ARTICLE

Repeatability of automatic measurements by a new anterior segment optical coherence tomographer combined with Placido topography and agreement with 2 Scheimpflug cameras

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Purpose: To evaluate the repeatability of automatic measurements by a new anterior segment optical coherence tomographer (AS-OCT) combined with Placido topography and their agreement with those provided by 2 rotating Scheimpflug cameras.

Setting: G.B. Bietti Foundation IRCCS, Rome, Italy.

Design: Evaluation of a diagnostic test instrument.

Methods: Unoperated eyes and eyes with previous myopic excimer laser surgery were analyzed. Three consecutive scans were acquired with an AS-OCT device (MS-39) and 1 with 2 rotating Scheimpflug cameras (Pentacam HR and Sirius). The following parameters were evaluated: simulated keratometry, posterior and total corneal power, total corneal astigmatism, corneal asphericity, thinnest corneal thickness, central epithelial thickness, corneal diameter, and aqueous depth. Repeatability was assessed using test–retest variability, the coefficient of variation (CoV), and the intraclass correlation coefficient; agreement was assessed by the 95% limits of agreement.

Results: The study comprised 96 unoperated eyes and 43 eyes with previous myopic excimer laser surgery. High repeatability was achieved in both groups, as shown by a CoV less than 1.0% for most parameters. The repeatability of epithelial thickness was slightly lower than that of the whole corneal thickness, although the CoV was still good (1.87% in unoperated eyes; 3.28% in post-refractive surgery eyes). Moderate repeatability was found for total corneal astigmatism measurements, with a CoV greater than 20.0%. Agreement with Scheimpflug cameras was high for aqueous depth and thinnest corneal thickness and moderate for most other parameters.

Conclusion: The high repeatability of automatic measurements by the new AS-OCT device supports its use in clinical practice.

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Imaging of the anterior segment of the eye has undergone an impressive evolution over the past 15 years. The introduction of scanning-slit topography first and Scheimpflug technology later has allowed clinicians to obtain new information about their patients. They can measure posterior and total corneal astigmatism to plan toric intraocular lens (IOL) implantation,[1–10] use elevation maps of the anterior and posterior corneal surface, and pachymetric maps to detect keratoconus and ectasia,[11–14] calculate total corneal power (TCP) by ray tracing to calculate IOL power after corneal refractive surgery,[15] and apply corneal densitometry in the follow-up of eyes after refractive surgery.[16]

On the other hand, one of the main limitations of Scheimpflug imaging is the low resolution and poor quality of anterior segment scans. In this regard, anterior segment optical coherence tomography (AS-OCT) is known to produce better images with higher definition (Figure 1). The first commercially available AS-OCT device was a time-domain instrument, the Visante (Carl Zeiss Meditec AG), which uses a 1310 nm infrared light wavelength and could obtain no more than 4 simultaneous radial cross-sectional

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scans of the anterior segment.[17] To generate corneal maps, it was later combined with Placido corneal topography (Visante Omni).[18–21] Subsequently, the RTVue-100 (Optovue, Inc.), which relied on spectral-domain OCT (SD-OCT) and a shorter wavelength centered at 830 nm, was introduced.[22] The current version (Cornea Advance, Optovue, Inc.) is able to acquire 8 evenly spaced 6.0 mm radial cross-sections of the anterior segment and provide users with corneal and pachymetric maps. Until now, a greater number of radial scans could be acquired only by the Casia SS-1000 and subsequently by the Casia 2 (Tomey Corp.), both of which use SD-OCT and a 1310 nm light source. These 2 devices acquire 16 radial B-scans centered on the corneal vertex, each of them 10.0 mm long and 6.0 mm deep, to generate corneal curvature and thickness maps.[23]

The purpose of this study was to evaluate the repeatability of automatic measurements provided by a new AS-OCT device combined with Placido corneal topography (MS-39, CSO) and assess their agreement with those of the corresponding measurements taken with a rotating Scheimpflug camera (Pentacam HR, Oculus Optikgeräte GmbH) and a rotating Scheimpflug camera combined with Placido disk topography (Sirius, Costruzione Strumenti Oftalmici).

PARTICIPANTS AND METHODS

This prospective comparative study enrolled patients with healthy unoperated corneas and those who had corneal refractive surgery performed using an excimer laser. The study was performed in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and approved by the G.B. Bietti Foundation IRCCS Clinical Research Ethics Committee. All patients provided informed consent.

Exclusion criteria were the presence of keratoconus or suspect keratoconus as shown by 1 or both Scheimpflug cameras,[11,12] a previous diagnosis of dry eye, a history of corneal disease or trauma, any kind of ocular surgery, and contact lens use in the past month. One eye of each patient was randomly selected.

Instruments

The MS-39 (software version 3.6) uses SD-OCT and Placido-disk corneal topography to obtain measurements of the anterior segment of the eye. After autocalibration, the scanning process acquires (in approximately 1 second) 1 Placido top-view image and a series of 25 SD-OCT radial scans at a wavelength of 840 nm, with an axial resolution of 3.5 nm, a transverse resolution of 35 nm, and a maximum depth of 7.5 mm. Each scan is 16.0 mm long and includes 1024 A-scans. The ring edges are detected on the Placido image so that height, slope, and curvature data can be calculated using the arc-step method with conic curves. Profiles of the anterior cornea, posterior cornea, anterior lens, and iris are derived from the SD-OCT scans. Data for the anterior surface from the Placido image and SD-OCT scans are merged using a proprietary method. All other measurements for internal structures (posterior cornea, anterior lens, and iris) are derived solely from SD-OCT data.

The Pentacam HR (software version 1.20r10) is a rotating Scheimpflug camera. Scans were taken in the automatic release mode, and the 25-picture scan was used.

The Sirius (software version 3.2) combines a single rotating Scheimpflug camera and a Placido disk corneal topographer. The scanning process acquires a series of 25 Scheimpflug images (meridians) and 1 Placido top-view image. Technical details have been described.[24]

Measurement Procedures

The 3 instruments were used according to the manufacturers' guidelines in a random order. Each device was brought into focus, and the patient's eye was aligned along the visual axis with a central fixation light. The patients were instructed to blink completely just before each measurement, and no eyedrops were applied before testing.

With the AS-OCT device, 3 repeated consecutive measurements were taken by the same experienced examiner (G.S.) to assess repeatability. The patients were asked to sit back after each measurement, and the device was realigned before the subsequent measurement. All measurements were taken between 10 AM and 4 PM to minimize diurnal change and had to display good quality according to the instrument software or be repeated.

With the rotating Scheimpflug camera and the Scheimpflug camera–Placido topographer, only 1 measurement was acquired if the quality specification was OK; otherwise, the measurement

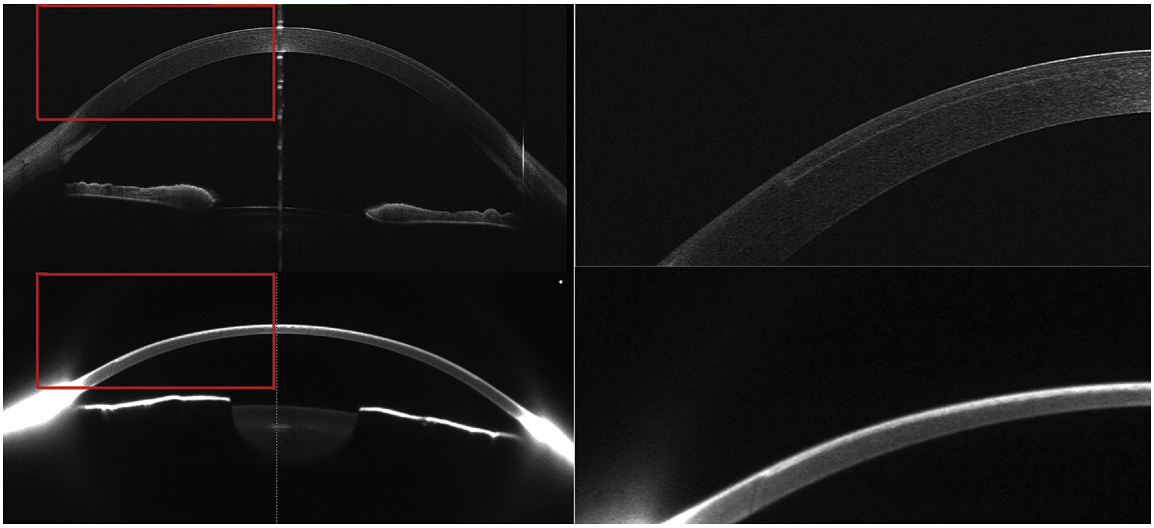

Figure 1. Horizontal section of a cornea with previous femtosecond laser in situ keratomileusis. *Top*: Anterior segment optical coherence tomography allows visualization of the flap edge and interface (*left*: whole-eye section; *right*: section of the cornea inside the *red box*). *Bottom*: With the Scheimpflug camera, the flap cannot be visualized.

was repeated until a good quality scan, as indicated by the instrument, was available. The starting sequence of the devices was drawn at random.

Measured Parameters

The following automatic measurements by the AS-OCT device were evaluated in this study:

- *Simulated keratometry (K)*. This value is obtained from the arithmetic mean of the curvature radii (in mm) of the flattest and steepest anterior corneal meridians. For each meridian, the radii are calculated by averaging the axial curvature from the fourth to the eighth Placido rings, which correspond to a diameter between 2.5 mm and 4.0 mm in the average eye. (The diameter is slightly larger in flat corneas and smaller in steep corneas.) The curvature is converted in keratometric diopters (D) using the standard keratometric index of 1.3375.
- *Posterior corneal curvature*. This value is the arithmetic mean of the corneal radii of the pair of meridians 90 degrees apart with the greatest and least curvature in the 3.0 mm zone of the posterior corneal surface. The conversion from the curvature (mm) into power (diopters [D]) is performed by using the refractive indices of the cornea (1.376) and the aqueous humor (1.336.)
- *Total corneal power*. This value (defined as the mean pupil power) is the total power of the cornea obtained by ray tracing through its anterior and posterior surfaces and a 3.0 mm diameter entrance pupil. The angle of refraction of incoming parallel rays is calculated using Snell's law and the following indices of refraction: 1.000 for air, 1.376 for cornea, and 1.336 for aqueous.
- *Total corneal astigmatism (TCA)*. This value, obtained over a 3.0 mm diameter area centered on the pupil, was analyzed with and without vector analysis. With the former approach, the polar value along the zero-degree meridian, defined as the **KP(0)** vector, and the polar value along the 45-degree meridian, defined as the **KP(45)** vector, were calculated.[25] When vector analysis was not performed, only magnitude was evaluated.
- *Corneal asphericity*. This measurement is expressed as the asphericity (Q) values of the anterior and posterior corneal surfaces in the 8.0 mm zone. The Q value is zero when the curve is a circle, lies between -1 and zero when the curve is a prolate ellipse, and is higher than zero when the curve is an oblate ellipse.
- *Corneal diameter and thinnest corneal thickness.*
- *Epithelial thickness*. The instrument automatically calculates the epithelial thickness in the 8.0 mm zone and provides measurements over 25 sectors. The present study evaluated the central reading over an area of 3.0 mm and the 4 paracentral measurements (nasal, temporal, superior, and inferior), with a diameter between 3.0 mm and 6.0 mm.
- *Aqueous depth.* This is the axial distance between the corneal endothelium and the anterior surface of the lens.

With the exception of central epithelial thickness, the corresponding values provided by the rotating Scheimpflug camera and the Scheimpflug camera–Placido topographer were analyzed to assess agreement. With the Scheimpflug camera–Placido topographer, the "adjusted corneal diameter" setting was selected.

STATISTICAL ANALYSIS

In the present study, the term *repeatability* was used according to the definition of the International Organization for Standardization,[26] which considers it a part of accuracy. Accuracy includes trueness and precision. Trueness is the inverse of bias and is obtained by comparing the measurement result with the accepted reference (conventional true) value. Precision is the inverse of statistical uncertainty and is normally expressed in terms of the standard deviation (SD). The factors involved include (1) the operator, (2) the equipment used, (3) the equipment calibration, (4) the environment, and (5) the elapsed time between measurements. Precision has 2 conditions: (1) repeatability and (2) reproducibility. Under repeatability conditions, factors such as 1 to 5 are considered constant and do not contribute to the variability of the measurement result. Under reproducibility conditions, those factors can vary. Repeatability and reproducibility are the 2 extremes of precision.

Repeatability was assessed on the basis of intrasession test–retest variability, the coefficient of variation (CoV), and the intraclass correlation coefficient (ICC). The following methods were used:

- *Intrasession test–retest variability*. Also known as repeatability or limits of repeatability, this was calculated by multiplying the pooled within-participant SD by 2.77.[27] On the basis of repeatability, it can be expected that the difference between 2 measurements for the same participant will be less than 2.77 within-participant for 95% of pairs of observations.
- *Coefficient of variation*. This was calculated as the within-participant divided by the mean of the measurements and expressed as a percentage. The CoV was not calculated for parameters with both positive values and negative values; for example, **KP(0)** and **KP(45)**.[28]
- *Intraclass correlation coefficient*. This is defined as the ratio of the between-subjects variance to the sum of the pooled within-subject variance and the between-subjects variance. The ICC, which approaches 1.0 when there is no variance between repeated measurements, was automatically calculated using SPSS software (version 22, IBM Corp.) with the 2-way mixed model and absolute agreement. Intraclass correlation coefficients ranging from 0 to 1 are commonly classified as follows: ICC less than 0.75 = poor agreement; ICC 0.75 to less than 0.90 = moderate agreement; ICC 0.90 and more = high agreement.[29]

The level of agreement between the 3 instruments was evaluated according to the method described by Bland and Altman,[30] who suggested plotting the differences between measurements (y-axis) against their mean (x-axis). Bland and Altman plots allowed an assessment of the existence of any systematic difference between measurements (ie, fixed bias). The mean difference is the estimated bias, and the SD of the differences measures the random fluctuations around this mean. The 95% limits of agreement (LoA) were defined as means $\pm$1.96 SD of the differences between the 2 measurement techniques. In addition, repeated-measures analysis of variance with a Bonferroni multiple-comparison post hoc test was used to compare the mean values measured by the 3 devices; with the AS-OCT-Placido topographer, only the first scan was used for this purpose. Finally, the tolerance index was calculated as described by Bergin et al.[31] This index was developed to assess whether the 95% LoA (interdevice noise) are wider than the limits of repeatability (intradevice noise). The tolerance index is computed as the log of the ratio between the LoA and the limits of repeatability. Two devices can be considered interchangeable if the tolerance index is smaller than the cutoff values shown in Table 1 in the paper by Bergin et al.[31] (ie, 0.27 for a sample of 40 eyes and 0.18 for a sample of 100 eyes).

The sample size was calculated to yield a minimum 15% confidence in the estimate. According to McAlinden et al.,[32] this means that at least 43 eyes had to be enrolled in each group.

RESULTS

The study enrolled 96 participants (mean age 46.5 years ± 16.5 [SD], range 18 to 83 years; 50 women) in the unoperated group and 43 patients (mean age 40.2 ± 10.1 years, range 24 to 69 years; 24 men) in the post-refractive surgery group. In the latter group, 37 eyes had myopic photorefractive keratectomy or laser in situ keratomileusis (LASIK) and 6 eyes had hyperopic LASIK.

Table 1 shows the test–retest repeatability, CoV, and ICC for the parameters measured by the AS-OCT device as well as by the Scheimpflug cameras. A CoV of less than 1.0% was obtained for most parameters in both groups of eyes and the ICC was more than 0.90 with all parameters, indicating excellent repeatability. The repeatability of central epithelial thickness measurements was slightly lower than that of whole corneal thickness measurements, although the CoV was still good. The repeatability of the 4 paracentral measurements was similar, with CoVs ranging between 1.95%

Table 1. Repeatability analysis of the measurements provided by AS-OCT combined with Placido corneal topography and comparison to the corresponding values given by different Scheimpflug cameras.

	Test–Retest Repeatability ($2.77\ S_w$)		Coefficient of Variation (%)		Intraclass Correlation Coefficient	
Parameter	Unoperated	P-RS	Unoperated	P-RS	Unoperated	P-RS
Simulated K (D)	0.20	0.25	0.16	0.22	0.999	1.000
Dual Scheimpflug analyzer (G2 version)[33]	0.27	—	0.23	—	0.991	—
Dual Scheimpflug analyzer (G4 version)[35]	—	—	0.16	0.19	0.998	—
Rotating Scheimpflug camera[33,34]	0.17	—	0.14	—	0.996	—
Scheimpflug camera–Placido topographer[24]	0.29	0.34	0.24	0.32	0.994	0.993
Posterior K (D)	0.07	0.05	0.39	0.28	0.997	0.999
Dual Scheimpflug analyzer (G2 version)[33]	0.07	—	0.35, 0.40	—	0.989, 0.998	—
Dual Scheimpflug analyzer (G4 version)[35]		—	0.40	0.32	0.992	0.990
Rotating Scheimpflug camera[33]	0.06	—	0.34	—	0.992	—
Scheimpflug camera–Placido topographer[24]	0.05	0.05	0.30	0.31	0.993	0.993
Total corneal power (D)	0.27	0.26	0.22	0.24	0.999	1.000
Dual Scheimpflug analyzer (G2 version)[33]	0.34	—	0.30	—	0.985	—
Dual Scheimpflug analyzer (G4 version)[35,41]		—	0.20, 0.21	0.21	0.996, 0.997	0.998
Rotating Scheimpflug camera[33]	0.14	—	0.11	—	0.998	—
Scheimpflug camera–Placido topographer[24]	0.34	0.45	0.28	0.43	0.992	0.991
TCA magnitude (D)	0.52	0.43	22.08	20.20	0.961	0.949
Dual Scheimpflug analyzer (G2 version)[33]	0.12	—	17.27	—	0.913	—
Dual Scheimpflug analyzer (G4 version)[35,41]	—	—	18.77, 28.16	24.18	0.811, 0.910	0.898
KP(0) vector	0.62	0.24	NA	NA	0.975	0.963
KP(45) vector	0.48	0.27	NA	NA	0.950	0.914
Corneal asphericity (Q value)	0.07	0.16	8.49	NA	0.978	0.932
Scheimpflug camera–Placido topographer[24]	0.11	0.10	—	—	0.904	0.995
Corneal diameter (mm)	0.12	0.34	0.37	1.02	0.997	0.967
Dual Scheimpflug analyzer (G1 version)[39]	0.14	—	0.41		0.995	
Thinnest corneal thickness (μm)	4.77	5.52	0.32	0.40	0.999	0.999
Dual Scheimpflug analyzer (G2 version)[33]	4.82	—	0.31	—	0.996	—
Dual Scheimpflug analyzer (G4 version)[41]		—	0.65	—	0.977	—
Rotating Scheimpflug camera[33]	9.84, 11.88	—	0.66, 0.76	—	0.981, 0.982	—
Scheimpflug camera–Placido topographer[24]	7.37	5.96	0.48	0.46	0.992	0.998
Central epithelial thickness (μm)	2.73	5.10	1.87	3.28	0.964	0.957
SD-OCT[38]		—	1.07	1.05	0.985	0.995
Nasal epithelial thickness (μm)	2.96	4.16	1.95	2.60	0.961	0.959
Temporal epithelial thickness (μm)	3.15	5.81	2.12	3.58	0.960	0.957
Superior epithelial thickness (μm)	4.36	5.79	2.95	3.70	0.958	0.958
Inferior epithelial thickness (μm)	3.10	4.73	2.02	2.89	0.960	0.961
Aqueous depth (mm)	0.04	0.04	0.45	0.51	1.000	0.999
Dual Scheimpflug analyzer (G2 version)[33]	0.06	—	0.71	—	0.995	—
Rotating Scheimpflug camera[33]	0.05	—	0.62	—	0.997	—
Scheimpflug camera–Placido topographer[24]	0.04	0.03	0.49	0.39	0.999	0.997

AS-OCT = anterior segment optical coherence tomography; K = keratometry; **KP(0)** = polar value along zero-degree meridian; **KP(45)** = polar value along the 45-degree meridian; P-RS = Post-refractive surgery; NA = not applicable; SD-OCT = spectral domain optical coherence tomography; S_w = within subject standard deviation; TCA = total corneal astigmatism and 2.95% in unoperated eyes and between 2.60% and 3.70% in post-refractive surgery eyes. The repeatability was only moderate for TCA measurements, with a CoV of more than 20%.

The tolerance index was more than 1 for all parameters when the measurements of the AS-OCT device were compared with those of the 2 Scheimpflug cameras. Being higher than the cutoff for the sample size of unoperated and post-refractive surgery eyes, the tolerance index showed that the measurements given by the new AS-OCT Placido topographer cannot be considered interchangeable with those provided by the other 2 devices.

Table 2 shows the mean values for each parameter measured by all 3 devices in the unoperated group. Compared with the 2 Scheimpflug cameras, the AS-OCT Placido topographer provided slightly higher simulated K and TCP values. For these parameters, the mean difference was statistically, but not clinically, significant, ranging between 0.06 D and 0.11 D for simulated K and between 0.13 D and 0.26 D for TCP. Accordingly, the agreement was high. Statistically, but not clinically, significant differences were also found for posterior corneal power, corneal diameter (slightly smaller than measured with the rotating Scheimpflug camera), and anterior Q value (higher than the value given by the rotating Scheimpflug camera). Among these parameters, relatively poor agreement (ie, wide 95% LoA) was found for the Q value. In contrast, the agreement for aqueous depth was excellent between the 3 devices (notwithstanding a statistically, but not clinically, significant difference) and thinnest corneal thickness (whose mean values did not show a statistically significant difference). Regarding corneal astigmatism, no statistically significant differences were detected for the mean TCA power. However, vectorial analysis showed statistically significant differences for the vectors **KP(0)** and **KP(45)**. Further vectorial analysis of the 50 eyes with a TCA power of 0.50 D or more as measured by all 3 devices showed that most of these eyes (n = 35) had with-the-rule astigmatism. In this subsample, no statistically significant difference was observed for the mean **KP(0)** values provided by the AS-OCT device (−1.15 ± 0.58), the rotating Scheimpflug camera (−1.14 ± 0.67), and the Scheimpflug camera–Placido topographer (−1.11 ± 0.65). However, a significantly more negative **KP(45)** vector was measured by the AS-OCT device (−0.15 ± 0.41) than by the rotating Scheimpflug camera (−0.01 ± 0.36) and the Scheimpflug camera–Placido topographer (0.03 ± 0.39) (P = .0003). This led to a small difference in the mean astigmatism, which was 1.17 D @ 94° with the AS-OCT device, 1.14 D @ 90° with the rotating Scheimpflug camera, and 1.11 D @ 89° with the Scheimpflug camera–Placido topographer.

In the post-excimer laser group, no statistically significant differences were detected and good agreement was found for simulated K, posterior K, and TCA power (Table 3). Regarding astigmatism, there were also no statistically significant differences for the **KP(0)** and **KP(45)** vectors, although in this case agreement was only moderate. However, statistically significant differences were observed for TCP. The mean value provided by the AS-OCT device was higher than those provided by the rotating Scheimpflug camera (by 0.17 D) and the Scheimpflug camera–Placido topographer (by 0.18 D); TCP also displayed slightly wider 95% LoAs with respect to simulated K. Results similar to those obtained in unoperated eyes were observed for aqueous depth (ie, excellent agreement and a statistically, but not clinically significant,

Table 2. Mean values from the 3 devices in the unoperated group.

Parameter	AS-OCT–Placido Topographer	Rotating Scheimpflug Camera		Scheimpflug Camera–Placido Topographer		
	Mean ± SD	Mean ± SD	95% LoA*	Mean ± SD	95% LoA†	P Value‡
Simulated K (D)	43.83 ± 1.51	43.72 ± 1.50	−0.28, +0.49	43.77 ± 1.52	−0.26, +0.38	<.0001§,¶
Posterior K (D)	−6.22 ± 0.27	−6.28 ± 0.27	−0.05, +0.16	−6.21 ± 0.27	−0.16, +0.12	<.0001§,¶
Total corneal power (D)	43.32 ± 1.50	43.06 ± 1.46	−0.23, +0.75	43.19 ± 1.52	−0.31, +0.56	<.0001§,¶
TCA power (D)	0.82 ± 0.56	0.79 ± 0.58	−0.57, +0.64	0.87 ± 0.56	0.00, +0.11	NS
KP(0) vector	−0.38 ± 0.80	−0.43 ± 0.78	−0.63, +0.72	−0.31 ± 0.87	−0.78, +0.63	.0083§
KP(45) vector	−0.11 ± 0.44	−0.02 ± 0.42	−0.59, +0.42	0.01 ± 0.46	−0.64, +0.41	.0002§,¶
Q value	−0.28 ± 0.09	−0.34 ± 0.12	−0.10, +0.22	−0.27 ± 0.11	−0.16, +0.13	<.0001§
Thinnest corneal thickness (μm)	539.42 ± 33.71	538.72 ± 34.23	−18.18, +19.58	538.29 ± 35.37	−19.22, +21.47	NS
Central epithelial thickness (μm)	52.79 ± 3.20	—	—	—	—	—
CD (mm)	11.71 ± 0.49	11.84 ± 0.44	−0.46, +0.19	11.74 ± 0.48	−0.54, +0.47	<.0001§
Aqueous depth (mm)	2.94 ± 0.41	2.88 ± 0.42	0.01, +0.12	2.89 ± 0.41	0.00, +0.11	<.0001§,¶
TCA (D @ axis)	0.40 @ 95	0.43 @ 91	NA	0.31 @ 90	NA	NA

AS-OCT = anterior segment optical coherence tomography; CD = corneal diameter; K = keratometry; **KP(0)** = polar value along 0-degree meridian; **KP(45)** = polar value along the 45-degree meridian; LoA = limits of agreement; NA = not applicable; NS = not significant; TCA = total corneal astigmatism
*AS-OCT − rotating Scheimpflug camera
†AS-OCT − Scheimpflug camera with Placido topographer
‡Analysis of variance
§Statistically significant difference between AS-OCT and rotating Scheimpflug camera according to Bonferroni multiple-comparison test
¶Statistically significant difference between AS-OCT–Placido topographer and Scheimpflug camera–Placido topographer according to Bonferroni multiple-comparison test

Table 3. Mean values from the 3 devices in the post-excimer laser group.

Parameter	AS-OCT–Placido Topographer	Rotating Scheimpflug Camera		Scheimpflug Camera–Placido Topographer		
	Mean ± SD	Mean ± SD	95% LoA*	Mean ± SD	95% LoA†	*P* Value‡
Simulated K (D)	40.75 ± 2.98	40.67 ± 2.97	−0.28, +0.44	40.69 ± 2.98	−0.41, +0.54	NS
Posterior K (D)	−6.20 ± 0.26	−6.22 ± 0.27	−0.09, 0.13	−6.23 ± 0.29	−0.15, +0.22	NS
Total corneal power (D)	39.71 ± 3.49	39.54 ± 3.35	−0.51, +0.85	39.53 ± 3.57	−0.42, +0.78	.0044§,¶
TCA power (D)	0.75 ± 0.41	0.66 ± 0.36	−0.06, +0.18	0.75 ± 0.39	−0.06, +0.14	NS
KP(0) vector	−0.55 ± 0.52	−0.44 ± 0.48	−0.86, +0.64	−0.51 ± 0.58	−0.69, +0.63	NS
KP(45) vector	0.07 ± 0.40	0.00 ± 0.37	−0.54, +0.67	0.07 ± 0.36	−0.77, +0.76	NS
Q value	0.21 ± 0.75	0.19 ± 0.67	−0.31, +0.33	0.29 ± 0.79	−0.42, +0.25	.0031¶
Thinnest corneal thickness (μm)	492.02 ± 44.18	493.23 ± 44.85	−16.76, +14.34	489.58 ± 48.09	−20.01, +24.89	NS
Central epithelial thickness (μm)	55.77 ± 4.98	—	—	—	—	—
CD (mm)	11.87 ± 0.36	11.99 ± 0.40	−0.55, +0.32	12.29 ± 0.37	−0.32, −0.28	<.0001§
Aqueous depth (mm)	3.09 ± 0.36	3.03 ± 0.38	−0.06, +0.18	3.05 ± 0.37	−0.06, +0.14	<.0001§,¶
TCA (D @ axis)	0.55 @ 8	0.44 @ 90	NA	0.52 @ 87	NA	NA

AS-OCT = anterior segment optical coherence tomography; CD = corneal diameter; K = keratometry; **KP(0)** = polar value along 0-degree meridian; **KP(45)** = polar value along the 45-degree meridian; LoA = limits of agreement; NA = not applicable; NS = not significant; TCA = total corneal astigmatism
*AS-OCT − rotating Scheimpflug camera
†AS-OCT − Scheimpflug camera with Placido topographer
‡Analysis of variance
§Statistically significant difference between AS-OCT and rotating Scheimpflug camera according to Bonferroni multiple-comparison test
¶Statistically significant difference between AS-OCT–Placido topographer and Scheimpflug camera–Placido topographer according to Bonferroni multiple-comparison test

difference as a result of the slightly higher mean value with AS-OCT), thinnest corneal thickness (excellent agreement and no statistical difference), and corneal diameter (good agreement between the 3 devices and a lower mean value with the AS-OCT device than with the rotating Scheimpflug camera). Anterior Q value measurements, which were negative in the unoperated group and turned into positive values in the post-excimer laser surgery group, showed a statistically, but not clinically significant, difference; agreement between the 3 devices was only moderate for this parameter.

DISCUSSION

The main purpose of this study was to assess the repeatability of the automatic measurements provided by the new AS-OCT Placido topographer. As with any other new diagnostic device, assessing repeatability is mandatory before its measurements can be relied on in clinical practice. In this regard, the results of the repeatability analysis were good in both healthy eyes and post-refractive surgery eyes. The high repeatability of corneal power measurements (simulated K and TCP) was confirmed by a test–retest repeatability ranging between 0.20 D and 0.27 D. This means that the difference between 2 measurements in the same participant is expected to be less than a quarter of a diopter for 95% of pairs of observations. As previously explained,[24] this value has a low clinical impact in IOL power calculation. The repeatability values for corneal power are slightly better than those previously reported for the Sirius Scheimpflug camera–Placido topographer[24] and the Galilei G2 dual Scheimpflug analyzer (Ziemer Ophthalmic Systems AG)[33] and are similar to those reported for the Pentacam HR rotating Scheimpflug camera[33,34] and the Galilei G4 dual Scheimpflug analyzer (Ziemer Ophthalmic Systems AG).[35] Comparison to the repeatability of corneal power measurements provided by another AS-OCT device (RTVue) is difficult because in the only paper addressing this issue the author reported the pooled SD only.[22] However, if we divide the latter by the mean value of each parameter, we obtain a CoV of 0.39% and 0.65% for the anterior corneal curvature in unoperated eyes and post-LASIK eyes, respectively. These values are worse than those obtained in the present study.

Posterior corneal power measurements provided by the AS-OCT Placido topographer were similar to those obtained with Scheimpflug imaging and also showed similar repeatability.[24,33,35]

The repeatability of thinnest corneal thickness measurements was improved compared with that determined for the Sirius Scheimpflug camera–Placido topographer and the Pentacam HR rotating Scheimpflug camera[24,33,36] and was as high as the repeatability observed for the Galilei G2 dual Scheimpflug analyzer.[33] Measurements of the central epithelial thickness produced mean values (52.79 ± 3.20 μm and 55.77 ± 4.98 μm in unoperated eyes and in post-refractive surgery eyes, respectively) close to those previously reported with an AS-OCT device (53.4 ± 3.20 μm and 57.9 ± 6.08 μm, respectively) as well as with very high-frequency digital ultrasound (54.1 ± 2.96 μm and 60.5 ± 6.47 μm, respectively).[37] They showed slightly lower repeatability than measurements of the whole corneal thickness; however, they were still highly repeatable. The CoV were slightly higher than reported for the only other AS-OCT device that measures epithelial thickness, for which a CoV of 1.07% and 1.05% has been reported in unoperated eyes and post-refractive surgery eyes, respectively.[38]

The excellent repeatability previously reported for aqueous depth measurements with all Scheimpflug cameras[24,33] was confirmed with the new AS-OCT Placido topographer, which also provided highly repeatable measurements of corneal diameter (similar to those given by the Galilei dual Scheimpflug analyzer).[39]

The repeatability of total corneal astigmatism measurements was good, as shown by the ICC of more than 0.9 for magnitude and both vectors, but not as high as that of other parameters, as shown by the higher CoV (∼20%) of total corneal astigmatism magnitude. Several studies[33,35,40,41] have reported similar CoVs for total corneal astigmatism in unoperated eyes (from 17.27% to 28.16%) and post-refractive surgery eyes (24.18%) imaged by a Scheimpflug camera; they related the high CoV to the low mean astigmatism power (0.82 ± 0.56 D) and the consequent small mean value in the denominator. Accordingly, Aramberri et al.[33] found a relatively high CoV for the keratometric astigmatism magnitude measured by the Pentacam HR rotating Scheimpflug camera (10.55%) and the Galilei G2 dual Scheimpflug analyzer (35.72%). Higher repeatability is expected with higher astigmatism values.

Unfortunately, comparison with the Casia AS-OCT is not possible, because to our knowledge no studies of the repeatability of its measurements in unoperated eyes and post-refractive surgery eyes have been published.

Our study has advantages as well as limitations compared with previous studies. The main advantage is the large sample, with 96 healthy eyes and 43 post-refractive surgery eyes. These numbers are higher than those previously reported by other authors.[33,35,40,41] Also, we measured only 1 eye of each participant, eliminating the compounding of bilateral-eye data. Of the limitations, we must highlight that the present study did not include eyes with pathologic corneas (eg, with keratoconus) and did not assess many parameters that can be automatically measured by the new AS-OCT device, such as those regarding wavefront analysis, pupil size and centration, anterior and posterior corneal elevation, or midperipheral and peripheral corneal thickness. Finally, we did not separately evaluate young eyes and old eyes, which may have different levels of collaboration, thus leading to different repeatability results.

In conclusion, we found that the repeatability of the new MS-39 AS-OCT device combined with a Placido topographer was high for all measured parameters in healthy unoperated eyes and in eyes that had previous excimer laser surgery. Agreement with the measurements of the Pentacam HR rotating Scheimpflug camera and the Sirius Scheimpflug camera–Placido topographer was high for a few parameters, such as aqueous depth and thinnest corneal thickness, and moderate for most parameters. Overall, measurements taken with the new AS-OCT Placido topographer cannot be considered interchangeable with those provided by the 2 Scheimpflug cameras.

WHAT WAS KNOWN

- Imaging devices based on Scheimpflug cameras provide repeatable measurements of the anterior segment of the eye.
- Anterior segment OCT can provide images with higher resolution than Scheimpflug photography but has been less commonly used for measuring corneal power.

WHAT THIS PAPER ADDS

- The new AS-OCT Placido topographer provided repeatable measurements of corneal power, thickness, and diameter as well as aqueous depth.
- Agreement with 2 Scheimpflug cameras was moderate for most parameters, and the new AS-OCT Placido topographer measurements cannot be considered interchangeable with those provided by the 2 Scheimpflug cameras.

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