Intrasubject repeatability in keratoconus-eye measurements obtained with a new Scheimpflug photography–based system

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

SETTING: Vissum Corporation, Alicante, Spain.

DESIGN: Evaluation of technology.

METHODS: All keratoconus eyes had a comprehensive ophthalmologic examination including analysis with the Sirius system. Three consecutive measurements were obtained 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 comprised 61 eyes of 61 patients ranging in age from 14 to 64 years. For anterior and posterior corneal curvatures and power vector components, the S_w was 0.29 mm or less in all cases. The ICC was above 0.990 in all cases except the flattest curvature of the posterior corneal surface at 3.0 mm, which was 0.840 (moderate agreement), and the posterior power vector J0, which was 0.665 (poor agreement), 0.752, and 0.758 (moderate agreement) for 3.0 mm, 5.0 mm, and 7.0 mm, respectively. In shape factor measurements, the S_w was 0.12 or less in all cases and the ICC ranged between 0.989 and 0.999. Pachymetry, ACD, and WTW had ICC values very close to 1.

CONCLUSION: The new topography system provided repeatable measurements of corneal shape and other anatomic parameters in eyes with keratoconus.

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Keratoconus diagnosis and characterization have been implemented significantly in the past years with the development of new technologies and the introduction of new examination procedures in clinical practice.[1–10] At present, there is a wide range of instruments for keratoconus characterization, such as topography systems based on the Placido disk, scanning-slit and Scheimpflug-photography technologies, and optical coherence tomography (OCT) devices, that accurately describe not only the anterior corneal surface but also the posterior surface and the optical properties of both.[1–10] Proper combined analysis of anterior and posterior topographic data and aberrometric data as well as of pachymetric and corneal volume data has been shown to provide sufficient information for the complete characterization of the keratoconic cornea, facilitating the detection of incipient forms of keratoconus.[1,2,6,10]

Different Scheimpflug photography systems have been shown to provide repeatable measurements of several ocular parameters, especially in normal eyes.[11–19] A new device based on the combination of Scheimpflug-photography and Placido-disk technology (Sirius, Costruzione Strumenti Oftalmici) was recently introduced into clinical practice. It provides anterior segment tomographic and corneal topographic analyses in a few seconds without corneal contact. This device has been shown to give repeatable

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measurements of several anterior segment parameters, including anterior and posterior curvatures and pachymetry measurements, in healthy eyes.[20] However, no consistent data about the repeatability of this device for characterizing the corneal structure in keratoconus has been provided. The only study of this, by Savini et al.,[4] was preliminary. It included 13 eyes with keratoconus. The authors found that high repeatability was achieved for most parameters provided by the Sirius system, with an intraclass correlation coefficient (ICC) higher than 0.99 for all measurements except posterior corneal power (ICC 0.868).

The aim of the current study was to evaluate in keratoconus eyes the intrasubject 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 anterior chamber depth [ACD]) obtained with the Sirius topography system.

PATIENTS AND METHODS

All patients were randomly selected from the anterior segment consultation at Vissum Alicante, Vissum Corporation, Alicante, Spain, where this study was developed. All patients were informed about the study and signed an informed consent document in accordance with the Declaration of Helsinki.

One eye of each patient was chosen for the study according to a random-number sequence (dichotomic sequence 0 and 1) that was created using computer software. This was done in an attempt to avoid the correlation that often exists between 2 eyes of the same person.

The inclusion criterion was the presence of keratoconus diagnosed using the standard criteria; that is, corneal topography showing an asymmetric bowtie pattern with or without skewed axes and at least 1 keratoconus sign (eg, stromal thinning, conical protrusion of the cornea at the apex, Fleischer ring, Vogt striae, anterior stromal scar) on slitlamp examination.[7,8,10] The exclusion criteria were previous ocular surgery and other active ocular disease.

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Measurement Protocol

All eyes had 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 the intrasubject repeatability. The following anterior segment parameters were recorded and analyzed: corneal radius of the flattest meridian of both corneal surfaces in the 3.0 mm, 5.0 mm, and 7.0 mm central zones; corneal radius of the steepest meridian in the 3.0 mm, 5.0 mm, and 7.0 mm central zones; mean corneal radius in the 3.0 mm, 5.0 mm, and 7.0 mm central zones; axes of the flattest meridian of both corneal surfaces in the 3.0 mm, 5.0 mm, and 7.0 mm central zones; 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 (CCT); minimum corneal thickness (MCT); and ACD.

Measurement 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. The combination between 1 monochromatic 360-degree rotating Scheimpflug camera and a Placido disk allows analysis of the cornea and anterior segment, providing tangential and axial curvature data of the 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, this system allows measurement of 35 632 points of the anterior corneal surface and 30 000 points of the posterior corneal surface in high-resolution mode in approximately less than 1 second. With this point-by-point information of the anterior and posterior corneal surfaces, a pachymetric map is reconstructed. In the current study, software version 1.0.5.72 (Phoenix, Costruzione Strumenti Oftalmici) was used.

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.[21] Therefore, the vector components (J0, J45) and the overall strength blur (B) were calculated for each keratometric measurement using the standard procedure defined for this purpose.[21]

Statistical Analysis

Statistical analysis was performed using the 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: within-subject standard deviation (S_w) of the 3 consecutive measurements, intrasubject precision, the coefficient of variation (CoV), and the ICC. The S_w is a simple way of estimating the size of the measurement error. The intraobserver precision was defined as ($\pm 1.96 \times S_w$),[22] and this parameter indicates how large the range of error of the repeated measurements for 95% of observations is. 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.[22,23] 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 the variability in the parameter being measured. Furthermore, Spearman correlation coefficients were used to assess the correlation between the parameters evaluated, and the paired Student *t* test was used for comparing 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.

RESULTS

The study comprised 61 eyes of 61 patients with a mean age of 35 years (range 14 to 64 years). Thirty-nine patients (64%) were men and 22 (36%) were women. The sample comprised 38 right eyes (62.3%) and 23 left eyes (37.7%). The mean spherical equivalent was −3.54 D (range −19.00 to +1.50 D).

Intrasubject Repeatability for Curvature

Table 1 shows the outcomes of the intrasubject repeatability analysis of the measurements of curvature for both corneal surfaces. The S_w was 0.29 or lower in all cases, and the CoV value ranged between 4.25% and 0.43%. The lower ICC value associated with the curvature measurements was 0.840, which corresponded to the keratometric reading for the flattest meridian of the posterior corneal surface at the 3.0 mm corneal area. The remaining curvature measurements had an ICC value that ranged between 0.901 and 0.998.

Regarding the power vector components calculated from keratometric measurements, the S_w was less than 0.174 mm for all vector parameters (Table 2). Worse intrasubject repeatability was observed for J0 component of the posterior corneal surface. Specifically, poorer intrasubject repeatability was found for the posterior power vector component J0 at the 3.0 mm, 5.0 mm, and 7.0 mm central corneal zones, with associated ICC values of 0.665, 0.752, and 0.758, respectively. The remaining ICC values for the power vector components were above 0.920 (Table 2). The CoV of the keratometric power vector components was not considered because of its high value, which was the consequence of the small magnitude of these parameters. In addition, statistically significant differences were found in the S_w corresponding to the keratometric power vector components between areas of analysis (3.0 mm, 5.0 mm, and 7.0 mm) for the anterior and posterior corneal surfaces ($P < .01$), with the lower value for the 7.0 mm diameter.

Intrasubject Repeatability for Shape Factor

Table 3 shows the outcomes of the intrasubject repeatability analysis for the shape factor

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

Measure (mm)	Overall Mean	Range	S_w (mm)	CoV (%)	Pr (mm)	ICC	Range 95% CI
3aK1	7.35	5.04, 8.40	0.046	0.64	0.09	0.996	0.993, 0.997
3aK2	6.75	4.40, 7.90	0.039	0.59	0.08	0.998	0.996, 0.999
3pK1	6.36	3.49, 9.63	0.290	4.25	0.58	0.840	0.733, 0.909
3pK2	5.28	3.04, 6.68	0.120	2.31	0.23	0.963	0.938, 0.979
5aK1	7.37	5.35, 8.35	0.036	0.50	0.07	0.996	0.994, 0.998
5aK2	6.88	4.88, 7.93	0.031	0.47	0.06	0.998	0.997, 0.999
5pK1	6.31	4.02, 8.46	0.180	2.65	0.34	0.901	0.834, 0.943
5pK2	5.54	3.67, 6.72	0.080	1.44	0.16	0.982	0.970, 0.990
7aK1	7.44	5.84, 8.31	0.031	0.42	0.06	0.996	0.994, 0.998
7aK2	7.03	7.12, 8.36	0.030	0.43	0.06	0.998	0.997, 0.999
7pK1	6.36	4.65, 7.95	0.130	1.99	0.26	0.920	0.867, 0.954
7pK2	5.76	4.39, 6.76	0.060	1.03	0.12	0.986	0.977, 0.992

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

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

Measure (mm)*	Overall Mean	Range	S_w (mm)	Pr (mm)	ICC	Range 95% CI
3aJ0	+0.029	−0.67, +0.59	0.027	0.052	0.994	0.990, 0.997
3aJ45	+0.028	−0.56, +0.54	0.025	0.049	0.993	0.988, 0.996
3aB	7.05	4.73, 8.09	0.034	0.066	0.998	0.997, 0.999
3pJ0	+0.003	−1.49, +0.75	0.174	0.341	0.665	0.441, 0.809
3pJ45	+0.012	−1.95, +1.20	0.137	0.268	0.927	0.878, 0.958
3pB	5.86	3.28, 7.82	0.164	0.321	0.920	0.867, 0.955
5aJ0	+0.053	−0.47, +0.54	0.020	0.039	0.995	0.991, 0.997
5aJ45	+0.032	−0.45, +0.45	0.019	0.036	0.995	0.991, 0.997
5aB	7.13	5.12, 8.09	0.027	0.052	0.999	0.998, 0.999
5pJ0	+0.059	−078, +0.58	0.107	0.209	0.752	0.586, 0.858
5pJ45	+0.014	−1.25, +0.82	0.086	0.168	0.946	0.910, 0.969
5pB	5.95	3.85, 7.27	0.098	0.192	0.962	0.937, 0.978
7aJ0	+0.065	−0.40, +0.43	0.018	0.035	0.994	0.990, 0.997
7aJ45	+0.031	−0.35, +0.37	0.017	0.032	0.994	0.990, 0.997
7aB	7.24	5.68, 8.11	0.024	0.046	0.999	0.997, 0.999
7pJ0	+0.076	−0.52, +0.48	0.081	0.158	0.758	0.597, 0.862
7pJ45	+0.014	−0.91, +0.61	0.066	0.129	0.952	0.920, 0.973
7pB	6.07	4.53, 7.08	0.072	0.140	0.972	0.953, 0.984

CI = confidence interval; ICC = intraclass correlation coefficient; Pr = intraobserver precision; S_w = within-subject standard deviation
*Vector components (J0, J45) and the overall strength blur (B) for anterior (a) and posterior (p) corneal astigmatism calculated for 3.0 mm diameter (3aB, 3aJ0, 3aJ45, 3pB, 3pJ0, 3pJ45), 5 (5aB, 5aJ0, 5aJ45, 5pB, 5pJ0, 5pJ45), and 7.0 mm diameter (7aB, 7aJ0, 7aJ45, 7pB, 7pJ0, 7pJ45)

measurements of both corneal surfaces. The S_w was below 0.12 in all cases, and the ICC values ranged between 0.989 and 0.999. The CoV of the shape factor was not considered because of the existence of negative shape factor values, leading to negative values for this coefficient. The S_w values corresponding to the shape factor at 4.5 mm and 8.0 mm for both corneal surfaces were significantly different ($P < .01$), with larger values for the 4.5 mm area. In addition, the S_w values for the posterior flat meridian for the 3 corneal diameters correlated significantly with the steep meridian of both corneal surfaces and the CCT (Table 4).

Intrasubject Repeatability for Anterior Segment Anatomic Parameters

Values below 4 μm were obtained for S_w of the pachymetric measurements, with ICC values very close to 1 and a CoV of 0.51% (Table 5). The differences in the S_w values for the MCT and CCT pachymetric measurements were at the limit of statistical significance ($P = .05$). Regarding ACD and WTW, the S_w and CoV values were low, with ICC values close to 1.

DISCUSSION

In the past years, there has been much effort to implement corneal topography technology to increase its

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

Measure	Overall Mean	Range	S_w	Pr	ICC	Range 95% CI	Q Value	
							Mean*	Range
ap45	0.37	−2.98, 2.09	0.10	0.19	0.989	0.981, 0.994	−0.63	−3.98, 1.09
ap8	0.23	−2.29, 1.33	0.03	0.06	0.998	0.997, 0.999	−0.77	−3.29, 0.33
pp45	0.41	−3.50, 4.40	0.12	0.24	0.991	0.984, 0.995	−0.59	−4.50, 3.44
pp8	0.16	−2.03, 1.85	0.04	0.08	0.999	0.998, 0.999	−0.83	−3.03, 0.85

ap45 = mean anterior shape factor for a corneal area of 4.5 mm diameter; ap8 = mean anterior shape factor for a corneal area of 8.0 mm diameter; CI = confidence interval; ICC = intraclass correlation coefficient; pp45 = mean anterior shape factor for a corneal area of 4.5 mm diameter; pp8 = mean posterior shape factor for a corneal area of 8.0 mm diameter; Pr = intraobserver precision; S_w = within-subject standard deviation
*Q asphericity value was calculated from the shape factor (p with the expression $Q = p{-}1$)

Table 4. Most consistent correlations between different anterior surface, posterior surface, and morphological corneal parameters.

Measure	Correlation Spearman Coefficient	*P* Value
S_w for 3pK1		
Correlation with 5aK2	−0.287	.04
Correlation with 3pK2	−0.324	.02
S_w for 5pK1		
Correlation with 3aK2	−0.352	.01
Correlation with 5aK2	−0.352	.01.
Correlation with 7aK2	−0.323	02
Correlation with 3pK2	−0.375	<.01
Correlation with 5pK2	−0.302	.03
S_w for 7pK1		
Correlation with 3aK2	−0.385	<.01
Correlation with 5aK2	−0.392	<.01
Correlation with 7aK2	−0.357	<.01
Correlation with 3pK2	−0.416	<.01
Correlation with 5pK2	−0.346	.01
Correlation with 7pK2	−0.277	.04

3aK1 = anterior corneal radius of the flattest meridian in 3.0 mm central zone; 3aK2 = anterior corneal radius of the steepest meridian in 3.0 mm central zone; 3pK1 = posterior corneal radius of the flattest meridian in 3.0 mm central zone; 3pK2 = posterior corneal radius of the steepest meridian in 3.0 mm central zone; 5aK1 = anterior corneal radius of the flattest meridian in 5.0 mm central zone; 5aK2 = anterior corneal radius of the steepest meridian in 5.0 mm central zone; 5pK1 = posterior corneal radius of the flattest meridian in 5.0 mm central zone; 5pK2 = posterior corneal radius of the steepest meridian in 5.0 mm central zone; 7aK1 = anterior corneal radius of the flattest meridian in 7.0 mm central zone; 7aK2 = anterior corneal radius of the steepest meridian in 7.0 mm central zone; 7pK1 = posterior corneal radius of the flattest meridian in 7.0 mm central zone; 7pK2 = posterior corneal radius of the steepest meridian in 7.0 mm central zone; S_w = within-subject standard deviation

diagnostic ability. Technological advances and the increasing interest in corneal refractive surgery techniques have led to this relevant implementation of corneal analysis. Specifically, current corneal topography systems provide very detailed information about the corneal anatomy, and they are the best tool for characterizing the configuration of this ocular structure.[24] Pachymetry, anterior segment dimensions, anterior and posterior corneal curvatures, and corneal-volume analysis are some measurements provided by new corneal topography devices.[24] These advances are especially useful in the detection of corneal pathology such as keratoconus.[1,2,6,10] One example of the new corneal topographic systems is the Sirius device used in the current study, which combines Scheimpflug-photography and Placido-disk technologies. Although the consistency of the pachymetric measurements of this instrument has been reported,[20,25] there is limited published scientific evidence of the consistency of other corneal and anterior segment measurements provided by this device[4] in eyes with pathology. The aim of the current study was to evaluate in a group of eyes with keratoconus the intrasubject repeatability of the 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 this imaging system.

First, we evaluated the intrasubject repeatability of the anterior and posterior curvature measurements at the 3.0 mm, 5.0 mm, and 7.0 mm zones. This analysis confirmed that the instrument can provide consistent and repeatable curvature measurements for different areas of analysis and for both corneal surfaces. The CoV did not exceed 3% in all curvature parameters except for the posterior flattest curvature at the 3.0 mm diameter, which had an associated CoV of 4.25%. This parameter also had the lowest ICC value (0.840) for curvature measurements. This ICC represents a moderate level of repeatability. In 2011, Savini et al.[4] reported a CoV of 4.90% and an ICC value of 0.868 for the mean posterior corneal power in a sample of 13 subjects with keratoconus using the Sirius topographic system, outcomes that are highly consistent with ours. The range of ICC values is between 0 and 1, with the following grading system: ICC less than 0.75, low intrasubject repeatability; ICC 0.75 through 0.90, moderate intrasubject repeatability; ICC more than 0.90, high intrasubject repeatability.[19] The remaining curvature measurements showed ICC values that were very close to 1. This excellent repeatability is

Table 5. Intrasubjet repeatability outcomes for the other morphological parameters of the anterior segment analyzed with the Scheimpflug photography–based topography system.

Measure	Overall Mean	Range	S_w	CoV (%)	Pr	ICC	Range 95% CI
CCT (μm)	457.51	321.18, 580.42	2.30	0.51	4.51	0.998	0.997, 0.999
MCT (μm)	439.07	304.07, 547.74	3.18	0.73	6.23	0.995	0.991, 0.997
ACD (mm)	3.39	2.56, 4.27	0.02	0.64	0.04	0.998	0.996, 0.999
WTW (mm)	12.20	11.13, 13.68	0.07	0.56	0.13	0.989	0.982, 0.994

AC = anterior chamber depth; CCT = central corneal thickness; CI = confidence interval; CoV = coefficient of variation; ICC = intraclass correlation coefficient; MCT = minimal corneal thickness; Pr = intraobserver precision; S_w = within-subject standard deviation; WTW = white to white similar to that reported with other Scheimpflug photography–based corneal topography systems in normal healthy eyes.[11–18] Szalai et al.[26] recently evaluated the consistency of some corneal measurements obtained with a Scheimpflug photography–based topographer and an anterior segment OCT (AS-OCT) device in healthy eyes and in keratoconus eyes. The authors found comparable repeatability results for curvature values in both groups with both devices.

Furthermore, the consistency of curvature measurements was analyzed considering their vectorial power vector components and therefore the axis of anterior and posterior astigmatism. This analysis showed excellent intrasubject repeatability of the anterior corneal surface power vector components at 3.0 mm, 5.0 mm, and 7.0 mm, with ICC values very close to 1, as in a previous study using the same technology in normal healthy eyes.[20] The posterior power vector components had a high level of intrasubject repeatability (ICC >0.920) except for the posterior J0 component at 3.0 mm, 5.0 mm, and 7.0 mm corneal diameters, which had lower ICC values (0.665, 0.752, and 0.758, respectively), representing more limited repeatability. According to these results and the statistical analysis of differences, J0 posterior power vector measurements are less repeatable in the central cornea than in larger areas of corneal analysis. One reason for this finding may be the inclusion of more points of analysis for large areas, leading to a more complete analysis of the posterior corneal astigmatism, which is commonly very irregular in the keratoconus cornea and therefore more complex to analyze.[27] This is something that should be assessed further in future studies.

Regarding the shape factor, we found the geometry of the anterior and posterior corneal surfaces to be highly prolate, which is consistent with findings in previous studies of eyes with keratoconus.[4,10] Our research group evaluated the asphericity of the anterior and posterior corneal surfaces using a rotating Scheimpflug-based system for an 8.0 mm corneal diameter.[10] We found more negative asphericity (Q) values in both corneal surfaces with a higher grade of keratoconus. Savini et al.[4] also evaluated asphericity in an 8.0 mm corneal area with the Sirius device in 13 eyes with keratoconus. They found a mean Q value of -0.84 ± 0.41 (SD) (ICC 0.994) and -1.10 ± 0.70 (ICC 0.996) for the anterior corneal surface and the posterior corneal surface, respectively. These results were more negative than our results (anterior Q value derived from the shape factor of -0.77 and -0.83 for the posterior surface). This might be related to the differences in the severity of the keratoconus in the eyes in each study. The intrasubject repeatability reported by Savini et al.[4] for keratoconic eyes was very similar the repeatability we found (ICC 0.998 and 0.999 for anterior corneal surface and posterior corneal surface, respectively). Furthermore, we found small, but statistically significant differences in the shape factor between areas of analysis, with better repeatability for the 8.0 mm corneal diameter. A conic is a poor estimator of the peripheral shape of the anterior corneal surface. Therefore, there is a certain limitation in using a constant shape factor for finding an exact mathematic adjustment to the corneal surface, especially in keratoconus, in which the level of irregularity is high. González-Méijome et al.[28] obtained topographic data with the Medmont E300 videokeratoscope and analyzed the data using VOL-CT 6.89 software to calculate the Q values for different corneal diameters. The authors found different Q values depending on the area analyzed and that the difference between areas was greater as the astigmatism increased.

We also assessed the correlation between the S_w values for different corneal parameters and several clinical factors. Statistically significant, although weak correlations were found between S_w for some posterior curvature data and the curvature of both corneal surfaces. Specifically, the steeper the posterior cornea, the larger the variability in the repeated curvature measurements. This suggests a limited level of dependence of the consistency of the posterior corneal curvature measurements on the level of steepness of the posterior corneal surface. This finding was not reported in a previous study evaluating the intrasubject repeatability of the Sirius device in a normal healthy population.[13] This may be due to the difficulty in characterizing a significantly steep posterior corneal surface, which is normally associated with high levels of irregularity.[27] The analysis of the anterior corneal curvature is performed by combining the Placido-disk and Scheimpflug-photography data, whereas only data from the Scheimpflug camera is used for analysis of the posterior corneal shape. In agreement with our outcomes and using a swept-light source Fourier-domain AS-OCT and a high-resolution Scheimpflug camera, Szalai et al.[26] found that the S_w for the posterior corneal power was higher in a keratoconus group than in a normal group.

Finally, we analyzed the intrasubject repeatability of pachymetry and some additional anterior segment anatomical parameters. The morphologic parameters evaluated were consistent, with associated ICC values of over 0.989. Specifically, the variability in repeated CCT and MCT measurements was below 4 μm, which is not clinically relevant. This level of pachymetric repeatability is consistent with that reported in keratoconus eyes in previous studies using the same technology and only the Scheimpflug-photography analysis.[4,26,29] The level of repeatability for CCT and MCT is comparable to that obtained by our research group in normal eyes using the Sirius device.[13] Furthermore, the consistency for ACD and WTW parameters was excellent, with repeatability comparable to that reported for some other devices.[4,26]

In summary, the Sirius topography system provided consistent and repeatable anterior and posterior curvature measurements in keratoconus corneas as well as shape factor measurements for both corneal surfaces. A relative limitation was found in the analysis of the posterior corneal astigmatism assessed using the power vector components. In addition, other morphologic anterior segment parameters, such as pachymetry, ACD, and WTW, can be measured consistently in eyes with keratoconus using this fast and noninvasive technique.

WHAT WAS KNOWN

- Scheimpflug photography–based systems allow the clinician to obtain an analysis of the cornea and the anterior chamber in eyes with keratoconus.
- Systems based on the combination of Scheimpflug-photography and Placido-disk technology (Sirius) provide repeatable anterior and posterior corneal curvature in normal eyes.
- They also provide repeatable measurements of the anterior and posterior corneal shape factor and central and peripheral corneal thicknesses.

WHAT THIS PAPER ADDS

- The technology combining a rotating Scheimpflug camera and a Placido disk provided repeatable anterior and posterior curvature, pachymetric, and shape factor measurements in eyes with keratoconus.
- This technology provided WTW and ACD measurements in keratoconus eyes with excellent intrasubject repeatability.

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