Accuracy of Scheimpflug corneal power measurements for intraocular lens power calculation

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PURPOSE: To evaluate the accuracy of corneal power measurements by the Pentacam Scheimpflug system for intraocular lens (IOL) power calculation.

SETTING: Studio Oculistico d'Azeglio, Bologna, Italy.

METHODS: Consecutive patients having phacoemulsification and in-the-bag IOL implantation were prospectively studied. Intraocular lens power was calculated by entering 3 combinations of data into the Hoffer Q formula: (1) corneal power measurements by corneal topography (simulated keratometry) and axial length (AL) measurements by Ultrascan ultrasound (US) immersion biometry; (2) Scheimpflug corneal power measurements (simulated keratometry) and US AL measurements; (3) corneal power and AL measurements by partial coherence interferometry (PCI) (IOLMaster). The prediction error was calculated as the difference between the predicted and the measured refraction 1 month postoperatively.

RESULTS: Forty-one eyes were evaluated. The mean arithmetic error was zero for all combinations of measurements due to constant optimization. The mean absolute error (MAE) of the Scheimpflug–US combination was good (0.44 diopters [D] $\pm$ 0.30 [SD]) but significantly higher than the topography–US combination and PCI (0.33 $\pm$ 0.29 D and 0.33 $\pm$ 0.23 D, respectively) ($P = .043$). The percentage of eyes with an MAE of 0.75 D or greater was higher with the Scheimpflug–US combination (7 eyes, 17%) than with the corneal topography–US combination (2 eyes, 4.8%) or PCI (3 eyes, 7.3%).

CONCLUSION: Corneal power measurements with the Pentacam Scheimpflug system should be used in IOL power calculation formulas with caution because the accuracy is good but is not as high as with standard measurement methods.

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Today, an increasing number of technological solutions are available for measuring the biometric parameters required to calculate the intraocular lens (IOL) power for patients having cataract surgery. Corneal power can be measured by manual and automated keratometry, corneal topography, image analysis, Scheimpflug camera imaging (Pentacam, Oculus, and Galilei, Ziemer), and slit-scanning topography (Orbscan II, Bausch & Lomb). Axial length (AL) can be measured by ultrasound biometry and partial coherence interferometry (PCI), available on the IOLMaster optical biometer (Carl Zeiss Meditec) and more recently on the Lenstar LS900 optical biometer (Haag-Streit). Modern ophthalmic practices that specialize in anterior segment and refractive surgery are likely to be equipped with many of these devices, all of which have features that enable the surgeon to accurately evaluate the patient preoperatively and postoperatively. Paradoxically, though, choosing from so much data for IOL power calculation can generate confusion because it is not easy to know which is the most accurate combination of corneal power and AL measurements.

Studies[1,2] have shown that AL measurements by IOLMaster PCI improve the accuracy of IOL power calculation over that with applanation ultrasound (US) A-scan biometry. The accuracy of PCI and ultrasound systems seems equivalent when immersion biometry is used.[3,4]

To our knowledge, the accuracy of Pentacam corneal power measurements has not been analyzed in patients having cataract surgery, although some studies compared these measurements with values provided by corneal topography and the IOLMaster biometer.[5–7] The aim of this study was to evaluate the results of Pentacam corneal power measurements in

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association with AL measurements by US immersion biometry for IOL power calculation and compare them with results obtained with 2 validated methods: (1) corneal topography combined with US immersion biometry and (2) PCI corneal power and AL measurements.

PATIENTS AND METHODS

This prospective study evaluated eyes of consecutive patients having cataract surgery. Before being included in the study, patients were informed of the study's purpose and gave written consent. The study methods adhered to the tenets of the Declaration of Helsinki for the use of human participants in biomedical research.

Cataract surgery was performed using topical anesthesia and phacoemulsification through a near-clear 4.0 mm incision. An AcrySof MA60AC IOL (Alcon Laboratories) was implanted in all cases.

Preoperative and Postoperative Testing

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. In addition, the preoperative examinations included corneal power assessment by 3 devices: the TMS-2 corneal topography system (Tomey), the Pentacam Scheimpflug system (software version 1.16), and the IOLMaster optical biometer (software version 5). For presentation of data, the measurements by the 3 devices are referred to as topography, Scheimpflug, and PCI, respectively. Axial length measurements were by Ultrascan (Alcon Laboratories) US immersion biometry (referred to as US for data reporting) and PCI (IOLMaster). With all devices, the corneal power was obtained by converting the measured radius into diopters using the standard 1.3375 keratometric refractive index. The method of corneal radius measurement, however, was different between the technologies.

The TMS-2 corneal topography system, like all topographers, derives curvature data from the measured distances between the rings projected onto the cornea. Specifically, it uses the power of Placido mires 7, 8, and 9 of the videokeratoscope for 128 equally spaced meridians to calculate the simulated keratometry.[8] During the examination, patients were instructed to keep both eyes open and blink often until an image was acquired. Only images with no distortions of the rings (due to an irregular tear film) were processed and used for IOL power calculation.

The Pentacam is a Scheimpflug camera that measures the corneal radius on the basis of acquired images of the cornea using triangle calculation. It identifies 600 absolute elevation values within the central 4.0 mm zone of the cornea. Elevation values are calculated independent of the position of the cornea. For this purpose, well-centered measurements are necessary. The Pentacam automatically evaluates correct positioning and begins taking Scheimpflug images as soon as the correct alignment is reached. For image acquisition, the slit light of the device successively illuminates 25 slits through the cornea while rotating around the apex by 1/25th of 180 degrees for each slit. The transparent cells of the cornea disperse the light diffusely. Thus, the anterior and posterior surfaces of the cornea can be detected. This allows calculation of the corneal radii for each point on the topographic surface map. A camera captures the Scheimpflug images at a 45-degree angle. The image plane of the camera is slanted at a 45-degree angle toward the optical axis of the camera optics. This permits a sharp image of the light-dispersing corneal plane to be recorded onto the image plane of the camera, allowing the Scheimpflug image to be taken. Topographic data are computed using the triangle calculation.[6] Scans were repeated if the quality specification provided by the instrument was other than "OK." The simulated keratometry values were calculated from the anterior corneal radius measured at 3.0 mm.

IOLMaster assessment of the corneal radii is based on image analysis, in which distances between light reflections on the cornea are measured. Six light spots are projected hexagonally in a 2.3 mm radius on the cornea. The device records the reflection of these spots, measuring the separation of opposite pairs of light spots and calculating the toroidal surface curvature.[9] The mean of 3 measurements was used as the corneal power to be entered into IOL power calculation formulas.

For AL measurement by PCI, the patient was asked to fixate on the internal light of the optical biometer, after which 5 measurements were automatically acquired. The mean value of the measurements was used for calculations.

For US immersion biometry, topical anesthesia was administered. Then, an Ossoinig immersion shell filled with hydroxypropyl methylcellulose 2% was placed between the lids in routine fashion, and the distance between the anterior corneal vertex and the retina was measured with a 10 MHz A-scan probe with fixation light. The assumed US velocity for the anterior chamber and the vitreous was set at 1532 m/second; for the lens, it was set at 1641 m/second. The operator took 10 measurements; to be used in the analysis, the measurement had to show, for each surface, vertical peaks of the same height and a mean AL with a standard deviation less than 0.05 mm. The mean of the measurements was used for statistical analysis.

A final evaluation of subjective refractive outcomes was performed 1 month postoperatively, when refractive stability can be expected with small-incision clear cornea surgery and the type of IOL implanted.[10–12] All eyes had a corrected distance visual acuity of 20/20. To calculate the mean prediction error in refractive outcome (mean arithmetic error [ME]), the measured refractive spherical equivalent was subtracted from the predicted refraction (relevant to the IOL

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Dr. Hoffer is the author of the Hoffer Q formula and owns The EyeLab, which sells the Hoffer Programs database. No other author has a financial or proprietary interest in any material or method mentioned.

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implanted) according to the Hoffer Q formula.[13–15] The mean absolute error (MAE) was used for statistical comparisons.[16]

Optimization of Constants

Predictions by the Hoffer Q formula were optimized in retrospect by adjusting the personalized anterior chamber depth constant to give an arithmetic prediction error of zero in the average case, as described by Olsen[17] and Hoffer.[13,14,16] In this way, it was possible to evaluate the 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 the Hoffer Programs database (version 2.5, EyeLab). Optimized constants were 5.52 for the combination of topography and US, 5.40 for the combination of Scheimpflug and US, and 5.68 for PCI (manufacturer suggests a value of 5.20).

Statistical Analysis

All statistical tests were performed using GraphPad InStat (version 3a for Macintosh, GraphPad Software). In cases of bilateral surgery, only the eye operated on first was considered in the statistical analysis.

Unless otherwise indicated, all data are expressed as the mean ± SD. Repeated-measures analysis of variance (ANOVA) was used to compare mean values (eg, corneal power) by the different methods. Because some data did not show a Gaussian distribution (according to the Kolmogorov-Smirnov test), the Friedman test was used. The Friedman is a nonparametric test that compares 3 or more paired groups. Linear regression was performed to analyze relationships between variants. Ninety-five percent limits of agreement (LoA) were calculated according to the method proposed by Bland and Altman.[18] A P value less than 0.05 was considered statistically significant.

RESULTS

Of the 44 eyes (44 patients) in the study, 3 were excluded because the AL could not be measured by PCI due to posterior subcapsular opacities of the lens. Thus, 41 eyes (41 patients) were included in the statistical analysis. Of the 41 patients, 11 were men and 30 were women. The mean age of the patients was 76.5 ± 8.4 years.

The difference in the mean keratometric values between the 3 measurement devices was statistically different ($P = .0001$, ANOVA). The Bonferroni posttest showed no statistically significant difference between the mean topography values (43.85 ± 1.49 D) and the mean PCI values (43.97 ± 1.44 D), whereas the mean Scheimpflug values (43.67 ± 1.49 D) were statistically significantly lower than the mean topography values ($P < .05$) and mean PCI values ($P < .001$). The 95% LoA were larger between topography and Scheimpflug (from –0.83 to +1.19 D) and between PCI and Scheimpflug (from –0.59 to +1.18 D) than between topography and PCI (from –0.63 to +0.39 D).

The mean AL values were similar between US and PCI (mean 23.46 ± 1.49 mm and 23.50 ± 1.5 mm, respectively; range 21.34 to 28.83 mm and 21.35 to 28.86 mm, respectively). The mean difference between US and PCI was –0.047 ± 0.09 mm (range −0.30 to +0.32 mm; median −0.05 mm). With both techniques, the AL was lower than 22.0 mm in 4 eyes (9.7%), between 22.0 mm and 24.5 mm in 29 eyes (70.7%), between 24.5 mm and 26.0 mm in 5 eyes (12.2%), and longer than 26.0 mm in 3 eyes (7.3%).

Table 1. Mean arithmetic and absolute refraction errors (predicted – measured) and range.

Parameter	PCI	Topography + US	PCI + US	P Value
ME (D)	0.00 ± 0.41	0.00 ± 0.46	0.00 ± 0.54	> .05
MAE (D)	0.33 ± 0.23	0.33 ± 0.29	0.44 ± 0.30	.043
Range (D)	−0.82 to 0.76	−1.29 to 0.84	−1.11 to 1.06	NA

MAE = mean absolute error; ME = mean arithmetic error; NA = not applicable; PCI = partial coherence interferometry; US = ultrasound immersion biometry

Table 1 shows the ME and MAE values for the Hoffer Q formula. As expected, the ME was zero with all methods due to constant optimization. The MAE was higher with the combination of Scheimpflug and US than with the combination of topography and US. It was also higher than with PCI. These differences were statistically significant ($P = .043$, Friedman test).

The percentage of eyes with an MAE of 0.75 D or greater was higher with the combination of Scheimpflug and US (7 eyes, 17%) than with the combination of topography and US (2 eyes, 4.8%) or with PCI (3 eyes, 7.3%).

Linear regression between the corneal power difference measured by Scheimpflug with respect to topography and PCI values and the amount of prediction error showed a statistically significant relationship in both cases (Scheimpflug–topography: $r = -0.6241$, $P < .0001$; Scheimpflug–PCI: $r = -0.6870$, $P < .0001$). Figure 1 shows a scatterplot of the linear regression between the difference in corneal power in the first case (Scheimpflug − topography). These findings show that the lower the Scheimpflug corneal power assessment (with respect to the other measurements), the more positive the prediction error.

DISCUSSION

The Pentacam Scheimpflug system is a relatively new and rather expensive instrument that provides ophthalmologists with a large amount of data that can be useful in a variety of situations, including refractive surgery, phakic IOL implantation, and keratoconus diagnosis.[19–21] It would be valuable to know whether the corneal power measurements that it provides are reliable for IOL power calculation. In the present study, the accuracy was good; Scheimpflug corneal

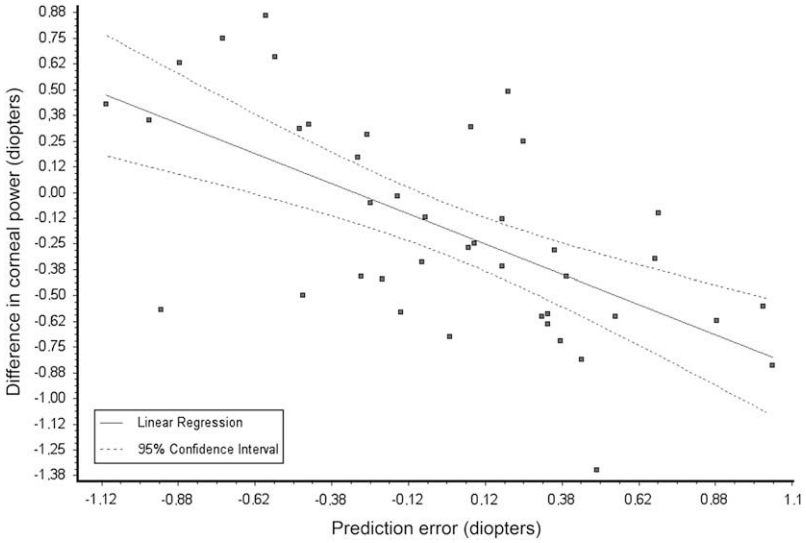

Figure 1. Linear regression between the difference in corneal power (Scheimpflug − topography, *y* axis) and the prediction error (predicted refraction − measured postoperative refraction, *x* axis) by the Hoffer Q formula.

power measurements combined with US measurements would have resulted in an MAE of 0.75 D or higher in 7 (17%) of 41 eyes. Optimized constants must be used to yield these results.

The MAE of the combined Scheimpflug and US corneal power measurements (0.44 ± 0.30 D) compares favorably with values reported in previous studies assessing the accuracy of autokeratorefractometry combined with PCI (0.43 ± 0.37 D),[2] manual keratometry combined with US (range 0.43 ± 0.5 to 0.55 ± 0.5 D),[16,22] and PCI (0.39 ± 0.29 D).[4]

On the other hand, when compared with 2 traditional methods of biometry, the Scheimpflug corneal power measurements showed a higher MAE; that is, lower accuracy. This finding shows that caution should be used before entering these values into IOL power calculation formulas. Because systematic errors (eg, corneal power underestimation) were eliminated by constant optimization, we assume that the higher incidence of prediction errors was the result of inaccurate measurements of the corneal radius and, as a consequence, of the corneal power. The strongest evidence supporting this observation is the highly statistically significant relationships detected by linear regression between the corneal power difference measured by the Scheimpflug system (with respect topography and PCI values) and the amount of prediction error. The lower accuracy of Scheimpflug simulated keratometry values can also be seen in the almost double 95% LoA between the Scheimpflug system and the other 2 instruments compared with the 95% LoA between PCI and topography.

The 95% LoA between the Scheimpflug and topography measurements (from −0.83 to +1.19 D) in this study are similar to those reported by our group (from −0.95 to +1.02 D) in a separate sample.[5] In our opinion, the most likely explanation for such agreement is the relatively long time required by the Scheimpflug device to acquire the image. We found that it may be difficult for the oldest patients to maintain fixation during scan acquisition, thus lowering the accuracy of corneal power measurements, even when the device still gives the "OK" quality specification.

Although this is the first study to evaluate the accuracy of Pentacam corneal power measurements for IOL power calculation, other studies have compared these values with those of the IOLMaster device and corneal topography. However, these studies did not enter the values into formulas for IOL power calculation. Reuland et al.[6] compared the Pentacam and IOLMaster corneal curvature. They found a statistically significant difference in 1 of the 2 measured meridians and a smaller, not statistically significant difference for the other meridian. They concluded that this difference is not clinically relevant and that, as a consequence, the Pentacam can be used as a biometric device. We concur that the Pentacam data can be used to calculate the IOL power; however, we would like to reiterate that the problem is not represented by the difference in the mean values between any device because overestimation or underestimation of the corneal power can be easily compensated by constant optimization. Instead, we should focus our attention on the LoA, which was similar in Reuland et al.'s study and our study. Thus, Reuland et al.'s results show that caution is warranted when using Pentacam corneal power measurements for IOL power calculation. The same observation can be applied to our previous study,[5] in which the mean values of the Pentacam device and corneal topography were not statistically different; however, agreement was poor.[5] Finally, Elbaz et al.[7] also report wide 95% LoA (range

–1.478 to +0.536 D) between IOLMaster and Pentacam measurements and a statistically significant underestimation of corneal power by the Pentacam device. Bases on this, the authors state that the measurements provided by these instruments are not interchangeable.

The present study has limitations. First, the sample we evaluated was relatively small. A larger sample might have allowed us to achieve a higher statistically significant difference. Second, our sample did not include eyes with irregular corneas (eg, keratoconus) or an unstable tear film; in these cases, comparison between the Scheimpflug device and the other instruments may lead to different results.[5] Third, for the sake of simplicity, we do not report the results with other IOL power calculation formulas. The results with the Hoffer Q formula were similar to those with the Holladay 1 and SRK/T formulas (data not shown),[23,24] although the difference was statistically significant only with the Holladay 1 formula ($P = .039$, ANOVA).

In conclusion, our data show the Pentacam corneal curvature measurements can be used for IOL power calculation in combination with AL measurements by US immersion biometry but do not offer the same accuracy of standard methods such as corneal topography and PCI optical biometry.

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