Intrasubject repeatability of corneal morphology measurements obtained with a new Scheimpflug photography–based system

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PURPOSE: To evaluate in normal healthy eyes the intrasubject repeatability of anterior and posterior corneal curvature measurements and other anatomic anterior segment measurements obtained with a new topography system combining Scheimpflug photography and Placido-disk technology.

SETTING: Vissum Corp., Alicante, Spain.

DESIGN: Evaluation of technology.

METHODS: All eyes received a comprehensive ophthalmologic examination including anterior segment analysis with the Sirius system. Three consecutive measurements were performed with the device to assess the intrasubject repeatability of the following parameters: anterior and posterior corneal curvature and shape factor, white-to-white (WTW) corneal diameter, central and minimum corneal thickness, and anterior chamber depth (ACD). The within-subject standard deviation (S_w) and intraclass correlation coefficient (ICC) were calculated.

RESULTS: This study included 117 eyes of 117 subjects (mean age 42 years; range 7 to 80 years). For anterior and posterior corneal curvatures, the S_w was 0.04 mm or lower and the ICC was higher than 0.990. For shape-factor measurements, the S_w was below 0.08 in all cases and ICC values ranged between 0.909 and 0.994. Significantly larger S_w values were found for the anterior and posterior shape factor calculated for 8.0 mm compared with 4.5 mm ($P<.01$). An S_w value below 3 μm was observed for the central and minimum thickness, with ICC values close to 1. The mean S_w for ACD and WTW was below 0.1 mm.

CONCLUSION: In healthy eyes, the new topography system provided repeatable measurements of several anterior segment parameters, including anterior and posterior curvature and pachymetry.

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Several technologies for the comprehensive characterization of the anterior segment structures have been developed. These include Scheimpflug photography, a combination of scanning-slit and Placido-disk technologies, very-high-frequency ultrasonography, and optical coherence tomography (OCT).[1–4] Scheimpflug photography–based systems allow the clinician to obtain a complete analysis of the cornea and the anterior chamber, including the characterization of anterior and posterior corneal surfaces, pachymetric mapping, and measurement of the anterior chamber depth (ACD). All these measurements are obtained quickly and do not require the use of anesthesia or contact with the cornea, as required when using ultrasound-based systems.[5]

Several commercially available anterior segment analysis systems based on Scheimpflug photography have been shown to provide repeatable measurements of different anatomic parameters.[6–14] Recently, a new device based on the combination of Scheimpflug photography and Placido-disk technology was introduced into clinical practice. The device, the Sirius system (Costruzione Strumenti Oftalmici), has been shown to provide repeatable central and peripheral pachymetry measurements, although the measurements were not equivalent to those obtained with OCT.[15] However, the consistency of all remaining measurements provided by this new instrument has not been reported.

The aim of the current study was to evaluate in a group of normal healthy eyes the intrasubject

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repeatability of curvature and asphericity measurements of the anterior and posterior corneal surfaces as well as the intrasubject repeatability of other anatomic anterior segment measurements (pachymetry, corneal diameter, and ACD) obtained with the new topography system.

SUBJECTS AND METHODS

All subjects were selected randomly from the anterior segment consultation section at Vissum Alicante (Vissum Corp., Alicante, Spain), where this study was developed. One eye of each subject was chosen for the study according to a random-number sequence (dichotomic sequence, 0 and 1) that was created with purpose-developed software. Thus, an attempt was made to avoid the correlation that often exists between the 2 eyes of the same person. All subjects included in the study were free of ocular pathology to eliminate this variable as a cause of measurement error. In addition, all subjects were informed about the study and signed an informed consent document in accordance with the Declaration of Helsinki.

Measurement Protocol

All eyes received a comprehensive ophthalmologic examination that included measurement of uncorrected and corrected visual acuities, manifest refraction, Goldmann tonometry, biometry (IOLMaster, Carl Zeiss Meditec AG), and corneal topographic analysis with the Sirius system. The same experienced examiner (R.M.) performed all tests. In all cases, 3 consecutive measurements were taken with the Scheimpflug photography–based system to assess intrasubject repeatability. The following anterior segment parameters were recorded and analyzed: corneal radius of the flattest meridian for both corneal surfaces in the 3.0 mm, 5.0 mm, and 7.0 mm central zone; corneal radius of the steepest meridian in the 3.0 mm, 5.0 mm, and 7.0 mm central zone; mean corneal radius in the 3.0 mm, 5.0 mm, and 7.0 mm central zone; axes of the flattest meridian for both corneal surfaces in the 3.0 mm, 5.0 mm, and 7.0 mm central zone; mean shape factor for a 4.5 mm diameter corneal area of both corneal surfaces; mean shape factor for an 8.0 mm diameter corneal area of both corneal surfaces; white-to-white (WTW) corneal diameter; central corneal thickness; minimum corneal thickness; and ACD.

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Scheimpflug Photography–Based System

The Sirius system is a new topography device that uses the principles of Scheimpflug photography and enables the acquisition and processing of 25 radial sections of the cornea and anterior chamber in seconds.[15] The combination between 2 monochromatic 360-degree rotating Scheimpflug cameras and a Placido disk allows full analysis of the cornea and anterior segment, providing tangential and axial curvature data of anterior and posterior corneal surfaces, the global refractive power of the cornea, a biometric estimation of various structures, a corneal wavefront map with an analysis of visual quality, and corneal pachymetry maps. Specifically, the system can measure 35 632 points on the anterior corneal surface and 30 000 points on the posterior corneal surface in high-resolution mode in approximately 5 to 6 seconds. With this point-by-point information from the anterior and posterior corneal surfaces, a pachymetric map is reconstructed.[15] The current study used software version 1.0.5.72 (Phoenix, Costruzione Strumenti Oftalmici).

Corneal Astigmatism Notation

Keratometric measurements were also expressed and analyzed as power vectors. Power vectors are more helpful for detecting complex changes in keratometry because the trajectories are traced in a uniform dioptric space.[16] Therefore, the vector components (J0, J45) and the overall strength blur (B) were calculated for each keratometric measurement using the standard procedure.[16]

Statistical Analysis

Statistical analysis was performed using SPSS for Windows software (version 17.0, SPSS, Inc.). Normality of all data distributions was confirmed using the Kolmogorov-Smirnov test. Then, parametric statistics were always applied. Intrasubject repeatability for each anatomic parameter was assessed using the following statistical parameters: the within-subject standard deviation (S_w) of the 3 consecutive measurements, intrasubject repeatability, the coefficient of variation (CoV), and the intraclass correlation coefficient (ICC). The S_w is a simple way of estimating the size of the measurement error. The intraobserver precision was defined as follows: $\pm 1.96 \times S_w$,[17] and this parameter indicates how large the range of error of the repeated measurements is for 95% of observations. Finally, the ICC is an analysis of variance-based type of correlation that measures the relative homogeneity within groups (between the repeated measurements) in ratio to the total variation.[18] The ICC will approach 1.0 when there is no variance within repeated measurements, indicating that the total variation in measurements is due solely to variability in the parameter being measured. Furthermore, Pearson correlation coefficients were used to assess the correlation between the parameters evaluated, and the paired Student t test was used to compare the intrasubject repeatability associated with curvature measurements of different areas. All statistical tests were 2 tailed, and P values less than 0.05 were considered statistically significant.

The statistical power of the significance analyses was 96% considering the sample size as well as means and standard deviations of the main outcome measures. This estimation was performed with Ene software (version 2.0, GlaxoSmithKline) following a statistical standard procedure.

RESULTS

The study evaluated 117 eyes of 117 subjects. The mean age of the 55 men (47%) and 62 women (53%) was 42 years (range 7 to 80 years). Of the eyes, 58 (49.6%) were right eyes and 59 (50.4%) were left eyes. The mean spherical equivalent was −0.61 diopter (D) (range −12.5 to +8.13 D).

Intrasubject Repeatability for Curvature and Shape Factor

Table 1 shows the outcomes of the intrasubject repeatability analysis for the measurements of curvature for both corneal surfaces. The S_w was 0.04 mm or lower in all cases, and ICC values ranged between 0.994 and 0.997 for anterior surface measurements and between 0.997 and 0.998 for posterior surface measurements. The CoV was lower than 0.4% in all cases. When the intrasubject repeatability was evaluated for the power vector components of keratometric measurements, the S_w was below 0.021 mm, with associated values of ICC of more than 0.97 (Table 2). The CoV of the keratometric power vector components was not considered due to its high value, which was a consequence of the small magnitude of these parameters (Table 2). Furthermore, statistically significant differences were found in the S_w corresponding to the keratometric power vector components between the areas of analysis of 3.0 mm and 7.0 mm for both corneal surfaces ($P<.01$), with the lower S_w values for the largest area. Likewise, statistically significant differences in the S_w for K2 (steep keratometry reading) between the areas of analysis of 3.0 mm and 7.0 mm were found ($P<.01$), with no significant differences in the S_w for K1 (flat keratometry reading) ($P=.13$).

Table 3 shows the outcomes of the intrasubject repeatability analysis for the shape-factor measurements of both corneal surfaces. The within-subject SD was below 0.08 in all cases, and ICC values ranged between 0.909 and 0.994. The CoV was lower than 0.15% in all cases (Table 3). The within-subject SD values corresponding to the shape factor calculated for 4.5 mm and 8.0 mm for both corneal surfaces were significantly different ($P<.01$), with the largest value for the smallest area of analysis. Regarding the correlation analysis, a weak but statistically significant correlation was found between the S_w for the mean shape factor for a 4.5 mm diameter corneal area of the posterior corneal surface and the mean value of corneal radius of the steepest meridian in the 3.0 mm, 5.0 mm, and 7.0 mm central zone of the posterior corneal surface ($r = 0.328$, $P<.01$) (Figure 1).

Intrasubject Repeatability for Anatomical Parameters of the Anterior Segment

An S_w value below 3 μm was observed for the pachymetry measurements, with ICC values close to 1 and a CoV of 0.5% (Table 4). No significant differences were found in the S_w values associated with the minimum and central pachymetry measurements ($P=.56$). Regarding ACD and WTW, the S_w and CoV were low, with ICC values close to 1 (Table 4).

Table 1. Intrasubjet repeatability outcomes for the curvature measurements obtained for different corneal areas of analysis using the Scheimpflug photography–based topography system.

Parameter	Overall Mean	Overall Range	S_w (mm)	CoV (%)	IR (mm)	ICC	ICC 95% CI
3aK1 (D)	7.86	7.17, 8.51	0.041	0.36	0.08	0.995	0.993, 0.996
3aK2 (D)	7.68	7.00, 8.35	0.028	0.36	0.05	0.994	0.992, 0.996
3pK1 (D)	6.71	6.13, 7.34	0.021	0.32	0.04	0.997	0.996, 0.998
3pK2 (D)	6.31	5.48, 7.11	0.020	0.32	0.04	0.998	0.997, 0.998
5aK1 (D)	7.87	7.18, 8.52	0.023	0.29	0.04	0.996	0.995, 0.997
5aK2 (D)	7.70	7.05, 8.36	0.024	0.31	0.05	0.996	0.994, 0.997
5pK1 (D)	6.71	6.11, 7.33	0.017	0.26	0.03	0.998	0.997, 0.998
5pK2 (D)	6.33	5.72, 7.15	0.016	0.25	0.03	0.998	0.998, 0.999
7aK1 (D)	7.89	7.22, 8.53	0.021	0.26	0.04	0.997	0.996, 0.998
7aK2 (D)	7.73	7.12, 8.36	0.021	0.28	0.04	0.996	0.995, 0.997
7pK1 (D)	6.71	6.10, 7.32	0.021	0.25	0.03	0.998	0.997, 0.999
7pK2 (D)	6.39	5.84, 7.21	0.017	0.22	0.03	0.998	0.998, 0.999

3aK1 = anterior corneal radius of flattest meridian in 3.0 mm central zone; 3aK2 = anterior corneal radius of steepest meridian in 3.0 mm central zone; 3pK1 = posterior corneal radius of flattest meridian in 3.0 mm central zone; 3pK2 = posterior corneal radius of the steepest meridian for the 3.0 mm central zone; 5aK1 = anterior corneal radius of flattest meridian in 5-mm central zone; 5aK2 = anterior corneal radius of steepest meridian in 5.0 mm central zone; 5pK1 = posterior corneal radius of flattest meridian in 5.0 mm central zone; 5pK2 = posterior corneal radius of steepest meridian in 5.0 mm central zone; 7aK1 = anterior corneal radius of flattest meridian in 7.0 mm central zone; 7aK2 = anterior corneal radius of steepest meridian in 7.0 mm central zone; 7pK1 = posterior corneal radius of flattest meridian in 7.0 mm central zone; 7pK2 = posterior corneal radius of steepest meridian in 7.0 mm central zone; CI = confidence interval; CoV = coefficient of variation; ICC = intraclass correlation coefficient; IR = intraobserver repeatability; S_w = within-subject standard deviation

Table 2. Intrasubject repeatability outcomes for the curvature measurements obtained for different corneal areas of analysis using the Scheimpflug photography–based topography system and expressed in power vector notation.

Parameter	Overall Mean	Overall Range	S_w (mm)	IR (mm)	ICC	ICC 95% CI
3aJ0 (D)	+0.053	−0.16, +0.48	0.017	0.033	0.979	0.972, 0.985
3aJ45 (D)	+0.006	−0.19, +0.17	0.011	0.021	0.977	0.969, 0.984
3aB (D)	7.77	7.09, 8.43	0.02	0.05	0.995	0.994, 0.997
3pJ0 (D)	+0.192	0.00, +0.62	0.016	0.031	0.984	0.978, 0.988
3pJ45 (D)	+0.014	−0.20, +0.25	0.016	0.031	0.971	0.961, 0.979
3pB (D)	6.51	5.90, 7.17	0.014	0.027	0.999	0.998, 0.999
5aJ0 (D)	+0.054	−0.14, +0.49	0.011	0.021	0.991	0.988, 0.994
5aJ45 (D)	+0.005	−0.19, +0.17	0.007	0.014	0.988	0.984, 0.992
5aB (D)	7.78	7.11, 8.44	0.021	0.041	0.996	0.995, 0.997
5pJ0 (D)	+0.178	0.00, +0.59	0.011	0.022	0.992	0.988, 0.994
5pJ45 (D)	+0.012	−0.18, +0.20	0.012	0.023	0.981	0.974, 0.986
5pB (D)	6.52	5.96, 7.20	0.012	0.023	0.999	0.998, 0.999
7aJ0 (D)	+0.054	−0.13, +0.49	0.008	0.017	0.994	0.992, 0.996
7aJ45 (D)	+0.004	−0.20, +0.16	0.006	0.011	0.993	0.990, 0.995
7aB (D)	7.81	7.17, 8.45	0.019	0.038	0.997	0.996, 0.998
7pJ0 (D)	+0.147	−0.03, +0.54	0.009	0.018	0.993	0.991, 0.995
7pJ45 (D)	+0.012	−0.20, +0.22	0.011	0.022	0.980	0.973, 0.986
7pB (D)	6.55	5.99, 7.24	0.012	0.024	0.999	0.998, 0.999

B = overall blurring strength of power vector analysis; J0 and J45 = power vector coordinates
See Table 1 footnotes for other abbreviations.

DISCUSSION

In the past years, much effort has been made to implement corneal topography technology to increase its diagnostic ability. Technological advances and the increasing interest in corneal refractive surgery techniques have lead to this relevant implementation of corneal analysis. Specifically, the current corneal topography systems provide very detailed information about the corneal anatomy, and they are the best tools for characterizing the configuration of this ocular structure.[19] Pachymetry, anterior segment dimensions, anterior and posterior corneal curvatures, and corneal volume analysis are some parameters that the new corneal topography devices can evaluate.[19]

The Sirius is a new corneal topography system that combines Scheimpflug photography and Placido-disk technologies,[15] allowing the clinician to obtain a complete characterization of the cornea in a noninvasive way. The consistency of the pachymetry measurements of this instrument has been reported[15]; however, there is limited published scientific evidence of the consistency of other corneal and anterior segment measurements provided by this device.[20] The aim of the current study was to evaluate in a group of normal healthy eyes the intrasubject repeatability of curvature and asphericity measurements of anterior and posterior corneal surfaces as well as the intrasubject repeatability of other anatomic anterior segment measurements (pachymetry, corneal diameter, and ACD) obtained with this imaging system.

First, we evaluated the intrasubject repeatability of the anterior and posterior curvature measurements

Table 3. Intrasubjet repeatability outcomes for the shape factor measurements obtained at different corneal locations using the Scheimpflug photography–based topography system.

Parameter	Overall Mean	Overall Range	S_w	CoV (%)	IR	ICC	ICC 95% CI	Mean Q Value*	Q Value Range
ap45	0.89	0.58, 1.26	0.049	5.64	0.10	0.909	0.876, 0.935	−0.11	−0.42, 0.26
ap8	0.76	0.48, 1.06	0.019	2.55	0.04	0.987	0.983, 0.991	−0.24	−0.52, 0.61
pp45	0.91	0.30, 1.77	0.071	8.80	0.14	0.965	0.952, 0.975	−0.09	−0.70, 0.77
pp8	0.72	0.21, 1.12	0.021	3.53	0.04	0.994	0.992, 0.996	−0.28	−0.79, 0.12

ap45 = mean anterior shape factor for a 4.5 mm diameter corneal area; ap8 = mean anterior shape factor for an 8.0 mm diameter corneal area; CI = confidence interval; CoV = coefficient of variation; ICC = intraclass correlation coefficient; IR = intraobserver repeatability; pp45 = mean anterior shape factor for a 4.5 mm diameter corneal area; pp8 = mean posterior shape factor for an 8.0 mm diameter corneal area; S_w = within-subject standard deviation
*Q asphericity value was calculated from the shape factor P with the expression $Q = 1 - P$

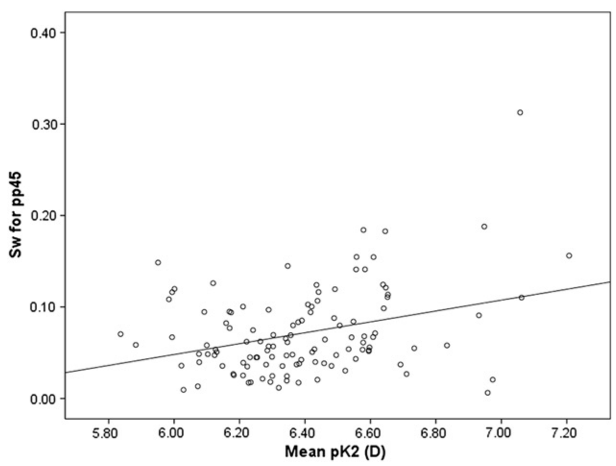

Figure 1. Relationship between the S_w corresponding to the shape factor for the 4.5 mm central zone of the posterior corneal surface (pp45) and the steepest keratometric reading of such surface (pK2).

at 3.0 mm, 5.0 mm, and 7.0 mm. This analysis confirmed that the instrument provides consistent and repeatable curvature measurements for different areas of analysis. The CoV did not exceed 0.4%, and the ICC was close to 1 for all types of measurements. The range of values for the ICC is between 0 and 1, with the following grading system: ICC greater than 0.75 = low intrasubject repeatability; ICC 0.75 to less than 0.90 = moderate intrasubject repeatability; ICC of 0.90 or greater = high intrasubject repeatability.[14] The excellent repeatability we found is similar to that reported for other Scheimpflug photography–based corneal topography systems.[6–13,20] Furthermore, the consistency of curvature measurements was analyzed based on their vectorial components and, therefore, the axis of anterior and posterior astigmatism. Our analysis also found excellent intrasubject repeatability of the corneal power vector components of the anterior and posterior corneal surfaces at 3.0 mm, 5.0 mm, and 7.0 mm, with ICC values close to 1. Statistically significant differences were detected, although they were small in magnitude in the S_w corresponding to the corneal power vector components between the areas of analysis of 3.0 mm and 7.0 mm of both corneal surfaces. Specifically, the larger the area of analysis, the better the repeatability. One factor accounting for this small and not clinically relevant difference may be the use of a different algorithm for calculating corneal power for each area of analysis evaluated. This is something that should be addressed in future studies.

The consistency of the shape-factor measurements was excellent for both corneal surfaces and for the 2 areas of analysis evaluated (4.5 mm and 8.0 mm). Our findings are similar to those reported in other studies using other Scheimpflug photography–based imaging devices.[8,20] In addition, we found that the larger the area of analysis, the better the intrasubject repeatability of shape-factor measurements for both corneal surfaces. In their calculations of anterior corneal asphericity using VOL-CT software (Sarver & Associates) and the data extracted from a Placido-based topography system, González-Méijome et al.[21] found that the intrasubject repeatability of this parameter was significantly better for the largest diameters. A similar trend was reported in another study evaluating the intrasubject repeatability of asphericity measurements for the posterior corneal surface with a Scheimpflug photography–based corneal topographer.[8] Two factors may account for the discrepancy in the consistency of shape-factor measurements between areas of analysis. First, the use of largest areas of analysis implies consideration of a greater number of points for defining the shape factor or asphericity with less probable variability in the adjustment. Second, it has been shown that a conic is a poor estimator of the peripheral shape of the anterior corneal surface because in that area, there is a more significant flattening and less astigmatism than in the central area.[22] Therefore, using a constant shape factor for finding an exact mathematic adjustment to the corneal surface is a limitation. In any case, the consistency of the shape-factor measurements provided by the evaluated device was excellent, confirming little variation

Table 4. Intrasubjet repeatability outcomes for the other morphology parameters of the anterior segment analyzed with the Scheimpflug photography–based topography system.

Parameter	Overall Mean	Overall Range	S_w	CoV (%)	IR	ICC	ICC 95% CI
CCT (μm)	542.96	454.23, 634.8	2.80	0.52	5.49	0.997	0.996, 0.998
MCT (μm)	539.48	450.91, 631.25	2.83	0.52	5.54	0.997	0.996, 0.998
ACD (mm)	2.91	1.82, 3.68	0.02	0.54	0.03	0.999	0.999, 0.999
WTW (mm)	12.04	9.52, 13.26	0.06	0.48	0.11	0.974	0.965, 0.982

ACD = anterior chamber depth; CCT = central corneal thickness; CI = confidence interval; CoV = coefficient of variation; ICC = intraclass correlation coefficient; IR = intraobserver repeatability; MCT = minimal corneal thickness; S_w = within-subject standard deviation; WTW = white to white of repeated measurements that was not clinically relevant.

Finally, we also evaluated the intrasubject repeatability of pachymetry and some additional anterior segment anatomical parameters. The intrasubject repeatability of the central and minimum pachymetry measurements was excellent and consistent with that reported for the Sirius and other Scheimpflug-based devices.[6,14,15,23] The variability of repeated measurements of pachymetry parameters evaluated in the current study was below 3 μm, which is not clinically relevant. In a previous study evaluating the consistency of central and peripheral pachymetric measurements in normal healthy eyes obtained with the Sirius system,[15] measurements at 4.0 mm nasally, inferiorly, and temporally were somewhat less consistent than the central and peripheral measurements at 2.5 mm. Potential factors in this phenomenon include the greater difficulty in processing Scheimpflug images at the edges due to the greater degree of distortion and blur usually present at this level, the reduction of data sampling per area in the periphery versus the central region, and the error of repeatability of peripheral pachymetry due to the use of an unstable reference point as the center of the pupil instead of the corneal vertex.[24] Therefore, future studies evaluating the repeatability of peripheral pachymetry in eyes with a more complex thickness distribution (keratoconus, post-keratorefractive surgery, post-keratoplasty) should be performed to confirm the validity of these measurements obtained with the evaluated device in such cases. Savini et al.[20] report a preliminary study of this issue. The authors evaluated the repeatability of the thinnest and apex corneal thickness obtained with the device used in the current series in 17 eyes that had previous myopic excimer laser surgery and 13 eyes with keratoconus. They report excellent outcomes; however, they did not analyze peripheral pachymetry. In addition to pachymetry, excellent consistency was also obtained for ACD and WTW parameters, with repeatability comparable to that reported for several other devices.[5,6,9,20,25,26]

In summary, this new Sirius topography system based on the combination of a rotating Scheimpflug camera and a Placido disk provided repeatable anterior and posterior curvature and shape-factor measurements as well as pachymetry measurements using a fast, noninvasive technique. In addition, the device provided WTW and ACD measurements with excellent intrasubject repeatability. Future studies are required in large sample of eyes to confirm whether this trend also occurs in pathologic corneas and in corneas that have had previous surgery. The results in our study suggest that the system can be a useful tool in clinical research.

WHAT WAS KNOWN

- Scheimpflug photography–based systems allow the clinician to obtain a complete analysis of the cornea and the anterior chamber, including characterization of anterior and posterior corneal surfaces, pachymetric mapping, and measurement of the ACD.
- The combination of Scheimpflug photography and Placido-disk technology (Sirius system) has been shown to provide repeatable central and peripheral pachymetry measurements, although the measurements were not equivalent to those obtained with optical coherence tomography.

WHAT THIS PAPER ADDS

- The combination of a rotating Scheimpflug camera and a Placido disk provided repeatable anterior and posterior curvature and shape-factor measurements as well as pachymetry measurements using a fast, noninvasive technique.
- This technology provides white-to-white and ACD measurements with excellent intrasubject repeatability.
- This technology is a useful tool in clinical research.

REFERENCES

1. Dubbelman M, Sicam VADP, van der Heijde GL. The shape of the anterior and posterior surface of the aging human cornea. Vision Res 2006; 46:993–1001
2. Maldonado MJ, Nieto JC, Díez-Cuenca M, Piñero DP. Repeatability and reproducibility of posterior corneal curvature measurements by combined scanning-slit and Placido-disc topography after LASIK. Ophthalmology 2006; 113:1918–1926
3. Rondeau MJ, Barcsay G, Silverman RH, Reinstein DZ, Krishnamurthy R, Chabi A, Du T, Coleman DJ. Very high frequency ultrasound biometry of the anterior and posterior chamber diameter. J Refract Surg 2004; 20:454–464
4. Radhakrishnan S, Rollins AM, Roth JE, Yazdanfar S, Westphal V, Bardenstein DS, Izatt JA. Real-time optical coherence tomography of the anterior segment at 1310 nm. Arch Ophthalmol 2001; 119:1179–1185. Available at: http://archopht.ama-assn.org/cgi/reprint/119/8/1179. Accessed January 28, 2012
5. Piñero DP, Plaza AB, Alió JL. Anterior segment biometry with 2 imaging technologies: very-high-frequency ultrasound scanning versus optical coherence tomography. J Cataract Refract Surg 2008; 34:95–102
6. Savini G, Carbonelli M, Barboni P, Hoffer KJ. Repeatability of automatic measurements performed by a dual Scheimpflug analyzer in unoperated and post-refractive surgery eyes. J Cataract Refract Surg 2011; 37:302–309
7. Wang L, Shirayama M, Koch DD. Repeatability of corneal power and wavefront aberration measurements with a dual-Scheimpflug Placido corneal topographer. J Cataract Refract Surg 2010; 36:425–430
8. Piñero DP, Saenz González C, Alió JL. Intraobserver and interobserver repeatability of curvature and aberrometric

measurements of the posterior corneal surface in normal eyes using Scheimpflug photography. J Cataract Refract Surg 2009; 35:113–120
9. Shankar H, Taranath D, Santhirathelagan CT, Pesudovs K. Anterior segment biometry with the Pentacam: comprehensive assessment of repeatability of automated measurements. J Cataract Refract Surg 2008; 34:103–113
10. Chen D, Lam AKC. Reliability and repeatability of the Pentacam on corneal curvatures. Clin Exp Optom 2009; 92:110–118. Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1444-0938.2008.00336.x/pdf. Accessed January 28, 2012
11. Kawamorita T, Uozato H, Kamiya K, Bax L, Tsutsui K, Aizawa D, Shimizu K. Repeatability, reproducibility, and agreement characteristics of rotating Scheimpflug photography and scanning-slit corneal topography for corneal power measurement. J Cataract Refract Surg 2009; 35:127–133
12. Menassa N, Kaufmann C, Goggin M, Job OM, Bachmann LM, Thiel MA. Comparison and reproducibility of corneal thickness and curvature readings obtained by the Galilei and the Orbscan II analysis systems. J Cataract Refract Surg 2008; 34: 1742–1747
13. Chen D, Lam AKC. Intrasession and intersession repeatability of the Pentacam system on posterior corneal assessment in the normal human eye. J Cataract Refract Surg 2007; 33:448–454
14. Lackner B, Schmidinger G, Pieh S, Funovics MA, Skorpik C. Repeatability and reproducibility of central corneal thickness measurement with Pentacam, Orbscan, and ultrasound. Optom Vis Sci 2005; 82:892–899. Available at: http://www.oculus.de/chi/downloads/dyn/sonstige/sonstige/lackner_pachymetry.pdf. Accessed January 28, 2012
15. Milla M, Piñero DP, Amparo F, Alió JL. Pachymetric measurements with a new Scheimpflug photography-based system; intraobserver repeatability and agreement with optical coherence tomography pachymetry. J Cataract Refract Surg 2011; 37:310–316
16. Thibos LN, Horner D. Power vector analysis of the optical outcomes of refractive surgery. J Cataract Refract Surg 2001; 27:80–85
17. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1:307–310. Available at: http://www-users.york.ac.uk/~mb55/meas/ba.pdf. Accessed January 28, 2012
18. Bland JM, Altman DG. Statistical notes. Measurement error and correlation coefficients. BMJ 1996; 313:41–42; correction, 744. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2351452/pdf/bmj00549-0045.pdf. Accessed January 28, 2012. Correction available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2352111/pdf/bmj00560-0056b.pdf. Accessed January 28, 2012
19. Salomão MQ, Esposito A, Dupps WJ Jr. Advances in anterior segment imaging and analysis. Curr Opin Ophthalmol 2009; 20:324–332
20. Savini G, Barboni P, Carbonelli M, Hoffer KJ. Repeatability of automatic measurements by a new Scheimpflug camera combined with Placido topography. J Cataract Refract Surg 2011; 37:1809–1816
21. González-Méijome JM, Villa-Collar C, Montés-Micó R, Gomes A. Asphericity of the anterior human cornea with different corneal diameters. J Cataract Refract Surg 2007; 33:465–473
22. Read SA, Collins MJ, Carney LG, Franklin RJ. The topography of the central and peripheral cornea. Invest Ophthalmol Vis Sci 2006; 47:1404–1415. Available at: http://www.iovs.org/cgi/reprint/47/4/1404. Accessed January 28, 2012
23. de Sanctis U, Missolungi A, Mutani B, Richiardi L, Grignolo FM. Reproducibility and repeatability of central corneal thickness measurement in keratoconus using the rotating Scheimpflug camera and ultrasound pachymetry. Am J Ophthalmol 2007; 144:712–718
24. Shankar H, Pesudovs K. Reliability of peripheral corneal pachymetry with the Oculus Pentacam [letter]. J Cataract Refract Surg 2008; 34:7. reply by R Khoramnia, TM Rabsilber, GU Auffarth, 8. Letter available at: http://www.pesudovs.com/konrad/Docs/Shankar%20letter.pdf. Accessed Januaray 28, 2012
25. Piñero DP, Plaza Puche AB, Alió JL. Corneal diameter measurements by corneal topography and angle-to-angle measurements by optical coherence tomography: evaluation of equivalence. J Cataract Refract Surg 2008; 34:126–131
26. Kohnen T, Thomala MC, Cichocki M, Strenger A. Internal anterior chamber diameter using optical coherence tomography compared with white-to-white distances using automated measurements. J Cataract Refract Surg 2006; 32:1809–1813