No.47 2019). The study was conducted according to the tenets of the Declaration of Helsinki.

Patients, aged between 20 and 100 years old, who completed preoperative measurements with both OLCI and Scheimpflug-PCI were included in this study. Patients with corneal disease, retinal disease, and previous ocular trauma were excluded. Patients were not eligible if warning signs were observed during measurements with the OLCI device. Warning signs were indicated by bad focus, insufficient interpalpebral space, tear film insufficiency, a high standard deviation on repetition, and movement or measurements not in range. Similarly, patients were not included if the color of the quality specification (QS) was red, which indicated a poor measurement quality because of blinking, poor eye alignment, and eye movement during the Scheimpflug-PCI evaluation. Regarding the ACD and AL comparison, pseudophakic eyes and cataract eyes that could not be measured by both OLCI and Scheimpflug-PCI due to severe cataracts were excluded. Subjects were also excluded when the signal-to-noise ratio was less than 4 during the Scheimpflug-PCI measurement. At last, two cases that showed an AL about 38 mm by Scheimpflug-PCI despite good quality acquisition were also excluded from this study.

All cataract patients underwent comprehensive preoperative evaluation for cataract surgeries. Visual acuity, intraocular pressure, OLCI examinations, and Scheimpflug-PCI examinations were routinely performed by two experienced optometrists. For the OLCI examination, the patients were positioned with a chin and forehead rest. The subjects were asked to fixate on the internal fixation target, and the button was clicked. When a perfect green circle alignment signal appeared on the monitor, corneal curvature, ACD, and the AL reading were obtained simultaneously. Similarly, patients underwent Scheimpflug-PCI evaluation by looking at the fixation target in the scanning slit. If the “QS” button was red, the measurement was repeated until the corneal curvature and ACD reading were analyzed. Then, the AL was scanned for the IOL power calculation.

Regarding the OLCI device, keratometry was acquired based on the reflection of 24 rings of the Placido disk on the eye at a distance of 80 mm from the patient’s eye. The ACD was defined as the distance between the corneal epithelium and the anterior surface of the crystalline lens. It was measured along the optical axis where the distance was the greatest with a slit light projection measuring method. The AL was defined as the distance between the cornea and the inner limiting membrane, which was automatically calculated and shown in the OLCI after processing an interference signal from the retinal pigment epithelium of the eye.

In terms of the Scheimpflug-PCI device, keratometer data was defined as the simulated mean radius of the anterior curvature on a ring in 15 degrees around the corneal apex using a keratometric index of 1.3375. The ACD was defined as the ACD in the anterior corneal apex position measured from the corneal epithelium down to the anterior crystalline lens surface. The AL was defined by the same definition as for the OLCI device.

The magnitude of corneal astigmatism was defined as the difference between the steepest and flattest keratometer in each device. The power vector analysis described by Thibos et al.[13] was used to convert corneal astigmatism into cardinal (J0) and oblique (J45) vectors using the following equation:

$$J0=-(C/2)\cos(2\alpha),\ J45=-(C/2)\sin(2\alpha),$$

where C is the negative cylinder power and the angle α is the cylinder axis. The J0 vector describes a Jackson cross-cylinder with its axes at 180 degrees and 90 degrees, while the J45 vector describes a Jackson cross-cylinder with its axes at 45 degrees and 135 degrees.

All data obtained were collected in a spreadsheet and analyzed with SPSS software (version 17.0, SPSS Inc., Chicago, IL, USA). The data are expressed as the mean ± standard deviation (SD) with range. The Kolmogorov-Smirnov test was used to assess the normality of the data. All data followed a normal distribution. A paired t-test was used to evaluate the statistical significance of the differences between the readings from the two devices. The agreement between the two devices was evaluated using Bland-

Altman plots. The mean differences and 95% limits of agreement (LoA) were calculated. A P-value of less than 0.05 was considered statistically significant.

Results

One hundred sixty-four eyes of 95 patients were evaluated. Of the patients, 49 (51.6%) were women. The mean age of the patients was 65 ± 10 years (range 20 to 84 years). Regarding the ACD, nine of the 164 eyes were excluded because of eight pseudophakic eyes and one eye that was not analyzed by OLCI. In the AL comparison, 52 eyes were excluded due to failure in the measurements (19 eyes in both instruments, 30 eyes by Scheimpflug-PCI, and three eyes by OLCI). Table 1 shows the mean values for the AL, ACD, steep, flat, and mean corneal curvature measured by the two instruments.

Table 1
Mean AL, ACD, and K measured by OLCI and Scheimpflug-PCI

Parameter	OLCI	Scheimpflug-PCI	Difference	P value	95% LoA	CC γ (p value)
AL (mm)						
Mean ± SD	23.25 ± 0.85	23.23 ± 0.86	+ 0.02	< 0.0001*	-0.05, 0.10	0.9990 (< 0.0001)
Range	21.43, 26.03	21.37, 26.05				
95% CI	23.09, 23.41	23.06, 23.39				
ACD (mm)						
Mean ± SD	3.06 ± 0.37	3.15 ± 0.44	-0.09	0.0003*	-0.68, 0.50	0.7386 (< 0.0001)
Range	1.73, 3.90	2.07, 4.89				
95% CI	3.00, 3.12	3.08, 3.22				
Mean K (D)						
Mean ± SD	44.24 ± 1.51	44.29 ± 1.48	-0.05	0.1074	-0.87, 0.76	0.9614 (< 0.0001)
Range	40.98, 48.01	40.35, 47.95				
95% CI	44.00, 44.47	44.06, 44.52				
Flat K (D)						
Mean ± SD	43.59 ± 1.60	43.67 ± 1.59	-0.08	0.0428*	-1.13, 0.96	0.9445 (< 0.0001)
Range	38.91, 47.43	37.70, 47.60				
95% CI	43.34, 43.83	43.42, 43.92				

AL = axial length; ACD = anterior chamber depth; K = keratometry; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; LoA = limits of agreement; CC = correlation of coefficient; SD = standard deviation; CI = confidence interval; D = diopters

*Statistically significant

Parameter	OLCI	Scheimpflug-PCI	Difference	P value	95% LoA	CC γ (p value)
Steep K (D)						
Mean ± SD	44.89 ± 1.56	44.91 ± 1.51	-0.02	0.5845	-0.94, 0.90	0.9535 (< 0.0001)
Range	41.30, 48.74	41.30, 48.74				
95% CI	44.65, 45.13	44.68, 45.14				
AL = axial length; ACD = anterior chamber depth; K = keratometry; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; LoA = limits of agreement; CC = correlation of coefficient; SD = standard deviation; CI = confidence interval; D = diopters						
*Statistically significant						

The mean AL taken by OLCI was significantly longer than that by Scheimpflug-PCI. Figure 1 shows the Bland-Altman plot for the ALs. The mean ACD by OLCI was shallower than that by Scheimpflug-PCI. Figure 2 shows the Bland-Altman plot for the ACDs. The difference was statistically significant for flat K. The mean K and steep K were not significantly different between the two instruments. Figures 3 shows the Bland-Altman plots for the mean K, flat K, and steep K. All parameters taken by the two instruments were highly correlated ($p < 0.0001$), with the highest correlation coefficient that of the AL ($\gamma = 0.9990$).

Table 2 shows the magnitude and vector analysis of corneal astigmatism. There were strong correlations in the astigmatism magnitude, J0 vector, and J45 vector between the two instruments. OLCI provided slightly higher astigmatism measurements, but the difference was not statistically significant ($p = 0.1441$). The J45 vector was not statistically different between the two devices. However, there was a difference of the J0 vector between the two instruments ($p = 0.0087$).

Table 2
Corneal astigmatism measured by OLCI and Scheimpflug-PCI

Parameter	OLCI	Scheimpflug-PCI	Difference	P value	95% LoA	CC γ (p value)
Astigmatism magnitude (D)						
Mean ± SD	1.30 ± 0.96	1.24 ± 0.92	+ 0.06	0.1441	-0.02, 0.15	0.8210 (< 0.0001)
Range	0, 5.48	0, 5.60				
95% CI	1.15, 1.45	1.10, 1.38				
J0						
Mean ± SD	-0.22 ± 0.68	-0.14 ± 0.66	-0.08	0.0087*	-0.13, 0.02	0.8481 (< 0.0001)
Range	-2.66, 2.07	-2.77, 1.84				
95% CI	-0.32, -0.11	-0.24, -0.04				
J45						
Mean ± SD	0.06 ± 0.39	0.04 ± 0.38	0.02	0.4147	-0.02, 0.05	0.7905 (< 0.0001)
Range	-0.79, 2.11	-0.97, 2.09				
95% CI	0, 0.12	-0.02, 0.10				

OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; LoA = limits of agreement; CC = correlation of coefficient; SD = standard deviation; CI = confidence interval; D = diopters; J0 = Jackson cross-cylinder, axes at 90 degrees and 180 degrees; J45 = Jackson cross-cylinder, axes at 45 degrees and 135 degrees

*Statistically significant

Discussion

The precise and accurate measurements of corneal curvature, ACD, and AL are highly important for the exact calculation of IOL power and the visual outcomes of cataract surgeries.[1,2] Since 1999, many biometric devices based on PCI (IOLMaster, Carl Zeiss Meditec)[3], optical low-coherence reflectometry (Lenstar LS 900, Haag-Streit AG)[14], OLCI (Aladdin, Topcon)[15], Scheimpflug-PCI (Pentacam AXL, Oculus Optikgerate GmbH)[16], and swept-source optical coherence tomography(OA-2000, Tomey) have been introduced[10]. In our clinical settings, we introduced OLCI considering its superior ability to measure the AL in cases of dense cataracts and Scheimpflug-PCI for acquiring corneal topography with AL measurements, as well.[10]

The AL is one of the most important factors for calculating IOL power in cataract surgery.[17] Scheimpflug-PCI has an additional functional unit that measures the AL by PCI. Regarding AL measured by PCI and Scheimpflug-PCI, Shajari and associates reported no significant difference in ALs measured by PCI (IOLMaster 500, Carl Zeiss Meditec) and Scheimpflug-PCI because both devices measure the AL from the corneal epithelium to the retina using PCI.[16] In our study, the mean AL taken by OLCI was 0.02 mm longer than that by Scheimpflug-PCI with a strong positive correlation. Sabatino et al.[12] reported that the mean AL measured by OLCI was 0.04 mm longer than that by PCI in cataract patients, similar to our results. In contrast, Hoffer et al.[7] published that the ALs taken by PCI and OLCI were not different in cataract eyes and normal eyes, although there was a trend toward longer ALs measured by the OLCI in the cataract patients ($p = 0.077$). Similarly, Mandal et al.[15] also reported no difference in AL measured by OLCI and PCI. Our data showed excellent agreement because the 95% limit of agreement (LoA) of the AL difference was lower than 0.08 mm. However, the AL by PCI and OLCI was not interchangeable because there were five cases of AL differences of more than 0.08 mm 95% LoA in our study, consistent with other studies.[7,10,12,15] Two cases of AL, measured at 38.45 and 39.18 mm by Scheimpflug-PCI despite good signal-to-noise ratios, were excluded from our study. The AL of 38.45 mm was verified as 21.87 and 21.69 mm and the AL of 39.18 mm as 24.87 and 24.80 mm by OLCI and A-scan, respectively. This means that an extraordinary AL value measured by Scheimpflug-PCI alone should be confirmed by an A-scan or another type of biometry to obtain an exact IOL power calculation.

Although ACD is not used for IOL power calculation in the SRK/T formula,[17] it is used to predict an effective postoperative lens position in some theoretical formulas, such as the Holladay and Hoffer Q formulas.[18,19] Furthermore, a shallow ACD was correlated with the possibility of intraoperative complications in eyes with pseudoexfoliation syndrome in cataract surgery.[20] Nemeth and associates reported no significant difference between ACD measurements performed by PCI and the Pentacam HR® (Oculus, Wetzlar, Germany).[21] Shajari et al.[16] reported no significant difference between ACD measurements by PCI and Scheimpflug-PCI, which is similar to what was reported by Muzyka-Wozniak and Oleszko.[9] In contrast, Fernandez-Vigo et al. reported that the ACD measured by Pentacam® (Oculus, Wetzlar, Germany) was deeper than by PCI,[8] which is similar to a report by Dong and associates in normal eyes within 3 diopters of the refractive errors and by Utine et al. in myopic and emmetropic eyes.[11,22] Regarding the ACD measured by OLCI and PCI, Mandal and colleagues published an average ACD of 3.28 ± 0.47 mm by OLCI and 3.28 ± 0.43 mm by PCI, with no statistical significance between them,[15] whereas OLCI provided greater mean ACDs than that from PCI in two different studies.[7,12] We compared the ACD measurements by Scheimpflug-PCI and OLCI, which has not been previously reported. In our study, Scheimpflug-PCI provided significantly deeper ACD than OLCI and the 95% LoA was −0.68 mm to 0.50 mm, indicating relatively lower agreement than in the AL.

Comparison of corneal curvatures and astigmatism measured by the two different devices has been performed by many ophthalmologists, with most reporting different results. Shajari et al.[16] analyzed two corneal curvature measurements by PCI and Scheimpflug-PCI. They reported no significant difference in the corneal curvature and astigmatism by PCI and those of the Sim K 15 degree measurements by Scheimpflug-PCI, similar to the results reported by Visser and associates.[23] In contrast, Reuland et al.[24] reported a small but significantly larger flat K measurement by PCI than by Pentacam. Dong et al.[11] published larger steep K and mean K values by PCI and significant differences in cardinal astigmatism and the magnitude of astigmatism in the eyes within ± 3 diopter refractive errors. They suggested the reason for the greater corneal curvature by PCI was different analytical zones considering the prolate shape of the cornea and the device optimization for Pentacam. PCI measures the corneal power over an approximate 2.3 mm diameter area, whereas Pentacam analyzes an area 3.0 mm in diameter.[11]

Regarding the corneal curvatures measured by OLCI and PCI, some authors reported no significant differences in the average keratometry reading.[15] In contrast, other authors reported significant differences in the mean K between PCI and OLCI although the median difference in the mean K was less than 0.08 D, which would not result in a clinically significant change in the IOL power calculation.[12] Similarly, Hoffer et al.[7] reported a slightly steeper mean K value by PCI. In our study, we did not find significant differences in the steep K and the mean K measured by OLCI and Scheimpflug-PCI. However, the flat K by Scheimpflug-PCI were larger than that by OLCI. Although the agreement of those values from OLCI and Scheimpflug-PCI was excellent, the 95% LoA ranged from − 0.87 to 0.76, suggesting that those values were not interchangeable between OLCI and Scheimpflug-PCI.

Regarding the vector analysis of corneal astigmatism, we found a significant difference in J0 by OLCI and Scheimpflug-PCI. However, there were no significant differences in J45 or the magnitude of corneal astigmatism. We did not find a clear reason for the difference in J0. The difference may be due to several factors, such as the measurement accuracy or difference in the measurement principle, reconstruction algorithms, or point of measurement in the two devices.[25]

The study had several limitations. The study sample size was small and repeatability in each device was not investigated. Therefore, further studies with large sample sizes and prospective study designs may show more statistically significant results. Second, this study was limited to adult cataract patients who did not have corneal or retinal disease. If patients with those conditions are included, a similar analysis may show different results. Differences may also be seen when comparing the differences in measurements in normal eyes without cataracts. Finally, we did not evaluate the accuracy in IOL power calculation by the two devices. Further studies with different types of biometric instruments may provide more information for the exact IOL power calculation in specific ocular conditions.

Conclusions

This study found that OCLI and Scheimpflug-PCI showed strong correlations for AL, ACD, corneal curvature, and corneal astigmatism measurements in cataract patients. There were also small but statistically significant differences in the AL, ACD, flat K, and cardinal vector. The two devices are not interchangeable for IOL power calculations.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Institutional Review Board and the Independent Ethics Committee (MOHAP/DXB-REC/NDD/No.47 2019). The study was conducted according to the tenets of the Declaration of Helsinki.

Consent for Publication

Not applicable

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to the policy of our institutional review board but are available from the corresponding author on reasonable request.

Competing interests

No financial or proprietary interest in any material or method mentioned. The authors declare that they have no competing interests.

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Authors' contributions

Moonjung Kim(MK) and Eui Seok Han (ESH) made concept and design.

MK and ESH acquired data and it was mainly analyzed by ESH.

MK and ESH analyzed statistical significance and drafted manuscript.

All authors read and approved the final manuscript.

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Figures

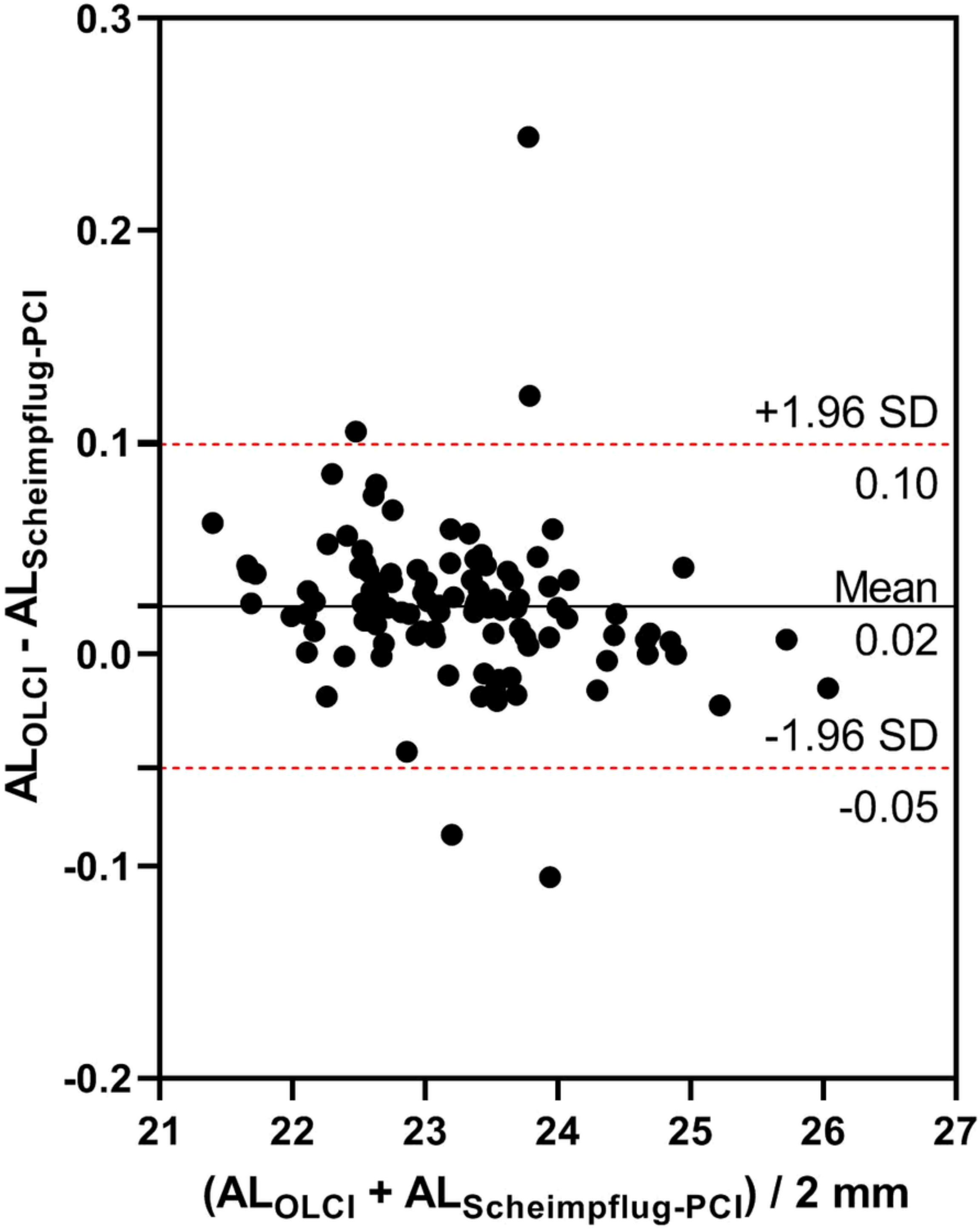

Figure 1

Bland-Altman plot for the mean axial length measured by the OLCI and Sheimpflug-PCI devices. (AL = axial length; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; SD = standard deviation)

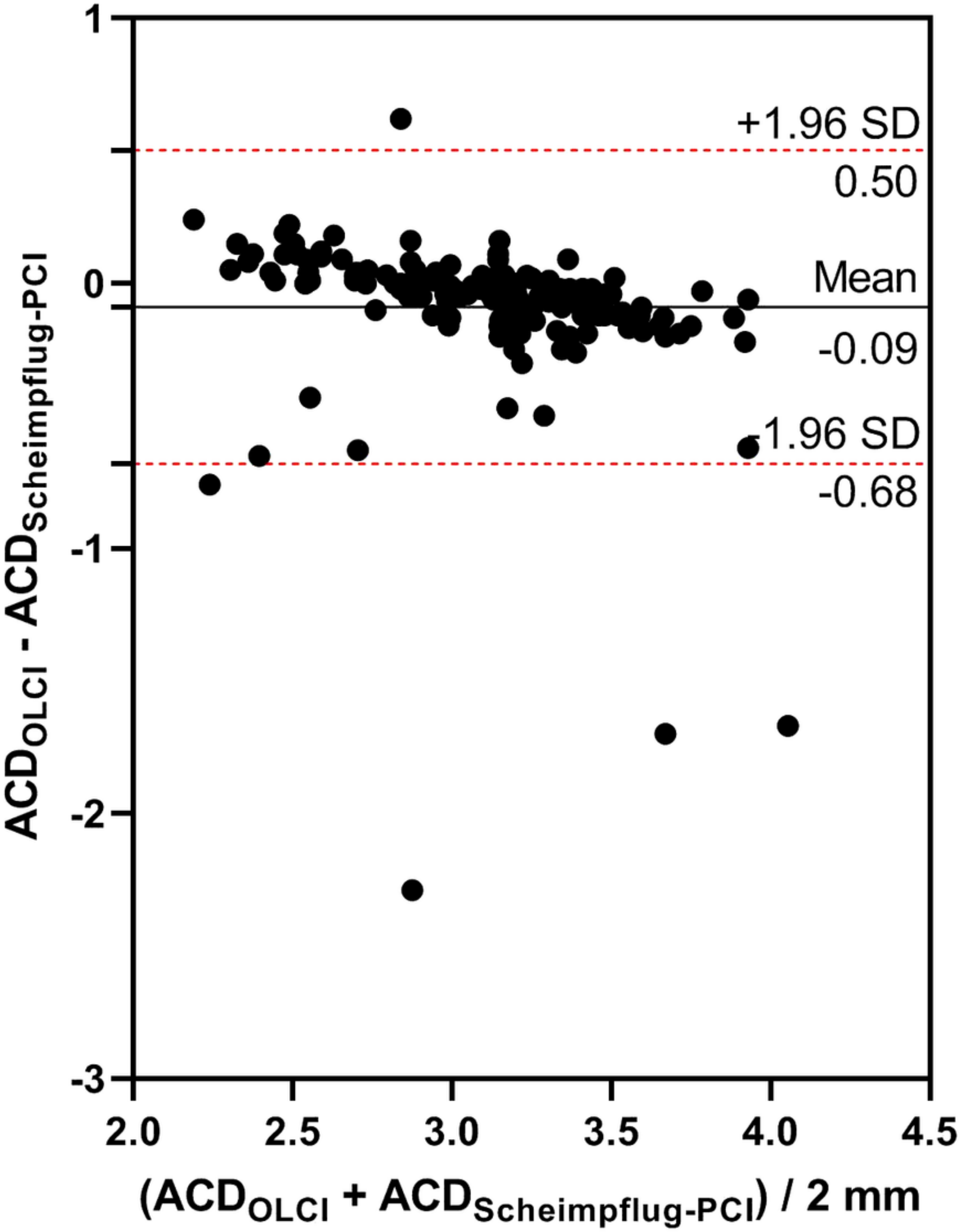

Figure 2

Bland-Altman plot for the mean anterior chamber depth measured by the OLCI and Sheimpflug-PCI devices. (ACD = anterior chamber depth; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; SD = standard deviation)

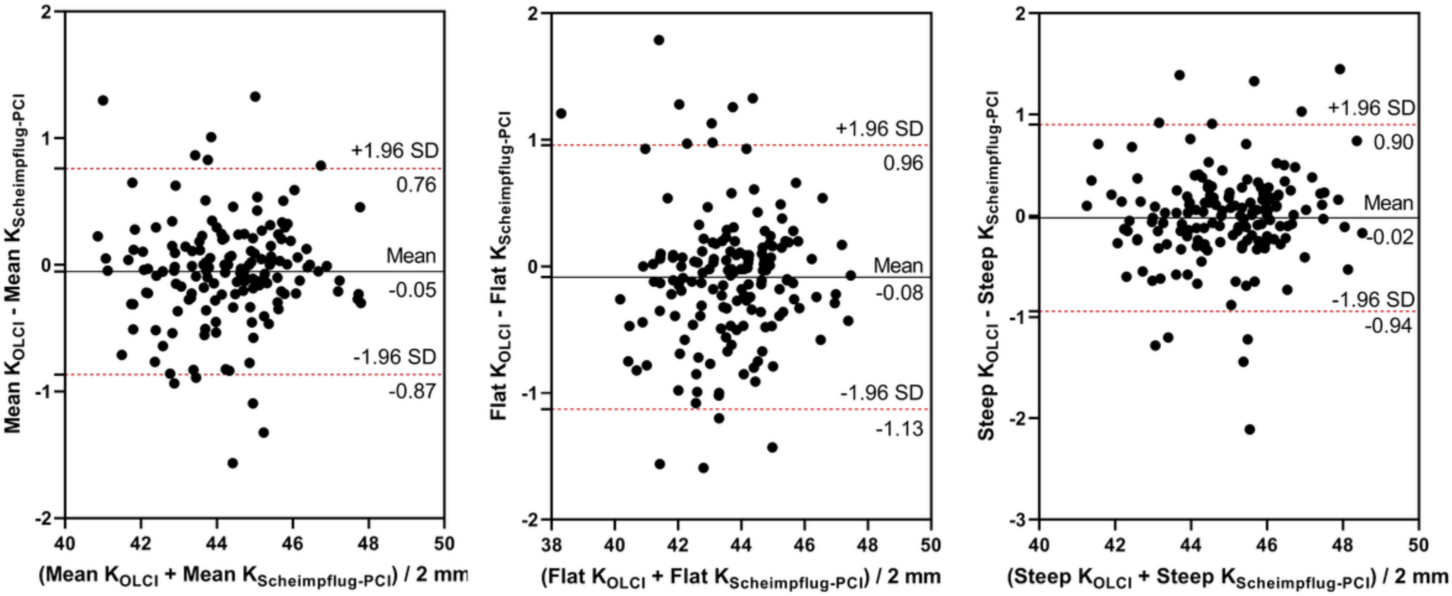

Figure 3

Bland-Altman plot for the mean, steep, and flat keratometric values measured by the OLCI and Sheimpflug-PCI devices. (K = keratometry; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; SD = standard deviation)