ARTICLE

Scheimpflug photography keratometry readings for routine intraocular lens power calculation

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PURPOSE: To prospectively evaluate keratometry (K) values obtained by Scheimpflug photography in eyes scheduled for cataract surgery, compare the results with K values obtained with an autokeratometer (automated K), and evaluate the K values in commonly used intraocular lens (IOL) power calculation formulas for routine cataract surgery.

SETTING: Private clinical ophthalmology practice, Lynwood, California, USA.

METHODS: The mean simulated K power (simulated K), equivalent K (equivalent K), and true net power (true net K) readings from the Pentacam Comprehensive Eye Scanner were compared with the automated K readings. Automated K, simulated K, and equivalent K values were compared in commonly used IOL power calculation formulas.

RESULTS: The mean automated K value was 43.49 diopters (D) $\pm$ 1.75 (SD) and the mean simulated K value, 43.49 $\pm$ 2.00 D (P>.1). The mean equivalent K value was 43.78 $\pm$ 1.97 D and exceeded the mean automated K and simulated K by 0.29 D (P>.1). The mean true net K was 42.31 $\pm$ 2.13 D, which was 1.18 D lower than the automated K and simulated K values (P = .015). The IOL prediction mean absolute error was 0.41 $\pm$ 0.27 D using the automated K method, 0.50 $\pm$ 0.36 D using the simulated K method (difference 0.09 D) (P>.1), and 0.65 $\pm$ 0.35 D using the equivalent K method (difference 0.24 D) (P<.01).

CONCLUSION: The K values from Scheimpflug photography did not improve accuracy over autokeratometer values for routine IOL power calculation.

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The Pentacam Comprehensive Eye Scanner (Oculus) is a noncontact optical system designed to image the anterior segment of the eye. It uses a Scheimpflug camera to produce a 3-dimensional analysis of the anterior segment. The instrument has proved to be valuable in the evaluation of the cornea[1–3] and the anterior chamber.[4]

The Pentacam device evaluates the anterior corneal surface and measures a simulated keratometry (K) value (simulated K). The unit also measures the posterior corneal radius, anterior corneal radius, and central corneal thickness (CCT). The computer software uses the correct indices of refraction to calculate the total corneal power. This measurement of the total corneal power is called the true net power (true net K) and is different from the corneal vertex power measured by manual, automated, or simulated keratometry. The true net K is not usually recommended for routine intraocular lens (IOL) power calculation because all commonly used IOL power formulas require the corneal vertex power based on a 1.3375 index of refraction, not the total corneal power. In an effort to keep the standard that has been set for IOL power calculation, the Pentacam unit was programmed to calculate an equivalent K reading (equivalent K), labeled the Holladay Report. The software of the unit evaluates the measurements taken at the central corneal front

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surface and adjusts them to reflect the difference in the back-surface power of the cornea for the mean of the population. The equivalent K readings can then be used in every IOL calculation formula without adjustment.

The purpose of this prospective study was twofold. The first goal was to evaluate the Pentacam K values in 32 normal cataractous eyes scheduled for routine cataract surgery with IOL implantation and compare the results with K values obtained with an autokeratometer (automated K). The second was to evaluate these K values in the commonly used IOL power calculation formulas for IOL power prediction error in routine cataract surgery.

PATIENTS AND METHODS

This prospective observational study comprised patients scheduled for cataract surgery between March 1, 2007, and March 15, 2007. Each eye was first evaluated with the Pentacam Comprehensive Eye Scanner (software version 1.14). All patients maintained good eye alignment, and the evaluations resulted in good-quality outputs. The mean simulated K, equivalent K, and true net K values were recorded in each eye. All 3 K values were compared with the automated K readings obtained by a Nidek autokeratometer that uses a keratometric refractive index of 1.3375. In all cases, the mean K value was used.

For the IOL power calculations, only the simulated K and equivalent K readings from the Pentacam were used; the results were compared with the automated K values. The IOL power calculations were performed using the Hoffer Q,[5] Holladay 1,[6] and SRK/T[7] formulas. The Hoffer Q formula was used in eyes with an axial length (AL) shorter than 22.0 mm; the Holladay 1 formula, in eyes with an AL between 24.5 mm and 26.0 mm; the SRK/T formula, in eyes with an AL longer than 26.0 mm; and an average of the 3 formulas in eyes with an AL between 22.0 mm and 24.5 mm, as advised by Hoffer.[5] The constants for all 3 formulas (pACD for the Hoffer Q; SF for Holladay 1; A constant for SRK/T) were personalized for each K-reading technique to eliminate errors caused by other factors.

All surgery was performed by the same surgeon (H.J.S.) using a 2.75 mm limbal incision. An acrylic IOL (SA60AT, Alcon Surgical, Inc.) was placed in the capsular bag in all cases. The final refraction was obtained 10 to 12 weeks after cataract surgery.

For each operated eye, the predicted IOL power that would give the actual postoperative refraction was calculated. The IOL prediction error is obtained by subtracting the predicted IOL power from the implanted IOL power. A positive value indicates that the formula predicted a lower power IOL than the implanted power and would have left the eye more hyperopic than desired. A negative value indicates that the formula predicted a higher power IOL than the implanted power and would have left the eye more myopic than desired. For each operated eye, the following were evaluated: (1) the mean arithmetic IOL prediction error and its standard deviation; (2) the mean absolute IOL prediction error (MAE) and its standard deviation; (3) the range of the prediction errors; (4) the number of eyes in which the IOL prediction error was within ±0.50 diopter (D), ±1.00 D, and ±2.00 D.

Statistical analysis was performed using SPSS for Windows software (version 17.0, SPSS, Inc.). Normality was checked by the Shapiro-Wilk test. The Pearson product-moment correlation coefficient (*r*) was used to statistically evaluate each scattergram correlation. Paired *t* tests were performed to establish whether there was a statistically significant difference between the different mean K readings as well as between the absolute IOL power prediction errors. A *P* value less than 0.05 was considered statistically significant.

RESULTS

Thirty-two eyes of 27 patients (12 men, 15 women) were enrolled the study. The mean age of the patients was 73.74 years ± 7.42 (SD) (range 54 to 92 years). There were 20 right eyes and 12 left eyes.

The mean AL was 24.27 ± 1.17 mm (range 21.22 to 26.38 mm). Three eyes (9%) had an AL less than 22.0 mm (Hoffer Q formula used), 24 eyes (75%) has an AL between 22.0 mm and 24.5 mm (average of 3 formulas used), 4 eyes (13%) had an AL between 24.5 mm and 26.0 mm (Holladay 1 formula), and 1 eye (3%) had an AL greater than 26.0 mm (SRK/T formula).

The mean automated K was 43.49 ± 1.75 D (range 38.87 to 46.37 D), the mean simulated K was 43.49 ± 2.00 D, the mean equivalent K was 43.78 ± 1.97 D, and the mean true net K was 42.31 ± 2.13 D. Figure 1 shows the difference between the simulated K and automated K readings. The correlation coefficient was 0.97 ($P<.001$). However, the simulated K readings were slightly lower than the automated K readings in flat corneas and slightly higher in steep corneas. Figure 2 shows the difference between the equivalent K and the automated K readings. The correlation coefficient was 0.94 ($P<.001$). However, the equivalent K readings were slightly higher than the automated K readings in steeper corneas. Figure 3 shows the difference between the true net K and the automated

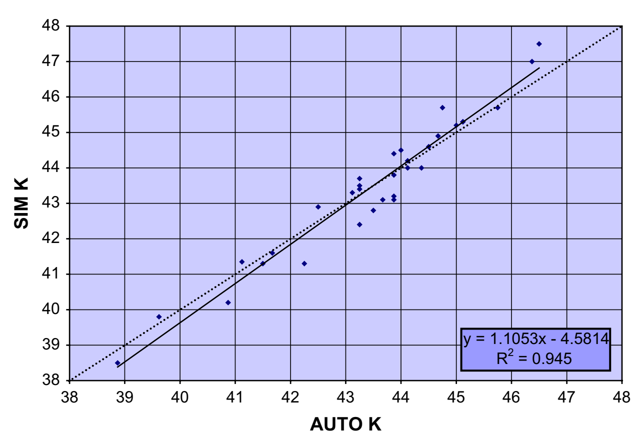

Figure 1. Scattergram of the simulated K (SIM K) versus automated K (AUTO K) readings (diopters). The solid line represents the regression line, and the dotted line represents the 1:1 line

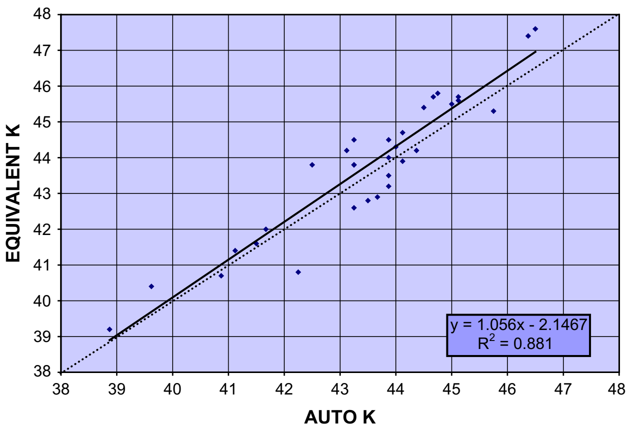

Figure 2. Scattergram of the equivalent K versus automated K (AUTO K) readings (diopters). The solid line represents the regression line, and the dotted line represents the 1:1 line

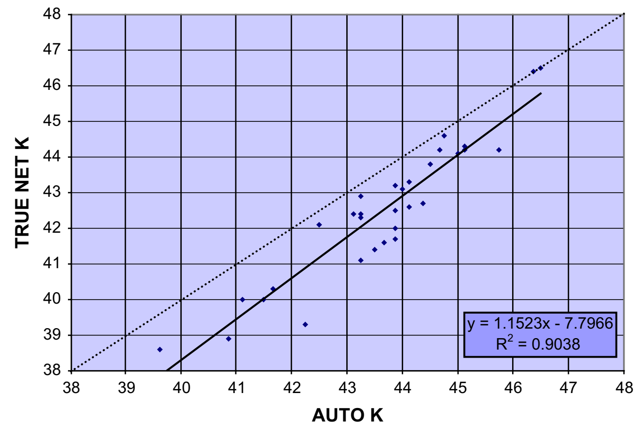

Figure 3. Scattergram of the true net K versus automated K (AUTO K) readings (diopters). The solid line represents the regression line, and the dotted line represents the 1:1 line

K readings. The correlation coefficient was 0.95 ($P<.001$). However, the true net K readings were consistently lower than the automated K readings, with a widening gap when the cornea flattened. Table 1 shows the difference between the Pentacam and automated K readings. The differences between mean simulated K and mean automated K (95% confidence interval [CI], −0.17 to +0.17) and mean equivalent K and mean automated K (95% CI, +0.05 to +0.53) were not statistically significant (both $P>.1$). The difference between mean true net K and mean automated K (95% CI, −1.42 to −0.82) was statistically significant ($P = .015$).

Table 2 shows the optimized constant values used in this study for each IOL power calculation formula. It also shows the adjustments needed when the Pentacam K readings were used instead of the automated K values.

Table 3 shows the IOL prediction errors with each K reading method. The MAEs with the simulated K and equivalent K methods exceeded the MAE with the automated K method by 0.09 D ($P>.1$) and 0.24 D ($P<.01$), respectively. The percentage of prediction errors within ±0.50 D and within ±1.00 D was the highest with the automated K method and simulated K method and lowest with the equivalent K method. All prediction errors were within ±2.00 D irrespective of the keratometric measurement method.

DISCUSSION

Automated keratometry is a clinically useful estimation of the central corneal power in normal eyes that have had no previous corneal surgery, and the generated K values are commonly used in current IOL power calculations. Keratometers estimate corneal power by reading 4 to 6 points of the central corneal zone. This central zone varies from 2.25 to 4.00 mm depending on the keratometer used and the corneal flatness.

Simulated keratometry is an output from computerized corneal topography systems, including the Pentacam system used in this study. It is obtained by averaging power along the 3.0 mm central ring, contrary to manual and automated keratometry in which only 4 to 6 points are measured. In our study, the mean

Table 1. Difference between Pentacam K readings and automated K readings.

Parameter	Difference (D) Mean ± SD	Range (D)	P Value
SimK − auto K	−0.0003 ± 0.50	−0.95 to +0.95	>.1*
Equivalent K − auto K	+0.29 ± 0.69	−1.45 to +1.25	>.1*
True net K − auto K	−1.17 ± 0.71	−2.95 to +0.03	.015

Auto K = automated K; SimK = simulated K
*No statistically significant difference

Table 2. Optimized constants used in this study* and adjustment needed to the constants when the Pentacam K readings are used instead of the automated K values.

K Reading Method	Optimized Constant (Adjustment) Hoffer pACD	Holladay SF	SRK/T A Constant
AutoK	4.96	1.21	118.17
SimK	4.94 (−0.02)	1.19 (−0.02)	118.11 (−0.06)
Equivalent K	5.23 (+0.27)	1.39 (+0.18)	118.46 (+0.29)

Auto K = automated K; SimK = simulated K
*In this study, axial length was measured with an immersion A-scan and an acrylic IOL (SA60AT, Alcon Surgical, Inc.) was used during surgery.

Table 3. Intraocular lens prediction error.

	Mean ± SD			Prediction Errors, n (%)	
K Reading Method	Arithmetic Error (D)	Absolute Error (D)	Range (D)	Within ±0.50 D	Within ±1.00 D
Auto K	−0.001 ± 0.49	0.41 ± 0.27	−1.10 to 0.73	19 (59)	31 (97)
SimK	0.003 ± 0.73	0.50 ± 0.36	−1.27 to 1.38	19 (59)	29 (91)
Equivalent K	−0.002 ± 0.73	0.65 ± 0.35	−1.40 to 0.70	11 (34)	28 (88)

Auto K = automated K; SimK = simulated K

simulated K values from the Pentacam were similar to the mean automated K values. However, the individual differences ranged from −0.95 to +0.95 D. The simulated K measurements were slightly lower than the automated K measurements in flat corneas and slightly higher in steep corneas. The MAE in IOL power calculations using the simulated K values was slightly higher than the MAE obtained with the automated K values (0.50 ± 0.36 D versus 0.41 ± 0.27 D); however, the difference was not statistically significant ($P>.1$).

In manual, automated, and simulated keratometry, the keratometer measures the anterior radius of corneal curvature in millimeters, which is translated into diopters by considering the entire corneal power to be at the anterior corneal surface. The relationship between the keratometric readings (in diopters) and the value of the anterior corneal radius (r in millimeters) is

$$D = 1000\,(n-1)/r \tag{1}$$

where n is the keratometric index of refraction

The index of refraction (n) varies whether the keratometer is measuring the corneal back vertex power or the total corneal power.[8,9] Original keratometers (Javal) incorrectly assumed that the back and front corneal radii were equal and therefore used a tear-film index of 1.336. Later, to standardize the results, an arbitrary index of refraction of 1.3375 was used so that a radius of 7.5 mm would yield 45.0 D.[8] According to Haigis,[9] the Javal index of 1.3375 can be deduced by calculating the corneal back vertex power of the Gullstrand eye.

The Pentacam used in this study measures the posterior corneal radius in addition to the anterior corneal radius and also measures CCT. The computer software uses the correct indices of refraction (1.376 for the cornea, 1.336 for the aqueous humor, and 1.000 for air) to calculate the total corneal power. This measurement of the total corneal power by the Pentacam is called the true net power (true net K) and is different from the corneal vertex power measured by automated and simulated keratometry. Holladay noted that the true net K values are consistently lower than the simulated K measurements (J.T. Holladay, MD, "IOL Calculations After Refractive Surgery with the Pentacam," Cataract and Refractive Surgery Today, 2007, July Supplement, pages 11–13). Our study confirms these findings. We recorded a 1.17 D lower mean true net K value than automated and simulated K values. The same discrepancy was also reported by Tang et al.,[10] who measured corneal power with high-speed optical coherence tomography (OCT). The mean total corneal power obtained by OCT and topography was significantly lower than the simulated K power (mean difference −1.13 ± 0.21 D) ($P<.0001$).

The total corneal power can also be deduced from the anterior corneal radius measured by automated K or simulated K and by substituting the Javal keratometric index of 1.3375 with the Zeiss keratometric index[9] of 1.3315 in equation 1. This measurement should theoretically be identical to the total corneal power (true net K) measured by the Pentacam. In an average cornea with an anterior radius of 7.76 mm, the difference between the corneal back vertex power ($n = 1.3375$ in equation 1) and the total corneal power ($n = 1.3315$ in equation 1) is 0.77 D. In our study, the mean difference between the automated K readings and the Pentacam true net K value was 1.17 ± 0.71 D. This higher than expected difference in our study suggests that the effective index of refraction needed to measure the total corneal power solely from its anterior curvature is actually closer to 1.329 than to the 1.3315 used in some keratometers. A similar index (1.329) was calculated by Dubbelman et al.[11] in 114 eyes using Scheimpflug imaging of the anterior and posterior corneal surfaces and by Fam and Lim[12] (1.327) in a large population-based study of 2429 patients measured with the Orbscan II (Bausch & Lomb).

True net K is not usually recommended for routine IOL power calculation because all commonly used IOL power formulas require the corneal vertex power based on a 1.3375 index of refraction. In an effort to keep the standard that has been set for IOL power calculation, the Pentacam unit was programmed to calculate instead an equivalent K reading (ie, the Holladay Report). The software of the unit used in this study evaluated the measurements taken at the central 4.0 mm corneal front surface, adjusting them to reflect the difference in the back-surface power of the cornea for the mean of the population. In our series, the mean equivalent K value was higher than the mean automated K and simulated K values by approximately 0.29 D ($P>.1$). When the equivalent K values were used in our routine IOL power calculations, the A constant had to be increased by 0.29 (Table 2). Despite optimization of the constants, the absolute IOL prediction error was statistically signficantly higher with the equivalent K method (0.65 $\pm$ 0.35 D) than with the automated K method (0.41 $\pm$ 0.27 D) ($P<.001$). Newer Pentacam software allows measurements of the equivalent K within 1.0 mm, 2.0 mm, 3.0 mm, and 4.5 mm of the central cornea. These measurements were not available with the unit used in this study, and therefore they were not evaluated. The intent of the Holladay Report with its equivalent K display is to reflect more accurately the change obtained by refractive surgery in an effort to improve IOL power calculations in these cases. However, a study by Savini et al.[13] showed poor accuracy in laser in situ keratomileusis eyes using the Pentacam Holladay Report equivalent K at the recommended 4.5 mm zone.

Traditionally, routine IOL power calculation uses manual, automated, or simulated K readings within the formulas. In our small series, the Pentacam K readings did not improve accuracy. Further studies with the newer Pentacam software that provides increased image resolution in a larger series are needed to better evaluate these K readings in the context of routine IOL power calculation.

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