Comparison of optical low coherence interferometry and Scheimpflug imaging combined with partial coherence interferometry biometers in cataract eyes

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Abstract:

PURPOSE: The purpose of the study was to evaluate the agreement between measurements by optical low-coherence interferometry (OLCI, Aladdin) and those by Scheimpflug imaging combined with partial coherence interferometry (Scheimpflug-PCI, Pentacam AXL) in cataract patients.

METHODS: This was a retrospective comparative study conducted in the United Arab Emirates. Axial length (AL), corneal power (keratometry, K), anterior chamber depth (ACD), and corneal astigmatism in patients with cataracts were measured with both devices. Difference and correlation were evaluated with paired *t*-test (p) and Pearson's correlation coefficient®, respectively.

RESULTS: A total of 164 eyes of 95 patients were analyzed (164 eyes for K, 155 for ACD, and 112 for AL). The mean AL taken by OLCI was longer than that by Scheimpflug-PCI (23.25 mm vs. 23.23 mm, $P \leq 0.0001$), showing an excellent correlation between the two ($r = 0.9990$). ACD measured by OLCI was 0.08 mm shallower than that by Scheimpflug-PCI ($P = 0.0003$, $r = 0.7386$). Corneal power measured by OLCI was lower than that by Scheimpflug-PCI (differences in mean K, flat K, and steep K were 0.05 diopters (D), 0.08 D, and 0.02 D, respectively), showing very strong correlations between the two devices ($r = 0.9614$, 0.9445, and 0.9535, respectively). Only flat K values measured with the two devices were significantly different ($P = 0.0428$). There were no statistically significant differences in the magnitude of astigmatism or J45 vector between the two devices ($P = 0.1441$ and $P = 0.4147$, respectively). However, J0 vector values were significantly different ($P = 0.0087$).

CONCLUSION: Although OCLI and Scheimpflug-PCI showed strong correlations for measurements of AL, K, ACD, and corneal astigmatism in cataract patients, there were small but statistically significant differences in AL, ACD, flat K, and J0 vector. Thus, these two devices are not interchangeable for calculating intraocular lens power.

Keywords:

Biometric parameters, cataract surgery, optical low-coherence interferometry, Pentacam AXL

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Introduction

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 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 could measure 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 can also measure ACD, lens thickness, vitreous length, and AL by analyzing the light reflected from tissue interfaces without having a direct contact.[3] It was used widely for

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IOL power calculation and considered the gold standard except for 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 could provide 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. AL and corneal astigmatism measured by OLCI show good agreement and correlation with those by PCI. However, keratometry (K) and ACD acquired by these 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 PCI (Scheimpflug-PCI) is composed of two functional units, a rotating Scheimpflug camera device and an optical biometry based on PCI for AL measurements. When biometric parameters measured by Pentacam AXL and PCI were compared, although they showed excellent agreement for ACD,[8] there were significant differences in corneal curvature and AL.[9]

In clinical settings, each type of biometry devices has its own advantage. OLCI shows 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 diseases such as keratoconus and preoperative screening prior to refractive surgeries. Previous studies have compared anterior segment parameters and AL measurements between a rotating Scheimpflug camera system and PCI.[8,9,11] Sabatino *et al*. have published a comparative analysis of optical biometers measured by OLCI and PCI.[12] However, current literature has not evaluated the correlation or agreement of results obtained with OLCI and Scheimpflug-PCI in cataract eyes.

Thus, 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 analysis of corneal astigmatism was performed and compared between these two devices.

Methods

This comparative study was performed retrospectively. Data of cataract patients who underwent preoperative measurements with OLCI and Scheimpflug-PCI between 2017 and 2019 were analyzed. 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 who completed preoperative measurements with both OLCI and Scheimpflug-PCI were included in this study. Patients with corneal disease, retinal disease, or previous ocular trauma were excluded. The eyes with previous ocular surgery or recent contact lens use were also excluded. Patients' data were excluded when OLCI or Scheimpflug-PCI could not measure K, ACD, or AL with good quality. 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 (SD) on repetition, and movement or measurements not in range. Patients were not included during the Scheimpflug-PCI evaluation when the signal-to-noise ratio was less than 4 or 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. Regarding ACD and AL comparison, cataract eyes that could not be measured by both OLCI and Scheimpflug-PCI due to severe cataracts were excluded. Two cases that showed an AL of 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 consecutively performed by two experienced optometrists. The optometrists were randomly assigned to the OLCI or Scheimpflug-PCI devices. For OLCI examination, patients were positioned with a chin and forehead rest. Subjects were asked to fixate on an internal fixation target, and the button was clicked. When a perfect green circle alignment signal appeared on the monitor, corneal curvature, ACD, and AL readings were obtained simultaneously. Similarly, patients underwent Scheimpflug-PCI evaluation by looking at the fixation target in a 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 IOL power calculation.

Regarding the OLCI device, keratometry was acquired based on reflection of 24 rings of a 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, keratometry was defined as the simulated mean radius of the anterior curvature on a ring in 15° around the corneal apex using a keratometric index of 1.3375. ACD was defined as the ACD in the anterior corneal apex position measured from the corneal epithelium down to the anterior crystalline lens surface. 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 keratometry and the flattest keratometry 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 equations:

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

Where C was the negative cylinder power and the angle α was the cylinder axis. J0 vector was a Jackson cross-cylinder with its axes at 180° and 90°. J45 vector was a Jackson cross-cylinder with its axes at 45° and 135°.

All data obtained were collected in a spreadsheet and analyzed with SPSS software, version 17.0 (SPSS Inc., Chicago, IL, USA). Data are expressed as mean ± SD with range. The Kolmogorov–Smirnov test was used to assess the normality of data. All data followed a normal distribution. A paired *t*-test was used to evaluate the statistical significance of differences between 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. $P < 0.05$ was considered statistically significant.

Results

A total of 164 eyes of 95 patients were evaluated. Of these patients, 49 (51.6%) were women. The mean age of all patients was 65 ± 10 years (range, 20–84 years). Regarding the ACD, 9 of 164 eyes were excluded because of pseudophakic eyes ($n = 8$) or if the eye ($n = 1$) was not analyzed by OLCI. In AL comparison, 52 eyes were excluded due to failure in measurements (19 eyes in both instruments, 30 eyes by Scheimpflug-PCI, and 3 eyes by OLCI). In detail, two cases were excluded according to exclusion criteria because AL was measured at 38.45 and 39.18 mm by Scheimpflug-PCI despite good signal-to-noise ratios. Fifty of 52 eyes were excluded due to severe cataracts. Table 1 shows the mean values of AL, ACD, steep, flat, and mean corneal curvature measured by the two instruments.

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

Table 2 shows the magnitude and vector analysis of corneal astigmatism. All parameters were strongly correlated (all $P < 0.0001$). OLCI provided a slightly higher magnitude of astigmatism than Scheimpflug-PCI. However, the difference between the two was not statistically significant ($P = 0.1441$). The J45 vector was not statistically different between the two devices. However, J0 vector measured with the two instruments was statistically different ($P = 0.0087$).

Discussion

Precise and accurate measurements of corneal curvature, ACD, and AL are highly important for the exact calculation of IOL power and visual outcomes of cataract surgeries.[1,2] Since 1999, many biometric devices such as 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

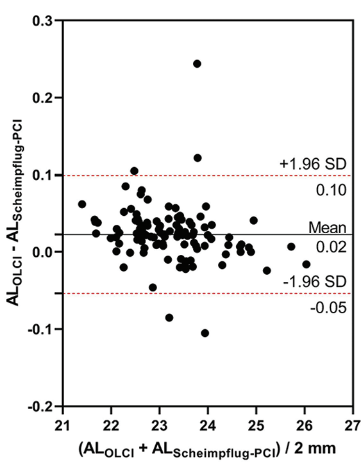

Figure 1: Bland–Altman plot for the mean axial length measured by the optical low-coherence interferometry and Scheimpflug-partial coherence interferometry devices (AL = axial length; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; SD = standard deviation)

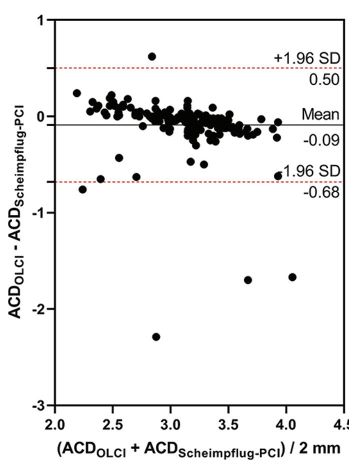

Figure 2: Bland–Altman plot for the mean anterior chamber depth measured by the optical low-coherence interferometry and Scheimpflug-partial coherence interferometry devices (ACD = anterior chamber depth; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; SD = standard deviation)

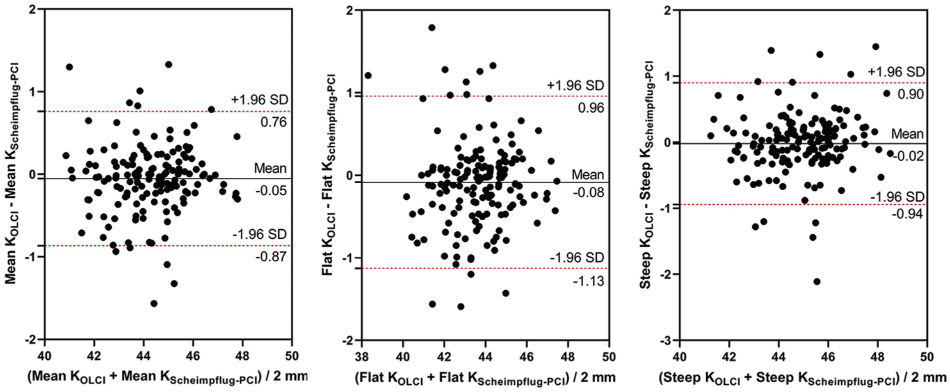

Figure 3: Bland–Altman plot for the mean, steep, and flat keratometric values measured by the optical low-coherence interferometry and Scheimpflug-partial coherence interferometry devices (K = keratometry; OLCI = optical low-coherence interferometry; Scheimpflug-PCI = Scheimpflug imaging combined with partial coherence interferometry; SD = standard deviation)

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 AL in cases of dense cataracts.[10,15] Scheimpflug-PCI was also used for acquiring corneal topography with AL measurements.

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 AL by PCI. Regarding AL measured by PCI and Scheimpflug-PCI, Shajari *et al*. have reported no significant difference in ALs measured by PCI (IOLMaster 500, Carl Zeiss Meditec) and Scheimpflug-PCI because both devices can measure AL from the corneal epithelium to the retina using PCI.[16] Haddad *et al*.[18] have also reported a similar result. Although there were two reports showing a statistical difference in ALs, the mean difference in AL was clinically insignificant.[9,19] In our study, the mean AL taken by OLCI was 0.02 mm longer than that by Scheimpflug-PCI, showing a strong positive correlation between the two devices. Sabatino *et al*.[12] have reported that the mean AL measured by OLCI is 0.04 mm longer than that by PCI in cataract patients, similar to our results. Ortiz *et al*.[20] have also reported a difference in AL between PCI and OLCI. In contrast, Hoffer *et al*.[7] have reported that ALs taken by PCI and OLCI are not different in cataract eyes or normal eyes, although there was a trend toward longer ALs measured by OLCI in cataract patients (P = 0.077). Mandal *et al*.[15] have also reported no significant 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, AL measured by PCI and OLCI was not interchangeable because five cases showed AL differences of more than 0.08 mm in 95% LoA of our study, consistent with other studies.[7,10,12,15,20] For two cases, AL was measured at 38.45 and 39.18 mm by Scheimpflug-PCI despite good signal-to-noise ratios. These two cases were excluded from our study. By OLCI and A-scan, the AL of 38.45 mm in one case was verified as 21.87 and 21.69 mm, respectively. The AL of 39.18 mm in the other case was verified 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.[21,22] Nemeth *et al.* have reported no significant difference between ACD measurements performed by PCI and Pentacam HR® (Oculus, Wetzlar, Germany).[23] Shajari *et al*.[16] have reported no significant difference between ACD measurements by PCI and Scheimpflug-PCI, similar to results reported by Muzyka-Wozniak and Oleszko.[9] In contrast, Fernandez-Vigo *et al*. have reported that the ACD measured by Pentacam® (Oculus, Wetzlar, Germany) is deeper than that measured by PCI,[8] similar to a report by Dong *et al*. for normal eyes within 3 diopters of refractive errors and by Utine *et al*. for myopic and emmetropic eyes.[11,24] Regarding the ACD measured by OLCI and PCI, Mandal *et al*. have published an average ACD of 3.28 ± 0.47 mm by OLCI and 3.28 ± 0.43 mm by PCI, showing no statistically significant difference between the two.[15] However, OLCI provided greater mean ACDs than PCI in two different studies.[7,12] We compared ACD measurements by Scheimpflug-PCI and OLCI. This has not been previously reported. In our study, Scheimpflug-PCI provided significantly deeper ACD than OLCI with 95% LoA of −0.68 mm to 0.50 mm, indicating relatively lower agreement than for AL.

Many ophthalmologists have compared corneal curvatures and astigmatism measured by these two different devices, with most of them reporting different results. Shajari *et al*.[16] have analyzed two corneal curvature measurements by PCI and Scheimpflug-PCI. They reported no significant difference in corneal curvature by PCI and Sim K 15° measurement by Scheimpflug-PCI, similar to results reported by Visser *et al*.[25] In contrast, Reuland *et al*.[26] have reported a small but significantly larger flat K measurement by PCI than by Pentacam. Dong *et al*.[11] have published larger steep K and

Table 1: Mean axial length, anterior chamber depth, and K measured by optical low-coherence interferometry and Scheimpflug imaging combined with partial coherence interferometry

Parameter	OLCI	Scheimpflug-PCI	Difference	*P*	95% LoA	CC γ *(P)*
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				
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				

*Statistically significant. 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

Table 2: Corneal astigmatism measured by optical low-coherence interferometry and Scheimpflug imaging combined with partial coherence interferometry

Parameter	OLCI	Scheimpflug-PCI	Difference	*P*	95% LoA	CC γ *(P)*
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				

*Statistically significant. 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° and 180°, J45: Jackson cross-cylinder, axes at 45° and 135°

mean K values by PCI with significant differences in cardinal astigmatism (V0) and the magnitude of astigmatism for eyes within ± 3 diopter refractive errors. They suggested that 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 area with a diameter of approximate 2.3 mm, whereas Pentacam analyzes an area with a diameter of approximate 3.0 mm.[11]

Regarding corneal curvatures measured by OLCI and PCI, some authors have reported no significant differences in the average keratometry reading.[15] In contrast, other authors have reported significant differences in mean K between PCI and OLCI, although the median difference in the mean K is <0.08 D, which would not result in a clinically significant change in IOL power calculation.[12] Similarly, Hoffer *et al*.[7] have reported a slightly steeper mean K value by PCI. In our study, we did not find significant differences in steep K and mean K measured by OLCI and Scheimpflug-PCI. However, flat K measured by Scheimpflug-PCI was larger than that by OLCI. Although the agreement for those values measured by 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 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 such difference in J0. The difference might be due to several factors, such as measurement accuracy, difference in the measurement principle, reconstruction algorithms, and point of measurement in the two devices.[27]

The study has several limitations. The study sample size was small. Repeatability in each device was not investigated. Therefore, further studies with large sample sizes and a prospective study designs are needed to show more statistically significant results. Second, this study was limited to adult cataract patients who did not have corneal or retinal diseases. If patients with those conditions are included, a similar analysis may show different results. Differences might also be seen when comparing differences in measurements for normal eyes without cataracts. Finally, we did not evaluate the accuracy in IOL power calculation by the two devices. The postoperative refractive errors were not compared due to limited number of cases for IOL power calculations by OLCI and Scheimpflug-PCI.

Conclusion

This study found that OCLI and Scheimpflug-PCI showed strong correlations for AL, ACD, corneal curvature, and corneal astigmatism measurements in cataract patients. However, there were small but statistically significant differences in AL, ACD, flat K, and corneal astigmatism with these two devices. Thus, these two devices are not interchangeable for IOL power calculations.

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Conflicts of interest

There are no conflicts of interest.

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