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Original Article

Agreement between Two Swept-Source Optical Coherence Tomography Biometers and a Partial Coherence Interferometer

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Purpose: To evaluate the level of agreement between ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), and IOLMaster 500 (Carl Zeiss AG, Jena, Germany).

Methods: Fifty-one eyes of 51 patients were included in the study. Flat keratometry (K) and steep K, vector component of astigmatism (Jackson cross-cylinder at 0° and 90° [J_0] and Jackson cross-cylinder at 45° and 135° [J_{45}]), anterior chamber depth, and axial length were compared using the three devices. Repeated measures analysis of variance was conducted to compare the mean values of the biometrics. Pearson correlation test was conducted to analyze the correlations of the measured values, and a Bland-Altman plot was used to assess the agreement between the three devices. The predicted intraocular lens power of each device was compared to the others using the SRK/T, Haigis, Barrett Universal II, and Kane formulas.

Results: All K values measured using ANTERION were flatter than those of other instruments. However, good agreement was observed for flat K (ANTERION - OA-2000; 95% limits of agreement [LoA], 0.86 diopters [D]) and steep K (ANTERION - OA-2000; 95% LoA, 0.93 D) and OA-2000 - IOLMaster 500 (95% LoA, 0.93 D). J_0 and J_{45} vector components of astigmatism were not statistically different; however, the agreements were poor between the devices (95% LoA ≥1.97 D). Anterior chamber depth values of ANTERION and OA-2000 were interchangeable (95% LoA, 0.15 mm). The axial length showed a high agreement (95% LoA ≤0.17 mm) among the three devices. The predicted intraocular lens powers of the three devices were not interchangeable regardless of formulas (95% LoA ≥1.04 D).

Conclusions: Significant differences in ocular biometrics were observed between ANTERION and the other two devices. This study demonstrated that only axial length showed good agreement among devices.

Key Words: Biometry, Partial coherence interferometer, Swept-source optical coherence tomography

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Ocular measurements such as axial length (AL), keratometry (K), corneal astigmatism, and anterior chamber depth (ACD) are essential for determining the power, type, and size of the intraocular lens for cataract surgery or phakic intraocular lens implantation surgery [1]. Recently, improvements in cataract surgery and intraocular lens have led to attempts to maximize patient satisfaction using premium intraocular lenses; therefore, improving the accuracy of ocular biometrics has become increasingly important.

A popular device for noncontact ocular biometry is the IOLMaster 500 (Carl Zeiss AG, Jena, Germany), which was introduced in 1999 using partial coherence interferometry. This device can measure ocular biometric measurements such as AL, steep and flat K, ACD, white-to-white, and pupil diameter, and shows good agreement with the contact method (A-scan) using ultrasound [2,3]. After that, other optical devices using different principles have also been introduced to the market and have shown comparable or superior accuracy with the IOLMaster 500. The Lenstar LS 900 (Haag-Streit AG, Koeniz, Switzerland), which uses optical low-coherence reflectometry, and the OA-2000 (Tomey, Nagoya, Japan) [4], which uses low coherence interferometer and swept-source combined with a placido disc topography are widely used these days. Recently, the efficacy of ANTERION (Heidelberg Engineering, Heidelberg, Germany), which is equipped with two imaging devices, swept-source optical coherence tomography, and an infrared camera, has been reported and its compatibility with existing devices has been demonstrated [5-9]. However, no study has compared ANTERION with the OA-2000 biometer so far. Therefore, this study aimed to measure and compare ocular biometric values using ANTERION with OA-2000 and IOLMaster 500 in cataract patients. Furthermore, we compared the predicted intraocular lens power with various intraocular lens power calculating formulas using the three devices.

Materials and Methods

Ethics statement

This study was a single-center, prospective, observational study. The biometric values of patients aged >20 years who visited Ewha Womans University Hospital and were diagnosed with cataracts between February 2021 and March 2021 were analyzed. Patients with a history of ophthalmic surgery or ocular trauma, who used contact lenses, whose biometric measurements could not be made due to severe posterior capsular opacification or media opacification, and those with eye diseases that could interfere with fixation during examination were excluded from this study. All participants gave written informed consent. This study was approved by the Institutional Review Board of Ewha Womans University Medicine Center (No. 2021-01-022-003) and was conducted in accordance with the Declaration of Helsinki. This study is registered at the Clinical Research Information Service (No. KCT0006595). This research was reviewed by an independent ethical review board and conforms with the principles and applicable guidelines for the protection of human subjects in biomedical research.

Instruments

1) ANTERION

ANTERION measures the corneal curvature using 65 radial scans in the 3.0 mm zone with a 1,300 nm wavelength light source at a speed of 50,000 A-scans/sec based on the swept source optical coherence tomography principle. The aqueous depth was measured using tomographic images of the cornea autosegmented with swept-source optical coherence tomography. The current software provides the values of both the aqueous depth (distance from the corneal endothelium to the anterior surface of crystalline lens [10]) and central corneal thickness. Thus, the ACD was calculated by adding the two values. AL was evaluated by measuring the length from the anterior surface of the cornea to the retinal pigment epithelium.

2) OA-2000

The OA-2000 device projects onto the cornea at 256 points in each of the nine rings of the 5.5 mm zone using the placido disc-based tomography technique and measures the corneal curvature in the central corneal region of 2, 2.5, and 3 mm. OA-2000 uses 1,060 nm swept-source optical coherence tomography and measures the AL, central corneal thickness, ACD, and lens thickness parameters using the wavelength of 1060 nm swept-source laser. AL is evaluated by measuring the length from the anterior surface to the retinal pigment epithelium based on the optical low-coherence reflectometry principle [11].

3) IOLMaster 500

The corneal curvature was calculated by an array of six regular hexagons reflected from the corneal surface at a diameter of 2.3 mm. The IOLMaster 500 is based on the partial coherence interferometry principle; however, the device uses a different principle to measure the ACD. The ACD was measured by projecting a 0.7 mm wide slit-light beam at 30° and assessing the distance between the light reflection of the anterior corneal surface and anterior lens surface [12]. The IOLMaster 500 measures AL based on the partial coherence interferometry principle using a laser diode generating 780 nm infrared light of short-coherence light [13,14].

Patient examinations

A single experienced examiner performed all measurements. First, a conventional autorefractor/keratomtetr (AR/K; Nidek ARK-510A, Nidek, Gamagori, Japan), which exams four points at 3.3 mm diameter circle [15], was measured. Then, ocular biometrics were measured first using the IOLMaster 500, followed by ANTERION and the OA-2000 to obtain the flat K and steep K, ACD, and AL values in a dark room. Corneal astigmatism was analyzed by power vector analysis with Jackson cross-cylinder at 0° and 90° (J_0) and Jackson cross-cylinder at 45° and 135° (J_{45}) according to the following equation: J_0 = -(steep K - flat K) / 2 × cos2α, and J_{45} = -(steep K - flat K) / 2 × sin2α, where steep K, flat K, and α represent the steep keratometry, flat keratometry, and cylindrical axis, respectively [16]. J_0 is the vector component of astigmatism along the vertical meridian, while J_{45} represents oblique astigmatism.

The Tecnis ZCB00 intraocular lens (Johnson & Johnson Vision, Irvine, CA, USA) was used in the calculations for intraocular lens power, which becomes emmetropic when calculated using four formulas (SRK/T, Haigis, Barrett Universal II, and Kane). ANTERION and the OA-2000 provide the intraocular lens power calculated using the Barrett Universal II formula in the device, but the IOLMaster 500 does not provide the formula. Thus, the intraocular lens power using the Barrett Universal II of the IOLMaster 500 was calculated using a website (https://calc.apacrs.org/barrett_universal2105/; Asia Pacific Association of Cataract and Refractive Surgeons, Singapore). The intraocular lens power using the Kane formula was calculated using a website (https://www.iolformula.com/; Kane Formula) for all three devices.

Statistical analysis

Statistical analyses were performed using IBM SPSS ver. 20.0 (IBM Corp., Armonk, NY, USA). A p-value of less than 0.05 was considered statistically significant. A repeated measures analysis of variance was conducted to compare the mean measured values and predicted intraocular lens power among the three devices, and the Bonferroni correction was used for post hoc analysis. To compare keratometric values, the values measured by optical biometers were compared with that measured by the conventional AR/K device. Pearson correlation test was conducted to assess correlations, and a Bland-Altman plot was

Table 1. Mean, standard deviation, and range of keratometry, vector components of astigmatism, anterior chamber depth, and axial length using four devices

Variable	ANTERION	OA-2000	IOLMaster 500	AR/K	p-value*
Flat keratometry (D)	43.58 ± 1.39 (39.88 to 46.28)	43.83 ± 1.39 (39.99 to 46.30)	43.93 ± 1.47 (40.23 to 47.14)	43.87 ± 1.46 (40.25 to 46.75)	<0.001
Steep keratometry (D)	44.45 ± 1.22 (41.47 to 46.50)	44.77 ± 1.29 (41.67 to 47.54)	44.85 ± 1.30 (42.13 to 48.35)	44.66 ± 1.30 (41.50 to 47.25)	<0.001
J_0 (D)†	0.06 ± 0.39 (-0.80 to 1.57)	-0.09 ± 0.37 (-0.84 to 0.71)	0.04 ± 0.42 (-1.34 to 1.38)	0.02 ± 0.34 (-0.84 to 1.15)	0.200
J_{45} (D)†	-0.07 ± 0.36 (-1.19 to 0.61)	-0.01 ± 0.43 (-1.43 to 1.59)	0.06 ± 0.35 (-0.63 to 0.89)	-0.04 ± 0.34 (-1.09 to 0.76)	0.307
Anterior chamber depth (mm)	3.08 ± 0.38 (2.35 to 3.91)	3.05 ± 0.37 (2.30 to 3.83)	3.13 ± 0.39 (2.37 to 3.79)	-	0.001
Axial length (mm)	23.64 ± 1.33 (21.50 to 27.63)	23.64 ± 1.32 (21.51 to 27.62)	23.61 ± 1.32 (21.49 to 27.61)	-	<0.001

Values are presented as mean ± standard deviation (range). The four devices are ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), IOLMaster 500 (Carl Zeiss AG, Jena, Germany), and AR/K.
AR/K = autorefractor/keratometer; D = diopters; J_0 = Jackson cross-cylinder at 0° and 90°; J_{45} = Jackson cross-cylinder at 45° and 135°.
*Obtained from repeated measured analysis of variance test; †Vector components of astigmatism.

used to calculate the 95% limits of agreement (LoA). According to the clinical purpose of intraocular lens power calculation, the range of 95% LoA was defined as good agreement: the 95% LoA of K <1.0 diopters (D) [17], J_0 and J_{45} <1.0 D [18,19], ACD <0.4 mm [20-22], and AL <0.2 mm [1,23]. Finally, for predicted intraocular lens power, we defined a range of 95% LoA <1.0 D as clinically acceptable [24].

Results

A total of 54 participants were enrolled in this study; however, three were excluded from the study as the AL could not be measured using the IOLMaster 500 due to posterior subcapsular cataract (NO2NC2C1P2, NO3NC3C2P3, and NO2NC2C2P3 based on Lens Opacities Classification System III grade [25]) in the center of the

Table 2. Difference, agreement, and correlation of flat and steep keratometry, J_0, and J_{45} using the four devices

Variable	Mean difference ± SD	95% CI	95% LoA	*p*-value*	Pearson correlation (*p*-value)
Flat keratometry (D)					
ANTERION vs. OA-2000	-0.25 ± 0.22	-0.34 to -0.17	-0.68 to +0.18	<0.001	0.987 (<0.001)
ANTERION vs. IOLMaster 500	-0.35 ± 0.30	-0.47 to -0.24	-0.94 to +0.24	<0.001	0.979 (<0.001)
OA-2000 vs. IOLMaster 500	-0.10 ± 0.27	-0.21 to 0	-0.63 to +0.43	0.067	0.983 (<0.001)
AR/K vs. ANTERION	0.29 ± 0.32	+0.17 to +0.42	-0.34 to +0.93	<0.001	0.975 (<0.001)
AR/K vs. OA-2000	0.04 ± 0.32	-0.08 to +0.16	-0.59 to +0.67	>0.999	0.976 (<0.001)
AR/K vs. IOLMaster 500	-0.06 ± 0.32	-0.18 to +0.06	-0.69 to +0.57	>0.999	0.976 (<0.001)
Steep keratometry (D)					
ANTERION vs. OA-2000	-0.32 ± 0.24	-0.41 to -0.23	-0.78 to +0.15	<0.001	0.984 (<0.001)
ANTERION vs. IOLMaster 500	-0.40 ± 0.31	-0.52 to -0.28	-1.00 to +0.20	<0.001	0.973 (<0.001)
OA-2000 vs. IOLMaster 500	-0.08 ± 0.24	-0.17 to +0.01	-0.55 to +0.38	0.106	0.983 (<0.001)
AR/K vs. ANTERION	0.21 ± 0.28	+0.10 to +0.32	-0.34 to +0.75	<0.001	0.977 (<0.001)
AR/K vs. OA-2000	-0.11 ± 0.31	-0.23 to +0.01	-0.72 to +0.50	0.093	0.971 (<0.001)
AR/K vs. IOLMaster 500	-0.19 ± 0.34	-0.32 to -0.06	-0.86 to +0.48	0.001	0.965 (<0.001)
J_0 (D)†					
ANTERION vs. OA-2000	0.15 ± 0.60	-0.07 to +0.38	-1.02 to +1.32	0.420	-0.241 (0.088)
ANTERION vs. IOLMaster 500	0.03 ± 0.64	-0.22 to +0.27	-1.23 to +1.28	>0.999	-0.263 (0.063)
OA-2000 vs. IOLMaster 500	-0.13 ± 0.51	-0.33 to +0.07	-1.13 to +0.88	0.483	0.160 (0.261)
AR/K vs. ANTERION	-0.04 ± 0.59	-0.27 to +0.18	-1.19 to +1.11	>0.999	-0.289 (0.040)
AR/K vs. OA-2000	0.11 ± 0.48	-0.07 to +0.30	-0.83 to +1.05	0.578	0.110 (0.441)
AR/K vs. IOLMaster 500	-0.01 ± 0.47	-0.149 to +0.16	-0.93 to +0.90	>0.999	0.267 (0.058)
J_{45} (D)†					
ANTERION vs. OA-2000	-0.06 ± 0.55	-0.28 to +0.15	-1.14 to +1.01	0.420	0.042 (0.771)
ANTERION vs. IOLMaster 500	-0.14 ± 0.50	-0.33 to +0.05	-1.12 to +0.85	>0.999	-0.009 (0.951)
OA-2000 vs. IOLMaster 500	-0.07 ± 0.55	-0.29 to +0.14	-1.16 to +1.01	0.483	0.019 (0.894)
AR/K vs. ANTERION	0.03 ± 0.52	-0.17 to +0.23	-0.98 to +1.05	>0.999	-0.111 (0.438)
AR/K vs. OA-2000	-0.03 ± 0.64	-0.28 to +0.22	-1.29 to +1.23	0.578	-0.380 (0.006)
AR/K vs. IOLMaster 500	-0.11 ± 0.47	-0.29 to +0.08	-1.03 to +0.82	>0.999	0.053 (0.714)

The four devices are ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), IOLMaster 500 (Carl Zeiss AG, Jena, Germany), and AR/K.
SD = standard deviation; CI = confidence interval; LoA = limits of agreement; D = diopters; AR/K = autorefractor/keratometer; J_0 = Jackson cross-cylinder at 0° and 90°; J_{45} = Jackson cross-cylinder at 45° and 135°.
*Obtained from repeated measured analysis of variance test with Bonferroni post hoc analysis; †Vector components of astigmatism.

lens. Finally, 51 eyes from 51 participants were analyzed. The mean age of the participants was 67.2 years (range, 45 to 79 years). Among the total participants, 18 participants were male and 33 participants were female.

The average flat K measured using the ANTERION, the OA-2000, the IOLMaster 500, and the AR/K device was 43.58 ± 1.39, 43.83 ± 1.39, 43.93 ± 1.47, and 43.87 ± 1.46 D, respectively (Table 1). ANTERION yielded the flattest values, and there were significant differences in the values measured using ANTERION and the other devices ($p < 0.05$) (Table 2). Analysis of agreement indicated that ANTERION and the OA-2000 were interchangeable (95% LoA, 0.86 D) (Table 2 and Fig. 1A-1C). On the other hand, the IOLMaster 500 was shown to be not interchangeable with both ANTERION (95% LoA, 1.18 D) and the OA-2000 (95% LoA, 1.06 D). When comparing flat K values measured by the three devices with that measured by conventional AR/K device, all three optical biometers showed good correlations with the AR/K device (all $p > 0.9$), however, ANTERION showed significantly flatter flat K than that of the AR/K device ($p < 0.001$). In agreement analysis for flat K, all optical biometers were not considered interchangeable with the AR/K device (95% LoA ≥1.25 D) (Table 2).

The mean steep K measured using the ANTERION, the OA-2000, the IOLMaster 500, and the AR/K device was 44.45 ± 1.22, 44.77 ± 1.29, 44.85 ± 1.30, and 44.66 ± 1.30 D, respectively (Table 1). The value measured by ANTERION was the flattest, and there were significant differences in the values measured using ANTERION and the other devices ($p < 0.05$) (Table 2). Meanwhile, there was no significant difference between the steep K measured using the IOLMaster 500 and OA-2000 ($p = 0.053$). In terms of agreement, the OA-2000 was shown to be interchangeable with both ANTERION (95% LoA, 0.93 D) and the IOLMaster 500 (95% LoA, 0.93 D) (Table 2 and Fig. 1D-1F). When comparing the steep K values with that measured by the AR/K device, ANTREION showed significantly flatter steep K ($p < 0.001$) and IOLMaster 500 showed significantly steeper steep K than the AR/K device ($p = 0.001$) (Table 1). In an agreement analysis, steep K values measured by three optical biometers were not interchangeable with that measured by the AR/K device (95% LoA ≥1.09 D) (Table 2).

Regarding corneal astigmatism, the mean J_0 vector component of astigmatism obtained from the ANTERION, the OA-2000, the IOLMaster 500, and the AR/K device was

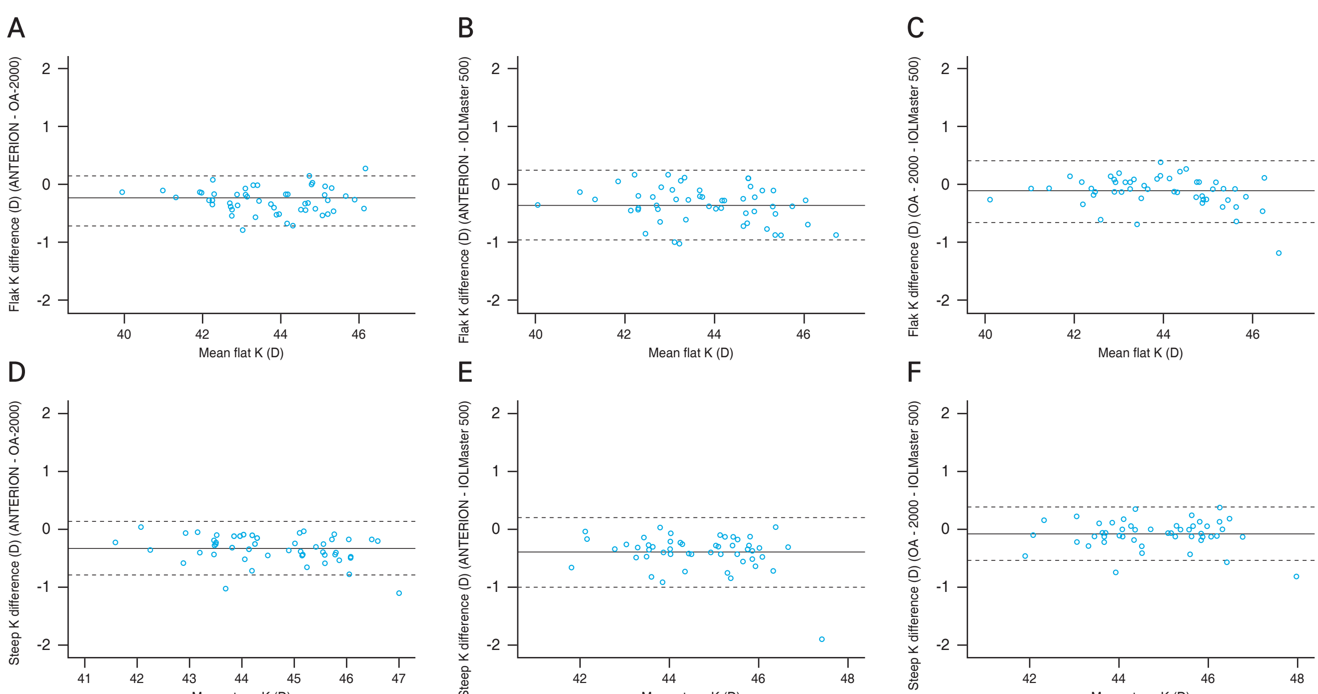

Fig. 1. Bland-Altman plots of (A-C) flat keratometry (K) and (D-F) steep K between ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), and IOLMaster 500 (Carl Zeiss AG, Jena, Germany). The mean (middle continuous line) and the lower and upper limits of agreement (±1.96 standard deviation, top and bottom dotted lines) are depicted. D = diopters.

0.06 ± 0.39, -0.09 ± 0.37, 0.04 ± 0.42, and 0.02 ± 0.34 D, respectively. The mean J_{45} vector component of astigmatism obtained from the ANTERION, the OA-2000, the IOLMaster 500, and the AR/K device was -0.07 ± 0.36, -0.01 ± 0.43, 0.06 ± 0.35, and -0.04 ± 0.34, respectively (Table 1). There were no significant differences in the J_0 (p = 0.200) and J_{45} (p = 0.307) vector components of astigmatism between the three devices (Table 1). However, the agreement analysis between the three devices revealed to be poor (95% LoA ≥1.97 D) (Table 2 and Fig. 2A-2F). All optical biometers showed no significant difference in J_0 and J_{45} with the AR/K device (all p > 0.05) yet showed poor agreements with the AR/K device (95% LoA ≥1.83 D) (Table 2).

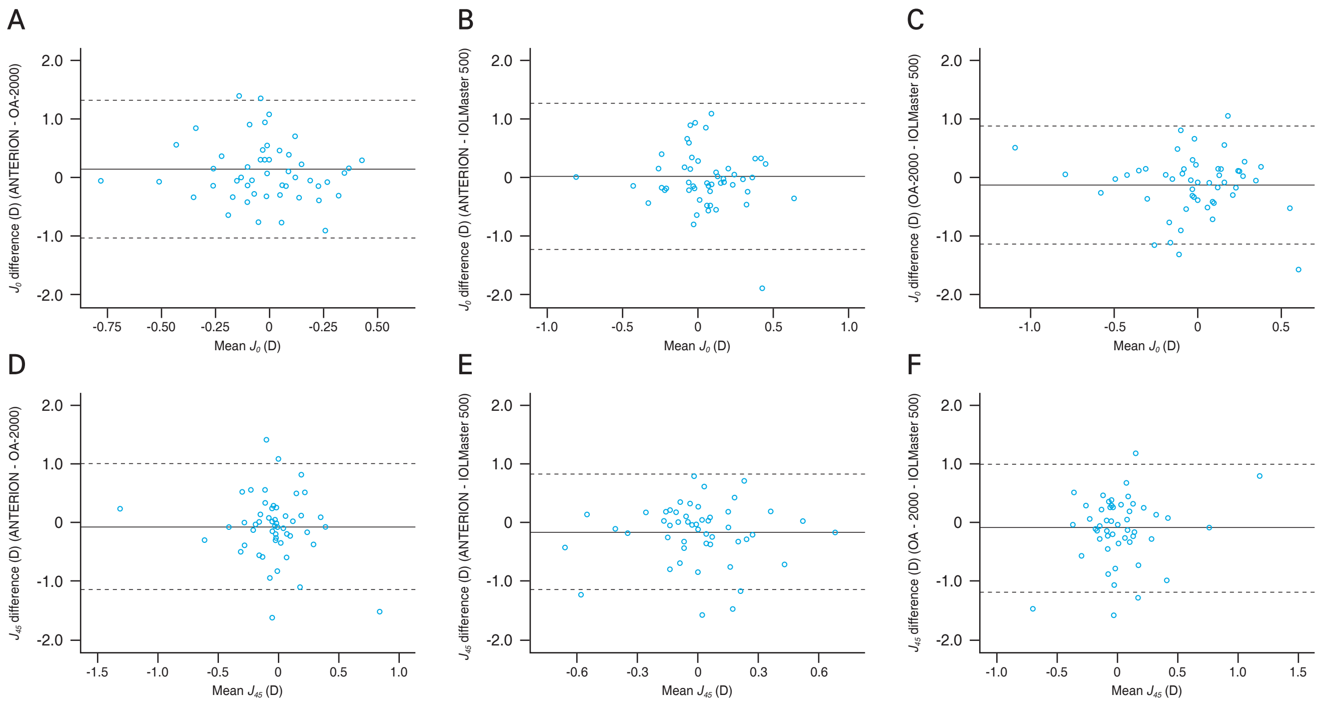

Fig. 2. Bland-Altman plots of vector component of astigmatism (A-C) Jackson cross-cylinder at 0° and 90° (J_0) and (D-F) Jackson cross-cylinder at 45° and 135° (J_{45}) between ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), and IOLMaster 500 (Carl Zeiss AG, Jena, Germany). The mean (middle continuous line) and the lower and upper limits of agreement (±1.96 standard deviation, top and bottom dotted lines) are depicted. D = diopters.

Table 3. Difference, agreement, and correlation of anterior chamber depth and axial length using the three devices

Variable	Mean difference ± SD	95% CI	95% LoA	p-value*	Pearson correlation (p-value)
Anterior chamber depth (mm)					
ANTERION vs. OA-2000	0.03 ± 0.04	+0.02 to +0.04	-0.05 to +0.11	<0.001	0.995 (<0.001)
ANTERION vs. IOLMaster 500	-0.05 ± 0.14	-0.10 to 0	-0.33 to +0.22	0.030	0.934 (<0.001)
OA-2000 vs. IOLMaster 500	-0.08 ± 0.15	-0.13 to -0.03	-0.37 to +0.20	0.001	0.927 (<0.001)
Axial length (mm)					
ANTERION vs. OA-2000	-0.01 ± 0.04	-0.02 to +0.01	-0.09 to +0.08	0.917	1.000 (<0.001)
ANTERION vs. IOLMaster 500	0.02 ± 0.04	0.01 to +0.04	-0.04 to +0.09	<0.001	1.000 (<0.001)
OA-2000 vs. IOLMaster 500	0.03 ± 0.02	0.02 to +0.04	-0.01 to +0.07	<0.001	1.000 (<0.001)

The three devices are ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), and IOLMaster 500 (Carl Zeiss AG, Jena, Germany).
SD = standard deviation; CI = confidence interval; LoA = limits of agreement.
*Obtained from repeated measured analysis of variance with Bonferroni post hoc analysis.

The mean ACD measured using the ANTERION, the OA-2000, and the IOLMaster 500 was 3.08 ± 0.38, 3.05 ± 0.74, and 3.13 ± 0.39, respectively (Table 1). There were significant differences among the measurements yielded by all devices (all $p < 0.05$) (Table 3). Good agreement was observed only between ANTERION and the OA-2000 (95% LoA, 0.15 mm) (Table 3 and Fig. 3A-3C).

The mean AL measured using ANTERION, the OA-2000, and the IOLMaster 500 was 23.64 ± 1.33, 23.64 ± 1.32, and 23.61 ± 1.32 mm, respectively (Table 1). There was no significant difference in the mean AL between the ANTERION and OA-2000 ($p = 0.917$). The AL of the IOLMaster 500 significantly differed from that of the other devices (all $p < 0.05$) (Table 3). However, the difference was

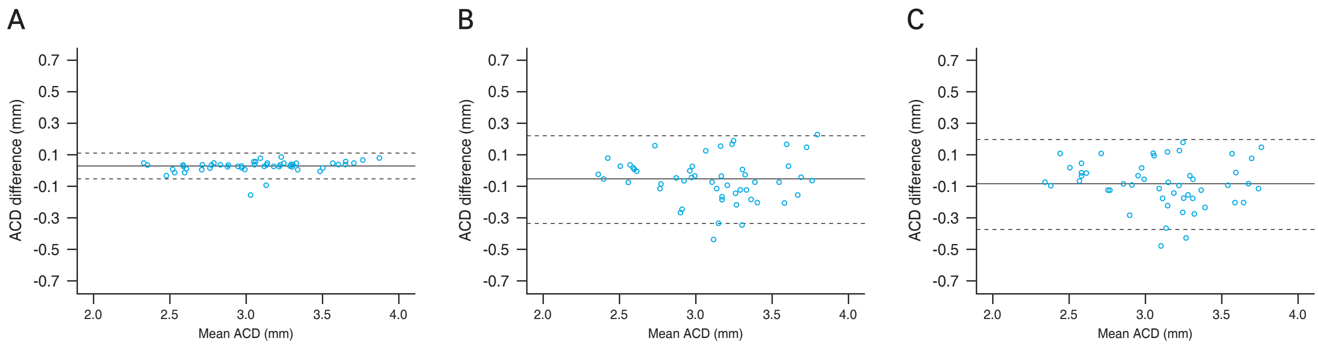

Fig. 3. Bland-Altman plots of anterior chamber depth (ACD) between (A) ANTERION (Heidelberg Engineering, Heidelberg, Germany) and OA-2000 (Tomey, Nagoya, Japan), (B) ANTERION and IOLMaster 500 (Carl Zeiss AG, Jena, Germany), and (C) OA-2000 and IOLMaster 500. The mean (middle continuous line), the lower and upper limits of agreement (±1.96 standard deviation, top and bottom dotted lines) are depicted.

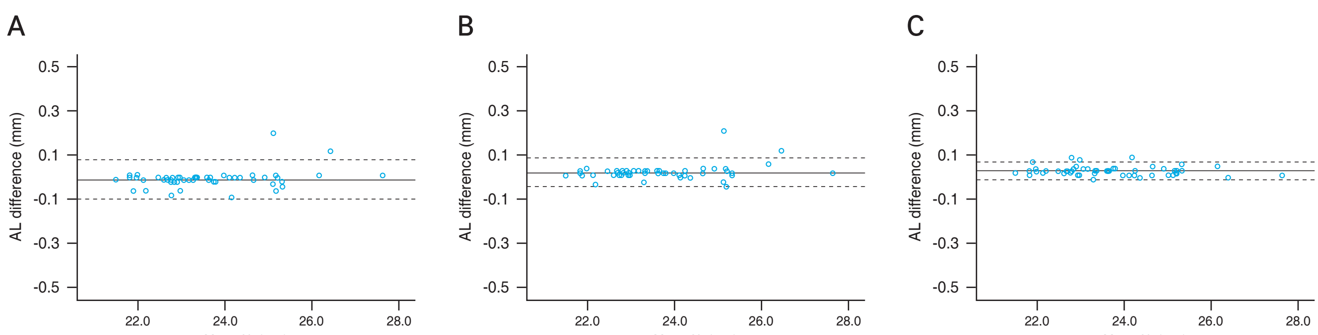

Fig. 4. Bland-Altman plots of axial length (AL) between (A) ANTERION (Heidelberg Engineering, Heidelberg, Germany) and OA-2000 (Tomey, Nagoya, Japan), (B) ANTERION and IOLMaster 500 (Carl Zeiss AG, Jena, Germany), and (C) OA-2000 and IOLMaster 500. The mean (middle continuous line), the lower and upper limits of agreement (±1.96 standard deviation, top and bottom dotted lines) are depicted.

Table 4. Mean, standard deviation, and range of predicted intraocular lens power using the three devices

Formula	ANTERION	OA-2000	IOLMaster 500	*p*-value*
SRK/T	20.80 ± 3.78 (10–27)	20.44 ± 3.78 (10–26)	20.46 ± 3.77 (10–26)	<0.001
Haigis	20.80 ± 3.76 (11–27)	20.41 ± 3.75 (10–26)	20.41 ± 3.70 (10–26)	<0.001
Barrett Universal II	20.71 ± 3.80 (11–27)	20.30 ± 3.81 (10–26)	20.33 ± 3.75 (10–26)	<0.001
Kane	21.12 ± 3.81 (11–27)	20.71 ± 3.82 (10–27)	20.76 ± 3.81 (10–27)	<0.001

Values are presented as mean ± standard deviation (range). The three devices are ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), and IOLMaster 500 (Carl Zeiss AG, Jena, Germany).
*Obtained from repeated measured analysis of variance test.

not clinically significant (range, 0.01 to 0.03 mm). Good agreement was observed among all devices with a narrow 95% LoA (≤0.17 mm) (Table 3 and Fig. 4A-4C).

Predicted intraocular lens powers, which becomes emmetropic using the SRK/T, Haigis, Barrett Universal II, and Kane formulas were compared (Table 4). The predicted intraocular lens power calculated by four formulas did not significantly differ between the OA-2000 and IOLMaster 500 ($p > 0.999$); however, the 95% LoA range was wide (1.24 to 1.70 D). The predicted intraocular lens power measured using ANTERION was approximately 0.34 to 0.40 D higher than that measured using the other devices ($p < 0.001$) (Table 5).

Discussion

This study compared ocular biometrics measured using the newest swept-source optical coherence tomography-based optical biometer, the ANTERION device, and the existing OA-2000 and IOLMaster 500 devices. The flat K and steep K were the flattest when measured by ANTERION, and the ACD was the deepest when measured by the IOLMaster 500. There was a high correlation between the measurements of all devices except the vector component of astigmatism; however, only the AL showed good agreement among all three devices. The predicted intraocular lens power, which was calculated using the SRK/T, Haigis, Barrett Universal II, and Kane formulas, did not significantly differ for all formulas between the IOLMaster 500 and OA-2000; however, the agreement was low. In addition, ANTERION demonstrated a higher predicted intraocular lens power than the other two devices.

In previous studies comparing OA-2000 and IOLMaster 500, mean K (95% LoA, -0.59 to +0.36 [26] or -0.97 to +1.03 D [27]), ACD (95% LoA, -0.58 to +0.39 [26] or -0.33 to +0.54 mm [27]), and AL (95% LoA, -0.16 to +0.05 [26] or -0.09 to +0.1 mm [27]) showed good agreement in 102 eyes of 68 patients with cataracts [26] and in 58 eyes of 58 patients with cataracts [27]. In contrast, studies comparing ANTERION and the IOLMaster 500 reported inconsistent agreements according to the studies. In a study of 48 eyes

Table 5. Difference, agreement, and correlation of predicted intraocular lens power using the three devices

Formula	Mean difference ± SD	95% CI	95% LoA	*p*-value*	Pearson correlation (*p*-value)
SRK/T					
ANTERION vs. OA-2000	0.36 ± 0.28	+0.26 to +0.46	-0.19 to +0.92	<0.001	0.997 (<0.001)
ANTERION vs. IOLMaster 500	0.34 ± 0.35	+0.22 to +0.47	-0.35 to +1.04	<0.001	0.996 (<0.001)
OA-2000 vs. IOLMaster 500	-0.02 ± 0.32	-0.13 to +0.09	-0.64 to +0.60	>0.999	0.997 (<0.001)
Haigis					
ANTERION vs. OA-2000	0.39 ± 0.34	+0.28 to +0.51	-0.27 to +1.05	<0.001	0.996 (<0.001)
ANTERION vs. IOLMaster 500	0.39 ± 0.42	+0.25 to +0.54	-0.42 to +1.21	<0.001	0.994 (<0.001)
OA-2000 vs. IOLMaster 500	0.00 ± 0.44	-0.15 to +0.15	-0.85 to +0.85	>0.999	0.993 (<0.001)
Barrett Universal II					
ANTERION vs. OA-2000	0.40 ± 0.26	+0.31 to +0.49	-0.12 to +0.92	<0.001	0.998 (<0.001)
ANTERION vs. IOLMaster 500	0.37 ± 0.43	+0.22 to +0.52	-0.48 to +1.22	<0.001	0.993 (<0.001)
OA-2000 vs. IOLMaster 500	-0.03 ± 0.35	-0.15 to +0.09	-0.72 to +0.66	>0.999	0.996 (<0.001)
Kane					
ANTERION vs. OA-2000	0.40 ± 0.32	+0.29 to +0.51	-0.22 to +1.02	<0.001	0.997 (<0.001)
ANTERION vs. IOLMaster 500	0.35 ± 0.40	+0.21 to +0.49	-0.44 to +1.14	<0.001	0.994 (<0.001)
OA-2000 vs. IOLMaster 500	-0.05 ± 0.39	-0.18 to +0.09	-0.81 to +0.72	>0.999	0.995 (<0.001)

The three devices are ANTERION (Heidelberg Engineering, Heidelberg, Germany), OA-2000 (Tomey, Nagoya, Japan), and IOLMaster 500 (Carl Zeiss AG, Jena, Germany).
SD = standard deviation; CI = confidence interval; LoA = limits of agreement.
*Obtained from repeated measured analysis of variance with Bonferroni post hoc analysis.

of 48 adults with or without cataracts, Chan et al. [22] compared the mean keratometry, vector components of astigmatism (J_0 and J_{45}), central corneal thickness, ACD, and AL. They reported that there were poor agreements in the mean keratometry, J_0, J_{45}, and the ACD: the 95% LoA for the mean keratometry, J_0, J_{45}, ACD, and AL was -0.588 to +0.357, -0.346 to +0.651, -0.398 to +0.485 D, -0.260 to +0.263, and -0.055 to +0.013 mm, respectively. In contrast, when comparing ANTERION, the MS-39 (Costruzione Strumenti Oftalmici, Florence, Italy), and the IOLMaster 500 in 96 eyes of 96 adults with or without cataracts, ANTERION and the MS-39 showed high agreement for simulated keratometry, posterior keratometry, central corneal thickness, and aqueous depth; and ANTERION and the IOLMaster 500 showed high agreement for simulated keratometry (95% LoA, -0.68 to +0.70 D), ACD (95% LoA, –0.50 to +0.57 mm), AL (95% LoA, -0.06 to +0.05 mm), and corneal diameter (95% LoA, -0.72 to +0.31 mm) [7]. Kim et al. [12] also reported that the flat K, steep K, J0, J45, ACD and AL exhibited good agreement (95% LoA, -1.18 to +0.83, -1.06 to +0.95, -0.60 to +0.73, -0.40 to +0.50 D, -0.14 to +0.26, and -0.15 to +0.21 mm, respectively) between ANTERION and the IOLMaster 500 in 175 eyes of 107 subjects aged 40 years or younger with clear lens or mild cataracts. One of the reasons for the discrepancies in previous studies may be because these previous studies interpreted the findings without defining the range of agreement. If clinical agreement for intraocular lens power calculation is defined as good agreement for 95% LoA of corneal curvature within 1.0 D when comparing ANTERION and IOLMaster 500, the range of 95% LoA in the previous study that reported high agreement (1.38 D [7]) can lead to an interpretation of low agreement in line with this study (95% LoA range steep K to flat K, 1.20 to 1.18 D). Likewise, the range of 95% LoA of flat K and steep K (2.01 and 2.01 D, respectively) in the study of Kim et al. [12] can be interpreted as low agreement.

A comparison of the ANTERION and the OA-2000 showed flatter corneal curvature for the ANTERION; however, the Bland-Altman plot showed good agreement between the two devices (95% LoA ≤0.93 D). The 95% LoA between the IOLMaster 500 and OA-2000 were 0.93 D for the steep K and 1.06 D for the flat K. The K between the two devices showed good or low agreement depending on the curvature. These differences may be caused by the different principles and ranges of K for each device.

In relation to J_0 and J_{45} vector components of astigmatism, this study revealed a wider 95% LoA range (2.51 and 1.97 D, respectively) than previous comparison studies (J_0 95% LoA range, 0.997 [22] and 1.33 D [12]; J_{45} 95% LoA range, 0.883 [22] and 0.90 D [12]) comparing the ANTERION with the IOLMaster 500. The agreements for the J_0 and J_{45} vector components measured using the three devices (1.83 ≤ 95% LoA ≤ 2.52) were relatively poorer than that for cylinder power (1.10 ≤ 95% LoA ≤ 1.53) (Table 2 and Supplementary Table 1). Thus, the lower agreement of devices regarding astigmatic vector components could be due to the corneal cylinder orientation rather than cylinder power. These findings might have occurred because of the relatively poor repeatability and reliability of the axis measurements performed using the devices [15,28]. This outcome should be considered when planning cataract surgery with toric intraocular lens implantation, considering preoperative astigmatism and postoperative residual astigmatism would affect visual function and vision-related quality of life [29].

For ACD, a measurement error of 0.1 mm causes a refractive error of 0.15 D [30], and a 95% LoA range corresponding to 20% of the mean ACD may be too broad for clinical purposes such as intraocular lens power calculation [20]. In this study, the ACD measured using the IOLMaster 500 was significantly deeper than that measured using ANTERION or the OA-2000 and showed low agreement (95% LoA ≥0.55 mm). Additionally, the ANTERION and the OA-2000 (95% LoA, 0.15 mm) showed good agreement for the measurement of ACD. Using the same criteria (95% LoA <0.4 mm) as our study, the results of all previous studies comparing ACD between the IOLMaster 500 and ANTERION (95% LoA, 0.4 [12], 0.52 [22], and 1.07 mm [7]) or the IOLMaster 500 and the OA-2000 (95% LoA, 0.87 [27] and 0.97 mm [26]) can be interpreted as low agreement, as observed in this study. As suggested by Elbaz et al. [20] and Chan et al. [22], the IOLMaster 500 cannot measure the axial ACD, as this device measures the ACD with a slit source projected from the temporal side, which would have led to deeper ACD measurements compared to other devices.

In this study, AL was the only variable that showed a high correlation and good agreement among all devices (all 95% LoA ≤0.17 mm). The IOLMaster 500 and OA-2000 showed the narrowest 95% LoA (0.08 mm) and the highest agreement. This was a narrower range than that reported in previous studies (0.21 [26] and 0.19 mm [27]). Among the studies that compared ANTERION and the IOLMaster 500, the range of 95% LoA was the widest (0.36 mm) in the study by Kim et al. [12], and this may be attributed to the participants of that study, which included children aged five years or older with poor cooperation.

The major limitation of the IOLMaster 500 is its high failure rate (38%) in the acquisition of AL in dense cataract or posterior subcapsular cataracts [31]. In a study by McAlinden et al. [23], the IOLMaster 500 showed a failure rate of 36.07%, whereas the OA-2000 demonstrated a failure rate of 0%. Three participants in this study were excluded from the analysis because the AL could not be measured using IOLMaster 500 due to posterior subcapsular cataract, whereas the AL of these three patients could be measured using the OA-2000 and ANTERION. This may be attributed to the longer wavelength of the OA-2000 and ANTERION (1,060 and 1,300 nm, respectively) for the measurement of AL compared with the IOLMaster 500 (780 nm), which increases penetration [23].

As for intraocular lens power calculation, no other study has compared the predicted intraocular lens power between ANTERION and other devices to date. Shetty et al. [21,32] reported a high intraclass correlation coefficient (≥0.977) of predicted intraocular lens powers in ANTERION, Lenstar LS 900, and IOLMaster 700 (Carl Zeiss AG). Kongsap [26] assessed intraocular lens power using the SRK/T formula derived from the OA-2000 and the IOLMaster 500 and reported similar intraocular lens power derived from both instruments (mean difference of 0.32 D), with an excellent correlation (r = 0.989) in cataract patients. In this study, various intraocular lens formulas (SRK/T, which is a third-generation formula [33], Haigis, which is a fourth generation formula [2], and the Barrett Universal II [34] and Kane formulas [35], which are fifth generation formulas with very high accuracy that have been introduced most recently) were used to calculate the predicted intraocular lens power in the three devices. Regardless of the formula, the predicted intraocular lens powers of ANTERION were significantly higher (0.34 and 0.40 D, respectively) than that of the other devices ($p < 0.001$). Additionally, agreement analysis revealed that ANTERION is clinically not interchangeable with other devices (95% LoA ≥1.04 D). Even though the power of most intraocular lens is 0.5 D increments, this difference may cause the postoperative refractive error to be more myopic. There was no significant difference in the predicted intraocular lens power between the IOLMaster 500 and OA-2000; however, the 95% LoA range was also wide (≥1.04 D). Considering that every 1.0 D error of the predicted intraocular lens power leads to 0.67 D of refractive errors [1], it would be difficult to conclude that the calculated intraocular lens powers of the devices are interchangeable.

The limitations of this study are as follows. The sample size was small, and those with a flat K (<41.0 D), steep K (>48.5 D), short AL (<22.0 mm), and long AL (>26.0 mm) were not included. It will be necessary to study such patients as well as a larger number of participants with various conditions, such as patients with corneal opacity or postrefractive surgery patients. In addition, analyzing the difference between the predicted target refraction using the predicted intraocular lens power and the postoperative measured refractive error would provide additional information for the comparison of ocular biometric measurements.

In conclusion, this study is the first to compare ocular biometrics measured using ANTERION, OA-2000, and IOLMaster 500 in eyes with cataracts. Each biometric differed significantly according to the device used. The flat K, steep K, J_0, J_{45}, and ACD, except AL, exhibited low agreement among the devices. The low agreements were also observed in the predicted intraocular lens power among the devices.

Supplementary Materials

Supplementary Table 1. Difference, agreement, and correlation of cylinder power using the four devices

Supplementary materials are available from: https://doi.org/10.334/kjo.2022.0017.

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References

1. Olsen T. Calculation of intraocular lens power: a review. *Acta Ophthalmol Scand* 2007;85:472-85.
2. Haigis W, Lege B, Miller N, Schneider B. Comparison of immersion ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to Haigis. *Graefes Arch Clin Exp Ophthalmol* 2000;238:765-73.
3. Lam AK, Chan R, Pang PC. The repeatability and accuracy of axial length and anterior chamber depth measurements from the IOLMaster. *Ophthalmic Physiol Opt* 2001;21:477-83.
4. Goebels S, Pattmoller M, Eppig T, et al. Comparison of 3 biometry devices in cataract patients. *J Cataract Refract Surg* 2015;41:2387-93.
5. Chan PP, Lai G, Chiu V, et al. Anterior chamber angle imaging with swept-source optical coherence tomography: comparison between CASIAII and ANTERION. *Sci Rep* 2020;10:18771.
6. Tana-Rivero P, Aguilar-Corcoles S, Tello-Elordi C, et al. Agreement between 2 swept-source OCT biometers and a Scheimpflug partial coherence interferometer. *J Cataract Refract Surg* 2021;47:488-95.
7. Schiano-Lomoriello D, Hoffer KJ, Abicca I, Savini G. Repeatability of automated measurements by a new anterior segment optical coherence tomographer and biometer and agreement with standard devices. *Sci Rep* 2021;11:983.
8. Oh R, Oh JY, Choi HJ, et al. Comparison of ocular biometric measurements in patients with cataract using three swept-source optical coherence tomography devices. *BMC Ophthalmol* 2021;21:62.
9. Fisus AD, Hirnschall ND, Findl O. Comparison of 2 swept-source optical coherence tomography-based biometry devices. *J Cataract Refract Surg* 2021;47:87-92.
10. Hoffer KJ. Definition of ACD. *Ophthalmology* 2011;118:1484.
11. Goto S, Maeda N, Noda T, et al. Comparison of composite and segmental methods for acquiring optical axial length with swept-source optical coherence tomography. *Sci Rep* 2020;10:4474.
12. Kim KY, Choi GS, Kang MS, Kim US. Comparison study of the axial length measured using the new swept-source optical coherence tomography ANTERION and the partial coherence interferometry IOL master. *PLoS One* 2020;15:e0244590.
13. Hua Y, Qiu W, Xiao Q, Wu Q. Precision (repeatability and reproducibility) of ocular parameters obtained by the Tomey OA-2000 biometer compared to the IOLMaster in healthy eyes. *PLoS One* 2018;13:e0193023.
14. Santodomingo-Rubido J, Mallen EA, Gilmartin B, Wolffsohn JS. A new non-contact optical device for ocular biometry. *Br J Ophthalmol* 2002;86:458-62.
15. Hashemi H, Heydarian S, Khabazkhoob M, et al. Keratometry in children: comparison between auto-refractokeratometer, rotating scheimpflug imaging, and biograph. *J Optom* 2019;12:99-110.
16. Thibos LN, Wheeler W, Horner D. Power vectors: an application of Fourier analysis to the description and statistical analysis of refractive error. *Optom Vis Sci* 1997;74:367-75.
17. Hashemi H, Heydarian S, Ali Yekta A, et al. Agreement between Pentacam and handheld Auto-Refractor/Keratometer for keratometry measurement. *J Optom* 2019;12:232-9.
18. Beato JN, Esteves-Leandro J, Reis D, et al. Agreement between IOLMaster 500 and Pentacam HR for keratometry assessment in type 2 diabetic and non-diabetic patients. *Int J Ophthalmol* 2020;13:920-6.
19. Liao X, Peng Y, Liu B, et al. Agreement of ocular biometric measurements in young healthy eyes between IOLMaster 700 and OA-2000. *Sci Rep* 2020;10:3134.
20. Elbaz U, Barkana Y, Gerber Y, et al. Comparison of different techniques of anterior chamber depth and keratometric measurements. *Am J Ophthalmol* 2007;143:48-53.
21. Shetty N, Kaweri L, Koshy A, et al. Repeatability of biometry measured by three devices and its impact on predicted intraocular lens power. *J Cataract Refract Surg* 2021;47:585-92.
22. Chan TC, Yu MC, Chiu V, et al. Comparison of two novel swept-source optical coherence tomography devices to a partial coherence interferometry-based biometer. *Sci Rep* 2021;11:14853.
23. McAlinden C, Wang Q, Gao R, et al. Axial length measurement failure rates with biometers using swept-source optical coherence tomography compared to partial-coherence interferometry and optical low-coherence interferometry. *Am J Ophthalmol* 2017;173:64-9.
24. Jasvinder S, Khang TF, Sarinder KK, et al. Agreement analysis of LENSTAR with other techniques of biometry. *Eye (Lond)* 2011;25:717-24.
25. Chylack LT Jr, Wolfe JK, Singer DM, et al. The lens opacities classification system III. The Longitudinal Study of Cataract Study Group. *Arch Ophthalmol* 1993;111:831-6.
26. Kongsap P. Comparison of a new optical biometer and a

standard biometer in cataract patients. *Eye Vis (Lond)* 2016;3:27.

27. Ghaffari R, Mahmoudzadeh R, Mohammadi SS, et al. Assessing the validity of measurements of swept-source and partial coherence interferometry devices in cataract patients. *Optom Vis Sci* 2019;96:745-50.
28. Xiong S, Lv M, Zou H, et al. Comparison of refractive measures of three autorefractors in children and adolescents. *Optom Vis Sci* 2017;94:894-902.
29. Anderson DF, Dhariwal M, Bouchet C, Keith MS. Global prevalence and economic and humanistic burden of astigmatism in cataract patients: a systematic literature review. *Clin Ophthalmol* 2018;12:439-52.
30. Norrby S. Sources of error in intraocular lens power calculation. *J Cataract Refract Surg* 2008;34:368-76.
31. McAlinden C, Wang Q, Pesudovs K, et al. Axial length measurement failure rates with the IOLMaster and Lenstar LS 900 in eyes with cataract. *PLoS One* 2015;10:e0128929.
32. Shetty R, Arora V, Jayadev C, et al. Repeatability and agreement of three Scheimpflug-based imaging systems for measuring anterior segment parameters in keratoconus. *Invest Ophthalmol Vis Sci* 2014;55:5263-8.
33. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens implant power calculation formula. *J Cataract Refract Surg* 1990;16:333-40.
34. Melles RB, Holladay JT, Chang WJ. Accuracy of intraocular lens calculation formulas. *Ophthalmology* 2018;125:169-78.
35. Connell BJ, Kane JX. Comparison of the Kane formula with existing formulas for intraocular lens power selection. *BMJ Open Ophthalmol* 2019;4:e000251.