Accuracy of corneal power measurements by a new Scheimpflug camera combined with Placido-disk corneal topography for intraocular lens power calculation in unoperated eyes

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PURPOSE: To assess the accuracy of the corneal power measurements with a new Scheimpflug camera combined with Placido-disk corneal topography (Sirius) (combined Scheimpflug camera–topographer) for intraocular lens (IOL) power calculation in unoperated eyes and compare the results with those by a validated corneal topographer (Keratron) (validated topographer).

SETTING: Private practice.

DESIGN: Case series.

METHODS: Consecutive patients having phacoemulsification and in-the-bag IOL implantation were studied. Intraocular lens power was calculated using the Hoffer Q, Holladay 1, and SRK/T formulas; the axial length, as measured by ultrasound immersion biometry; and 3 corneal power measurements: validated topographer simulated keratometry (K); combined Scheimpflug camera–topographer simulated K (derived from anterior corneal curvature only); combined Scheimpflug camera–topographer mean pupil power (derived from anterior and posterior corneal curvatures through ray tracing). The prediction error was calculated as the difference between the predicted refraction and the refraction measured 1 month postoperatively.

RESULTS: When the corneal power measurements from the combined Scheimpflug camera-topographer were used, the mean absolute error (MAE) ranged between 0.23 diopter (D) $\pm$ 0.24 (SD) (simulated K and Hoffer Q formula) and 0.33 $\pm$ 0.23 D (mean pupil power and SRK/T formula). There were no statistically significant differences between the MAE generated by the simulated Ks of the 2 devices with any of the 3 formulas.

CONCLUSION: Both corneal power measurements (simulated K and mean pupil power) provided by the new combined Scheimpflug camera–topographer were successfully entered into third-generation IOL power calculation formulas in unoperated eyes.

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Corneal power measurement is required by all formulas aimed at calculating the power of the intraocular lens (IOL) to be implanted in cataract surgery.[1–6] In addition to manual keratometry, surgeons can now choose among many devices for this purpose. We have recently shown that accurate and reliable measurements can be obtained with several technologies including standard Placido-disk corneal topography (TMS-2, Tomey Corp., and Keratron, Optikon 2000 SpA), automated keratometry (IOLMaster, Carl Zeiss Meditec AG), Scheimpflug camera imaging (Pentacam, Oculus, Inc.), and dual Scheimpflug

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camera imaging combined with Placido-disk corneal topography (Galilei, Ziemer Group).[7,8] Similar results have been reported by other groups.[9]

The purpose of this study was to evaluate the accuracy of IOL power calculation using a new instrument, the Sirius (Costruzione Strumenti Oftalmici), which measures corneal curvature by a Scheimpflug camera and a Placido disk, and compare its performance with that of a validated corneal topography system.[10,11]

PATIENTS AND METHODS

In this prospective study, all consecutive patients having cataract surgery by the same surgeon were enrolled. Phacoemulsification was performed through a temporal near-clear 3.5 mm incision under topical anesthesia; all eyes received an Acrysof MA60AC IOL (Alcon Laboratories, Inc.). Before being included in the study, each patient was informed of its purpose and gave his or her written consent. The study methods adhered to the tenets of the Declaration of Helsinki for the use of human participants in biomedical research.

Preoperatively, all patients had a slitlamp examination to rule out corneal abnormalities as well as standard testing, such as visual acuity, intraocular pressure measurement, and endothelial cell count. Corneal power was assessed using 2 devices: a Scheimpflug camera combined with Placido disk corneal topography (Sirius, software version 2.0) (combined Scheimpflug camera–topographer) and a traditional Placido-disk corneal topographer, the Keratron (validated topographer). The Sirius is a noninvasive system for measuring and characterizing the anterior segment. The scanning process acquires a series of 25 Scheimpflug images (meridians) and 1 Placido top-view image. The ring edges are detected on the Placido image so that height, slope, and curvature data are calculated using the arc-step method with conic curves. From the Scheimpflug images, profiles of the anterior cornea, posterior cornea, anterior lens, and iris are derived. Data for the anterior surface obtained from both the Placido image and Scheimpflug images are merged together using a proprietary method. All the other measurements for internal structures (posterior cornea, anterior lens, and iris) are derived solely from Scheimpflug data.

The Keratron is a Placido-disk corneal topographer that uses an arc-step algorithm to reconstruct the corneal profile as a series of arcs that would reflect the rays from the mires to the keratoscope's lens.[10,11]

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With both devices, simulated keratoemtry (K) was obtained by converting the measured radius into diopters (D) using the standard 1.3375 keratometric refractive index. Some differences, however, exist between the 2 instruments. The validated topographer, which projects 26 rings onto the cornea, calculates the simulated K as the mean between the power of the flattest meridian at the 3.0 mm diameter and the power of the meridian 90 degrees away from it, independently from its curvature (so that the latter is not necessarily the steepest meridian). The combined Scheimpflug camera–topographer, whose Placido disk projects 22 rings onto the cornea, calculates the simulated K by averaging the axial curvature from the fourth to the eighth Placido rings of the flattest and steepest meridians. The considered zone therefore has a variable diameter depending on the curvature of the cornea, and the principal meridians are not necessarily 90 degrees away.

In addition to simulated K, the Scheimpflug camera combined with Placido disk topography was used to measure the mean pupil power; that is, the corneal power calculated by ray tracing through the anterior and posterior corneal surfaces using the Snell law. For each point on the map, the angle of incidence was calculated relative to the anterior surface normal for incoming parallel rays. The angle of refraction was calculated using the Snell law with $n_{air} = 1.0$ and $n_{cornea} = 1.376$. This angle of refraction was used to determine the nonparallel direction of incoming rays relative to the posterior surface normal and to calculate the angle of incidence for the posterior surface. A new angle of refraction was calculated for the posterior surface using the Snell law with $n_{cornea} = 1.376$ and $n_{aqueous} = 1.336$. This final angle of refraction was used to calculate the intersection of the ray along the (0,0) axis, and the resultant focal length was used to determine mean pupil power for that point on the map. A diameter of 3.0 mm was arbitrarily chosen for all measurements, although the device offers the option of selecting a diameter ranging between 2.0 mm and 4.0 mm.

Because high repeatability has been reported for both instruments,[12,13] the first corneal power measurement provided by each was used for clinical and statistical purposes on condition that no artifacts related to blinking or tear-film breakup were evident.

Axial length (AL) measurements were performed using Ocuscan ultrasound immersion biometry (Alcon Laboratories, Inc.). A final evaluation was performed by assessing the subjective refractive outcomes 1 month postoperatively, which is when refractive stability can be expected with small-incision clear corneal surgery and the type of IOL implanted.[14–16] All eyes had a corrected distance visual acuity of 20/20. To calculate the mean prediction error in refractive outcome (mean arithmetic error), the measured manifest refractive spherical equivalent was subtracted from the predicted refraction (based on the IOL actually implanted) according to the Hoffer Q, Holladay 1, and SRK/T formulas.[2–4,6] The mean absolute error (MAE) was used for statistical comparisons. In addition to the mean values, the median absolute error was also calculated.

Constants Optimization

Predictions by the Hoffer Q, Holladay 1, and SRK/T formulas were optimized in retrospect by adjusting the pACD, SF, and A constants to give an arithmetic prediction error of zero in the average case, as previously performed by Olsen and Hoffer.[2,3,17,18] As a result, it was possible to evaluate the

Table 1. Optimized constants for IOL power calculation using ultrasound immersion biometry and the 3 corneal power measurements analyzed in this study.

Measurement	Hoffer Q (pACD)	Holladay (SF)	SRK/T (A-constant)
Validated topographer SimK	5.43 ± 0.27	1.65 ± 0.28	118.78 ± 0.50
Combined Scheimpflug camera–topographer SimK	5.29 ± 0.25	1.53 ± 0.25	118.60 ± 0.46
Combined Scheimpflug camera–topographer MPP	4.90 ± 0.29	1.17 ± 0.28	118.10 ± 0.47

pACD = personalized anterior chamber depth; MPP = mean pupil power; SF = surgeon factor; SimK = simulated keratometry

statistical error as representing the optimum prediction error rather than offset errors related to incorrect lens constants or systematic errors in the measuring environment.

Optimization was performed using Hoffer Programs (version 2.5, EyeLab).

Statistical Analysis

Repeated-measures of analysis of variance (ANOVA) was performed to compare the mean values of corneal power and MAEs in refractive outcome; the Friedman test (nonparametric repeated measures ANOVA) with the Dunn post test was performed for data without a normal distribution, as determined by the Kolmogorov-Smirnov test. A *P* value less than 0.05 was considered statistically significant. All statistical tests were performed using Graphpad Instat for Macintosh software (version 3a, Graphpad Software). For patients who had bilateral surgery, only the first eye operated on was considered for statistical analysis.

RESULTS

Forty patients were initially enrolled. After excluding 2 eyes of 2 patients (1 because of IOL implantation in the sulcus due to capsule rupture and 1 because of capsular bag distension syndrome), 38 eyes of 38 consecutive patients were analyzed. The mean age was 74.2 years ± 9.2 (SD); 25 patients were women. The mean AL was 23.56 ± 0.99 mm (range 21.61 to 25.87 mm).

The mean K power values given by the 3 corneal power measurements were statistically different ($P<.0001$, ANOVA). The Bonferroni post test showed that mean simulated K of the validated topographer (43.67 ± 1.45 D) was higher than the mean simulated K of the tested combined Scheimpflug camera–topographer (43.46 ± 1.45 D) as well as the mean pupil power of the latter device (42.87 ± 1.54 D). Post-test comparisons were all statistically significantly different from a statistical point of view ($P<.001$).

The mean arithmetic error was zero for all combinations of measurements due to constant optimization. Table 1 shows the optimized constants for each combination of corneal power measurement and IOL power calculation formula.

Table 2 shows the MAEs and median absolute errors for the Hoffer Q, Holladay 1, and SRK/T formulas. A statistically significant difference was found for the MAE calculated with the simulated K provided by the validated topographer ($P=.0017$) and the combined Scheimpflug camera–topographer ($P=.0014$). The Dunn post test showed that the MAE provided by the Hoffer Q formula was lower than that provided by the SRK/T in both cases ($P<.01$), while there was no statistically significant difference when comparing the Hoffer Q and the Holladay 1 formula and the latter and the SRK/T formula. The difference between the

Table 2. Mean absolute error and median absolute error in refraction prediction.

	Hoffer Q		Holladay		SRK/T		
Measurement	MAE ± SD (D)	Absolute Median (D)	MAE ± SD (D)	Absolute Median (D)	MAE ± SD (D)	Absolute Median (D)	*P* Value*
Validated topographer SimK	0.24 ± 0.27	0.15	0.28 ± 0.26	0.21	0.34 ± 0.26	0.29	.0017*
Combined Scheimpflug camera–topographer SimK	0.23 ± 0.24	0.13	0.26 ± 0.21	0.20	0.32 ± 0.22	0.28	.0014*
Combined Scheimpflug camera–topographer MPP	0.31 ± 0.24	0.27	0.30 ± 0.22	0.22	0.33 ± 0.23	0.29	NS
P value*	.0396*	—	NS	—	NS	—	—

MAE = mean absolute error (MAE); MPP = mean pupil power; NS = not significant; SimK = simulated keratometry
*Friedman test repeated-measures analysis of variance

MAEs obtained using the mean pupil power for calculations were not statistically significant.

For the Hoffer Q formula, the Friedman test showed a statistically significant difference beween the MAEs obtained with the 3 corneal power measurements ($P = .0396$); the MAEs were lower with the simulated K of both instruments than with the mean pupil power (although the post test showed that the difference was significant only between the simulated K of the combined Scheimpflug camera–topographer and the mean pupil power, $P < .01$). No differences were detected when considering the Holladay and SRK/T formulas.

With all formulas, the number of eyes with an MAE of 0.75 D or more was 3 (7.9%) with simulated K from validated topographer and 2 (5.3%) with simulated K from the combined Scheimpflug camera–topographer. When entering the mean pupil power into the Hoffer Q, Holladay, and SRK/T formulas, the number of eyes with an MAE greater than 0.75 D was 2 (5.3%), 3 (7.9%), and 1 (2.6%), respectively.

DISCUSSION

Our data show that the corneal power measurements provided by the Sirius, a new Scheimpflug camera combined with Placido-disk corneal topography, can be successfully entered into third-generation IOL power calculation formulas to achieve the desired postoperative refraction. The results obtained with the simulated K and mean pupil power measurements (MAE ranging between 0.23 $\pm$ 0.24 D and 0.33 $\pm$ 0.23 D) were close to those achieved in the same sample with a validated Placido-disk topographer, the Keratron, and better than those reported in most studies (Table 3).[7,8,18–21]

Such a low MAE is ascribable to the highly accurate corneal power measurements of the Sirius device; however, it should be considered that our sample was smaller than in most studies in Table 3 and did not include eyes shorter than 21.61 mm or longer than 25.87 mm, for which it is usually more difficult to achieve the desired refractive outcome. The lack of long eyes may also explain the relatively poorer performance of the SRK/T formula, which is known to provide better results in myopic eyes than the Hoffer Q and Holladay 1 formulas.[18,21]

Overall, the results obtained with the new Scheimpflug camera combined with Placido-disk topography matched those previously reported by our group with a similar device, the Galilei, a dual Scheimpflug analyzer that combines 2 Scheimpflug cameras and 1 Placido disk topographer,[8] and are better than those achieved with a rotating Scheimpflug camera, the Pentacam.[7] Taken together, these findings reinforce our opinion that when the simulated Ks are calculated, the addition of a Placido disk topographer increases the accuracy of the anterior corneal curvature measurements provided by Scheimpflug cameras. The simulated K of both devices, in fact, allowed us to obtain lower MAEs than those previously reported by our group using a Scheimpflug camera not combined with Placido disk topography.[8] Consistently, the precision of specular reflection topographers had been found to be superior to that of a Scheimpflug camera.[22] Because the Sirius device also gives the opportunity to rely only on the data of the Scheimpflug camera and discard those of the Placido disk, further studies are warranted to confirm the better performance of Placido disk topography compared with Scheimpflug analysis. However, the lower accuracy shown in this study by the mean pupil power should not be related to the presence of the Placido disk but to the fact that theoretical formulas to calculate the IOL power were developed to work with the simulated K and the standard 1.3375 keratometric index rather than with corneal power calculated using ray tracing.

Table 3. Mean absolute errors in refraction prediction reported in other studies of IOL power calculation in unoperated eyes.

Study*	Corneal Power Measured by	Axial Length Measured by	Formula	Sample Size (n)	Mean Absolute Error (D)
Present study	Sirius (SimK)	Immersion US	Hoffer Q	38	0.23 ± 0.24
Present study	Sirius (MPP)	Immersion US	Hoffer Q	38	0.31 ± 0.24
Savini et al.[7]	Galilei (SimK)	Immersion US	Hoffer Q	43	0.21 ± 0.18
Savini et al.[7]	Galilei (TCP)	Immersion US	Hoffer Q	43	0.27 ± 0.20
Savini et al.[6]	Pentacam (SimK)	Immersion US	Hoffer Q	41	0.44 ± 0.30
Olsen[18]	Autokeratometry	PCI	Olsen	461	0.43 ± NA
Hoffer[17]	Manual keratometry	Immersion US	Hoffer Q	317	0.45 ± 0.30
Narváez[19]	Manual keratometry	Immersion US	Hoffer Q	643	0.53 ± 0.44

MPP = mean pupil power; NA = not available; PCI = partial coherence interferometry; SimK = simulated keratometry; TCP = total corneal power; US = ultrasound
*First author

Entering the mean pupil power into these formulas, however, is possible because the MAE (ranging between 0.30 D and 0.33 D) is still relatively low. This is probably the most important result in this study. As in the case of the total corneal power of the Galilei system, the mean pupil power is calculated by ray tracing and does not rely on the keratometric index of refraction, a well-known source of error in IOL power calculation after refractive surgery.[23] The keratometric index depends on a fixed ratio between the anterior and posterior corneal curvature and becomes invalid once refractive surgery variably changes that ratio; therefore, simulated K cannot be used in corneal refractive surgery.[24] The mean pupil power, on the other hand, is calculated using ray tracing and the Snell law and thus is not affected by laser-induced refractive changes. Although a direct demonstration is needed to support this statement, it is likely that the good results we obtained in unoperated eyes will be replicated in eyes with previous corneal refractive surgery once the mean pupil power is entered into double-K formulas.[25]

Another interesting finding of our study is the excellent MAE obtained by the combination of the conventional Placido disk corneal topography system and immersion ultrasound biometry (range 0.24 $\pm$ 0.27 D to 0.34 $\pm$ 0.26 D, depending on the IOL power formula). These results are similar to those previously achieved with the same device in another study and confirm the high accuracy of standard corneal topography measurements for IOL power calculation.[8] The slight differences in the method adopted by the Keratron and Sirius to measure the radius of the principal meridians and compute the simulated K do not seem to be clinically relevant.

In addition to evaluating only unoperated eyes, this study was limited by the relatively small sample size and the lack of eyes with irregular corneas (eg, keratoconus) or an unstable tear film.

In conclusion, we found that corneal power measurements obtained with the Sirius Scheimpflug camera combined with corneal topography led to accurate results in IOL power calculation and can be safely relied on in unoperated eyes.

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