COMPARISON OF INTRAOCULAR LENS POWER CALCULATION METHODS IN EYES THAT HAVE UNDERGONE LASER-ASSISTED IN-SITU KERATOMILEUSIS

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ABSTRACT

Purpose: To compare methods of calculating intraocular lens (IOL) power for cataract surgery in eyes that have undergone myopic laser-assisted in-situ keratomileusis (LASIK).

Methods: Eleven eyes of eight patients who had previously undergone myopic LASIK (amount of LASIK correction, –5.50 ± 2.61 D (SD); range, –8.78 to –2.38 D) and subsequently phacoemulsification with implantation of the SA60AT IOLs were included (refractive error after cataract surgery, –0.61 ± 0.79 D; range, –2.0 to 1.0 D). We evaluated the accuracy of various combinations of (1) single-K versus double-K (in which pre-LASIK keratometry is used to estimate effective lens position) versions of the IOL formulas; the Feiz-Mannis method was also evaluated; (2) four methods for calculating corneal refractive power (clinical history, contact lens overrefraction, adjusted EffRP ($EffRP_{adj}$), and Maloney methods); and (3) four IOL formulas (SRK/T, Hoffer Q, Holladay 1, and Holladay 2). The IOL prediction error was obtained by subtracting the IOL power calculated using various methods from the power of the implanted IOL, and the F test for variances was performed to assess the consistency of the prediction performance by different methods.

Results: Compared to double-K formulas, single-K formulas predicted lower IOL powers than the power implanted and would have left patients hyperopic in the majority of the cases; the Feiz-Mannis method had the largest variance. For the Hoffer Q and Holladay 1 formulas, the variances for $EffRP_{adj}$ were significantly smaller than those for the clinical history method (0.43 D^2 vs 1.74 D^2, $P = .018$ for Hoffer Q; 0.75 D^2 vs 2.35 D^2, $P = .043$ for Holladay 1). The Maloney method consistently underestimated the IOL power but had significantly smaller variances (0.19 to 0.55 D^2) than those for the clinical history method (1.09 to 2.35 D^2) ($P < .015$). There were no significant differences among the variances for the four formulas when using each corneal power calculation method.

Conclusions: The most accurate method was the combination of a double-K formula and corneal values derived from $EffRP_{adj}$. The variances in IOL prediction error were smaller with the Maloney and $EffRP_{adj}$ methods, and we propose a modified Maloney method and second method using Humphrey data for further evaluation.

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INTRODUCTION

An unfortunate consequence of corneal refractive surgery is difficulty in accurately calculating intraocular lens (IOL) power in eyes undergoing cataract surgery.[1-3] These IOL power errors can be attributed primarily to three factors: (1) inaccurate measurement of anterior corneal curvature by standard keratometry or computerized videokeratography; (2) inaccurate calculation of corneal power from the anterior corneal measurement by using the standardized value for refractive index of the cornea (1.3375); this occurs because procedures that remove corneal tissue (eg, excimer laser photorefractive keratectomy [PRK] or laser-assisted in-situ keratomileusis [LASIK]) change the relationship between the front and back surfaces of the cornea; and (3) incorrect estimation of effective lens position (ELP) by the third- or fourth-generation formulas when the postoperative corneal power values are used;[4,5] the Haigis formula is an exception because it does not use the K-reading for ELP prediction.[6]

Several methods have been proposed to improve the accuracy of estimating corneal power in eyes that have undergone LASIK. These approaches can be categorized according to whether or not they require knowledge of data acquired before LASIK was performed. Those that depend upon pre-LASIK data and the specific values that are needed include the clinical history method[7] (manifest refraction and corneal power values), Feiz-Mannis

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method[8] (manifest refraction and corneal power values), and a topographical method based on adjusting the measured EffRP ($EffRP_{adj}$)[9] (manifest refraction) method. Methods that do not require knowledge of any of the pre-LASIK data include contact lens overrefraction, adjusting corneal power using a correcting factor,[10] direct measurement using Orbscan topography,[11] and a method proposed by Maloney (Robert K. Maloney, MD, personal communication, October 2002).

Briefly, the calculations in methods evaluated in this study are as follows:

1. Clinical history: Postoperative corneal power is calculated by subtracting the change in manifest refraction at the corneal plane induced by the refractive surgical procedure from the corneal power values obtained prior to refractive surgery.[7]
2. Feiz-Mannis method[8]: To first determine the IOL power as if the patient had not undergone corneal refractive surgery, IOL power is calculated using pre-LASIK corneal power values and the axial length measured just prior to cataract surgery. To this value is added the LASIK-induced change in refractive error divided by 0.7.
3. $EffRP_{adj}$: The $EffRP_{adj}$ is calculated by multiplying the LASIK-induced refractive change by 0.15 D and subtracting this value from the measured EffRP, which is displayed in the Holladay Diagnostic Summary of the EyeSys Corneal Analysis System (effective refractive index: 1.3375) (EyeSys Technologies, Inc, Houston, Texas).[9]
4. Contact lens overrefraction[12]: Corneal power is calculated as the sum of the contact lens base curve, power, and overrefraction minus the spherical equivalent of the manifest refraction without a contact lens.
5. Maloney method: The corneal power at the center of the axial topographic map is modified according to this formula:

$$\text{Central power} = [\text{central topographic power} \times (376/337.5)] - 4.9$$

In the third- or fourth-generation IOL calculation formulas, corneal power values are used in the calculation of the ELP. In eyes following myopic corneal refractive surgery, the calculated ELP will be erroneously anterior if the lower postoperative corneal power values are used; this results in implantation of a lower-power IOL, predisposing to a postoperative hyperopic refractive error. Aramberri[4] proposed a modified IOL formula, in which the K-reading before refractive surgery is used to estimate the ELP and the K-reading after refractive surgery is used to calculate the IOL power (the so-called double-K formula), in contrast to the traditional method, in which one K-reading (the so-called single-K formula) is used for both calculations. Based on Aramberri's work, we theoretically compared the IOL power calculated using single-K and double-K methods and found that single-K formulas underestimate the IOL power in myopic LASIK eyes and that the ELP-related prediction errors varied with the formulas, the amount of LASIK correction, and the axial length of the eye.[5,13]

The purpose of this study was to evaluate the accuracy of various methods of IOL power prediction using combinations of both single-K and double-K versions of four IOL formulas (SRK/T, Hoffer Q, Holladay 1, and Holladay 2), with four methods for calculating corneal power (clinical history, contact lens overrefraction, $EffRP_{adj}$, and Maloney methods); the Feiz-Mannis method was also evaluated.

METHODS

Subjects

Upon obtaining institutional review board approval, we analyzed IOL power results in 11 consecutive eyes of eight patients who had previously undergone LASIK for myopia and underwent cataract surgery from July 2002 through July 2003. All cataract surgeries were performed in the same manner by the same surgeon (D.D.K.) using a temporal clear corneal incision, phacoemulsification, and implantation of the SA60AT IOL (Alcon Surgical, Inc, Fort Worth, Texas). Preoperatively, the clinical history and $EffRP_{adj}$ methods were used for corneal power estimation, and the double-K Holladay 2 formula was used for IOL power calculation for all but eyes 7 and 8, for which the single-K Holladay 1 formula was used. Targeting at postoperative myopia of around 0.75 D, we selected either the average or the lower of the two IOL powers to minimize the risk of postoperative hyperopia.

IOL Power Calculation Methods

Retrospectively, we compared the IOL power implanted with the IOL power calculated by using the following combinations:

1. The single-K and double-K versions of each IOL calculation formula. For the SRK/T, Hoffer Q, and Holladay 1 formulas,[14-16] the single-K and double-K values were calculated by using the post-LASIK and pre-LASIK K-readings for the ELP prediction, respectively. In both of the single- and double-K versions, the post-LASIK K-reading was used in the vergence portion of the formulas. These two versions of formulas were implemented in the Excel spreadsheet. For the Holladay 2 formula, the single-K formula was used by entering only the post-LASIK corneal power value, whereas the

double-K calculation was obtained by checking the "Previous RK, PRK…" box and then entering the pre-LASIK K-reading.

2. The Feiz-Mannis method and four methods for calculating corneal power: clinical history, contact lens overrefraction, $EffRP_{adj}$, and Maloney method (central values from Humphrey Atlas, effective refractive index: 1.3375), and
3. Four intraocular lens calculation formulas: SRK/T, Hoffer Q, Holladay 1, and Holladay 2

IOL Prediction Error

The IOL prediction error was obtained by the following steps:

1. For a given combination of formula and corneal power value, determine by interpolation the IOL power that would give the actual postoperative manifest refraction after cataract surgery (predicted IOL power). The refractive error after cataract surgery was obtained at the most recent examination (range, 3 weeks to 1 year).
2. Subtract the predicted IOL power from the power of IOL implanted to get the IOL prediction error. Thus, a positive value indicates that formula predicts an IOL of lower power than the power of the implanted IOL; this would leave the patient hyperopic.

For example (see case 1), implantation of a 19 D IOL gave the postoperative refractive error of –0.75 D. For the double-K Holladay 2 formula and corneal power determined from clinical history method, the IOL power predicted to give this refractive error was 18.31 D; the IOL prediction error was +0.69 D.

The results were evaluated by four criteria:

1. Mean arithmetic IOL prediction error. Positive values indicate that the method underestimated the IOL power.
2. Mean absolute IOL prediction error.
3. Variance of the mean arithmetic IOL prediction error. A smaller variance indicates better consistency of the IOL prediction with that method; by adjusting to correct for the mean IOL prediction error, a better refractive outcome might be expected.
4. The number of eyes with certain refractive prediction error. With assumption that 1 D of IOL prediction error produces 0.7 D of refractive error at spectacle plane,[8] the number of eyes with refractive prediction error of less than –1 D (IOL prediction error, < –1.43 D), within –1 to +0.5 D (refractive errors within this range are considered to be acceptable), and greater than +0.5 D (IOL prediction error, > +0.71 D) were computed for each method.

The mean IOL prediction errors produced by different methods were compared using the paired *t* test. The variance of the mean arithmetic IOL prediction error by various methods was tested using the F test for variances to assess the consistency of the prediction performance by different methods. A probability of less than 5% ($P < .05$) was considered statistically significant.

RESULTS

The mean age of the eight patients was 50 years (range, 37 to 60 years). The amount of LASIK-induced correction was –5.50 ± 2.61 D (SD) (range, –8.78 to –2.38 D), and the mean manifest refraction after cataract surgery was –0.61 ± 0.79 D (range, –2.0 to 1.0 D) (Table 1). The eye with the greatest amount of hyperopia was one of the two eyes for which we used the single-K Holladay 1 formula (case 7). To illustrate the spectrum of outcomes for each eye, the IOL prediction errors with Holladay 2 formula for all cases using various methods are shown in Table 2, and the mean arithmetic and absolute IOL prediction errors with the single-K and double-K versions of the four formulas are shown in Table 3. The numbers of eyes within certain refractive prediction errors at the spectacle plane are shown in Table 4.

Single-K Versus Double-K Versus Feiz-Mannis Approach

Comparing the single-K to the double-K versions of each of the formulas, the single-K versions tended to underestimate IOL power in the majority of the patients (Table 3); this would have left most patients hyperopic. The one exception was the single-K Hoffer Q formula, which had a mean prediction error of –0.12 D for clinical history and –0.09 D for $EffRP_{adj}$. However, several of the eyes calculated with this approach also would have been hyperopic. The Feiz-Mannis method had a mean prediction error of –0.25 D to –0.78 D, but had high variances of 1.90 to 2.53 D^2 and correspondingly high ranges of prediction errors (Table 3).

Because of the better performance of the double-K formulas, we compare below the results with the various methods for calculating corneal power only for double-K versions of these formulas. The contact lens overrefraction method was performed in six of 11 eyes and was found to be the least accurate method (Tables 2 and 3); therefore, this method was not evaluated with the double-K versions of the IOL formulas.

Methods for Calculating Corneal Power

With the double-K version of the four formulas, the mean

TABLE 1. DEMOGRAPHIC SUMMARY FOR 11 EYES WITH PRIOR LASIK CORRECTION THAT UNDERWENT CATARACT SURGERY

CASE	AGE (YR)	PRIOR LASIK CORRECTION (D)	AXIAL EYE LENGTH (MM)	REFRACTION BEFORE CATARACT SURGERY (D)	IOL POWER IMPLANTED (D)	REFRACTION AFTER CATARACT SURGERY (D)
1	44	–4.25	25.97	–2.375	19	–0.75
2	37	–2.38	24.36	–0.25	21.5	–0.50
3	37	–2.75	24.40	0.125	21.5	–0.75
4	49	–7.27	25.08	–0.50	25.5	–1.125
5	49	–7.18	25.24	–0.75	23.5	0.125
6	60	–8.78	28.72	0	17.5	–0.50
7	57	–7.89	27.97	–0.25	18.5	1.00
8	44	–8.39	30.36	–1.50	15.5	0
9	59	–2.63	23.90	–2.625	22	–1.125
10	53	–6.50	25.59	–4.50	23.5	–2.00
11	59	–2.50	24.30	–2.00	21.5	–1.125

IOL, intraocular lens; LASIK, laser-assisted in-situ keratomileusis.

TABLE 2. INTRAOCULAR LENS (IOL) PREDICTION ERROR (D) WITH HOLLADAY 2 FORMULA USING DIFFERENT METHODS (IMPLANTED IOL POWER – PREDICTED IOL POWER)*

	SINGLE-K HOLLADAY 2					DOUBLE-K HOLLADAY 2		
CASE	CLINICAL HISTORY	CONTACT LENS OVERREFRACTION	$EFFRP_{ADJ}$†	MALONEY	FEIZ-MANNIS	CLINICAL HISTORY	$EFFRP_{ADJ}$†	MALONEY
1	1.31	–0.43	–0.35	0.94	0.73	0.69	–1.37	0.23
2	0.35	N/A ‡	0.07	1.07	–0.36	–0.01	–0.35	0.90
3	0.14	N/A	0.68	0.79	–0.49	–0.26	0.41	0.54
4	0.93	1.65	0.59	2.71	–1.11	–0.85	–1.32	1.54
5	0.39	1.80	1.54	2.41	–1.30	–0.92	–0.04	1.28
6	1.24	6.36	1.70	2.44	0.05	0.17	0.74	1.64
7	0.67	5.03	0.84	1.91	–0.38	–0.57	–0.35	1.00
8	2.01	8.08	–0.22	1.73	2.36	1.10	–1.69	0.74
9	–1.14	N/A ‡	–0.07	0.81	–1.93	–1.94	–0.57	0.50
10	–0.80	N/A ‡	0.39	1.64	–2.90	–2.40	–0.83	0.76
11	–0.41	N/A ‡	–0.04	0.97	–1.09	–1.00	–0.53	0.72

*A positive value indicates a lower power predicted than the power implanted and would leave patient hyperopic.
†Adjusted effective refractive power obtained from EyeSys corneal topography.[9]
‡Contact lens overrefraction was not performed.

arithmetic prediction errors produced by the clinical history method (range, –1.02 to –0.55 D) and $EffRP_{adj}$ (range, –0.98 to –0.54 D) were comparable (all $P > .05$), but significantly different from the mean arithmetic prediction errors predicted by the Maloney method (range, +0.45 to +0.90 D) (all $P < .002$) (Table 3). The highest myopic and hyperopic errors were –3.50 D and 2.38 D using the clinical history method, –2.09 D and 0.74 D using $EffRP_{adj}$, and –0.45 D and 2.03 D with the Maloney method (compared to –3.54 D and 2.88 D for the Feiz-Mannis method), respectively. The $EffRP_{adj}$ and Maloney methods tended to produce smaller mean absolute errors with the four formulas (range, 0.69 to 0.98 D, and 0.53 to 0.90 D, respectively) than did the clinical history method (range, 0.90 to 1.24 D), although these differences were not statistically significant (all $P > .05$).

For the double-K Hoffer Q and Holladay 1 formulas, the variances for $EffRP_{adj}$ method were significantly smaller than those for the clinical history method (0.43 D^2 vs 1.74 D^2, $P = .018$ for Hoffer Q; 0.75 D^2 vs 2.35 D^2, $P = .043$ for Holladay 1). The variances for the Maloney method with all four double-K formulas (range, 0.19 to 0.55 D^2) were significantly smaller than those for the clinical history method (range, 1.09 to 2.35 D^2) (all $P < .015$), but not for $EffRP_{adj}$ method (range, 0.43 to 0.75 D^2) (all $P > .05$).

Of the 11 eyes, the numbers of eyes with refractive prediction error of –1.0 to +0.5 D were seven to eight eyes with the double-K clinical history method, seven to 10 eyes with the double-K $EffRP_{adj}$ method, and three to eight with the double-K Maloney method (Table 4). The highest number with refractive prediction error of –1.0 to

TABLE 3. MEAN ARITHMETIC AND ABSOLUTE INTRAOCULAR LENS PREDICTION ERROR (D) USING DIFFERENT METHODS (IMPLANTED IOL POWER – PREDICTED IOL POWER).

	SINGLE-K FORMULA					DOUBLE-K FORMULA		
METHODS	CLINICAL HISTORY	CONTACT LENS OVERREFRACTION	$EFFRP_{ADJ}$*	MALONEY	FEIZ-MANNIS	CLINICAL HISTORY	$EFFRP_{ADJ}$*	MALONEY
SRK/T								
Arithmetic error								
Mean	0.87 ± 1.27	4.26 ± 3.13	0.88 ± 0.81	1.94 ± 1.00	–0.78 ± 1.40	–1.02 ± 1.13	–0.98 ± 0.72	0.45 ± 0.51
Range	–1.12 to 3.07	0.09 to 8.54	–0.13 to 2.12	0.64 to 3.40	–3.44 to 2.00	–3.25 to 0.97	–2.09 to 0.01	–0.45 to 1.13
Absolute error								
Mean	1.29 ± 0.78	4.26 ± 3.13	0.91 ± 0.78	1.94 ± 1.00	1.22 ± 0.99	1.20 ± 0.92	0.98 ± 0.72	0.53 ± 0.40
Range	0.34 to 3.07	0.09 to 8.54	0.00 to 2.12	0.64 to 3.40	0.18 to 3.44	0.01 to 3.25	0.01 to 2.09	0.03 to 1.13
Hoffer Q								
Arithmetic error								
Mean	–0.12 ± 1.27	3.58 ± 3.62	–0.09 ± 0.61	1.25 ± 0.60	–0.25 ± 1.59	–0.61 ± 1.32	–0.57 ± 0.65	0.88 ± 0.50
Range	–2.64 to 2.10	–0.77 to 8.73	–1.13 to 0.83	0.40 to 2.37	–3.27 to 2.88	–3.33 to 1.69	–1.69 to 0.49	-0.03 to 1.75
Absolute error								
Mean	0.83 ± 0.93	3.84 ± 3.29	0.51 ± 0.31	1.25 ± 0.60	1.11 to 1.12	1.08 ± 0.93	0.69 ± 0.51	0.88 ± 0.49
Range	0.05 to 2.64	0.77 to 8.73	0.12 to 1.13	0.40 to 2.37	0.06 to 3.27	0.07 to 3.33	0.06 to 1.69	0.03 to 1.75
Holladay 1								
Arithmetic error								
Mean	0.60 ± 1.46	4.20 ± 3.61	0.63 ± 0.88	1.78 ± 1.01	–0.55 ± 1.59	–0.67 ± 1.53	–0.62 ± 0.87	0.80 ± 0.74
Range	–1.61 to 3.41	–0.21 to 9.09	–0.34 to 2.01	0.60 to 3.12	–3.54 to 2.54	–3.50 to 2.38	–1.87 to 0.56	–0.23 to 2.03
Absolute error								
Mean	1.25 ± 0.90	4.27 ± 3.51	0.80 ± 0.71	1.78 ± 1.01	1.26 to 1.06	1.24 ± 1.08	0.84 ± 0.63	0.85 ± 0.67
Range	0.22 to 3.41	0.21 to 9.09	0.04 to 2.01	0.60 to 3.12	0.25 to 3.54	0.02 to 3.50	0.15 to 1.87	0.05 to 2.03
Holladay 2								
Arithmetic error								
Mean	0.43 ± 0.95	3.75 ± 3.25	0.47 ± 0.69	1.58 ± 0.71	–0.58 ± 1.38	–0.55 ± 1.05	–0.54 ± 0.75	0.90 ± 0.44
Range	–1.14 to 2.01	–0.43 to 8.08	–0.35 to 1.70	0.79 to 2.71	–2.90 to 2.36	–2.40 to 1.10	–1.69 to 0.74	0.23 to 1.64
Absolute error								
Mean	0.85 ± 0.55	3.89 ± 3.04	0.59 ± 0.57	1.58 ± 0.71	1.15 to 0.91	0.90 ± 0.73	0.75 ± 0.51	0.90 ± 0.44
Range	0.14 to 2.01	0.43 to 8.08	0.04 to 1.70	0.79 to 2.71	0.05 to 2.90	0.01 to 2.40	0.04 to 1.69	0.23 to 1.64

*Adjusted effective refractive power obtained from EyeSys corneal topography.[9]

+0.5 D was 10 eyes with $EffRP_{adj}$ combined with double-K Hoffer Q formula.

Comparison of the Double-K Formulas

When comparing the mean arithmetic IOL prediction errors of the four IOL formulas, the SRK/T formula yielded significantly higher IOL powers with the clinical history, $EffRP_{adj}$, and Maloney methods than the corresponding IOL powers produced by Hoffer Q and Holladay 2 formulas (all $P < .05$). However, there were no significant differences in the variances of prediction errors produced by different IOL formulas.

DISCUSSION

Reduced accuracy of IOL calculations following corneal refractive surgery is a clinical problem of growing importance. Although published studies suggest that the clinical history method is a helpful approach for calculating corneal power, the numbers of eyes were small, and unacceptably large refractive surprises still occurred.[3,17,18] Using the Holladay 2 formula, Randleman and associates[17] evaluated the accuracy of several techniques for calculating IOL power in 10 LASIK eyes. They found that large refractive errors occurred with each of the methods investigated and that the clinical history method, contact lens overrefraction, or the average of these two methods provided the most accurate results. Argento and colleagues[18] compared the predictability of various methods of IOL power calculation in seven cases (six post-LASIK eyes and one post-RK eye) using the Holladay 2, Hoffer Q, and SRK/T formulas and found that the clinical history method with the Hoffer Q formula provided the best results.

As described by Aramberri,[4] the single-K version of IOL formulas predicts IOL powers that are too low,

TABLE 4. NUMBER OF EYES WITHIN CERTAIN REFRACTIVE PREDICTION ERROR BY ASSUMING THAT 1 D OF INTRAOCULAR LENS PREDICTION ERROR PRODUCES 0.7 D OF REFRACTIVE ERROR AT THE SPECTACLE PLANE (N = 11 EYES)[8]

		DOUBLE-K FORMULA		
REFRACTIVE PREDICTION ERROR	FEIZ-MANNIS	CLINICAL HISTORY	$EFFRP_{ADJ}$*	MALONEY
SRK/T				
<-1.0 D	2	2	4	0
-1.0 to +0.5 D	8	8	7	8
>+0.5 D	1	1	0	3
Hoffer Q				
<-1.0 D	2	2	1	0
-1.0 to +0.5 D	7	7	10	4
>+0.5 D	2	2	0	7
Holladay 1				
<-1.0 D	2	3	3	0
-1.0 to +0.5 D	7	7	8	6
>+0.5 D	2	1	0	5
Holladay 2				
<-1.0 D	2	2	1	0
-1.0 to +0.5 D	7	8	9	3
>+0.5 D	2	1	1	8

*Adjusted effective refractive power obtained from EyeSys corneal topography.[9]

predisposing to postoperative hyperopia. Our data confirm the greater accuracy of the double-K versions of three third-generation and the Holladay 2 fourth-generation IOL calculation formulas. Tables for performing double-K adjustments on third-generation formulas have been published;[5] the Holladay 2 permits direct entry of two corneal power values for the double-K calculation. Another option is to use the Haigis formula, in which the corneal power is not used to estimate the ELP.[6]

With double-K version of the formulas, the mean arithmetic IOL prediction errors were comparable for the clinical history and $EffRP_{adj}$ methods, whereas the variance tended to be smaller for $EffRP_{adj}$, demonstrating better consistency of its performance. Reliable pre-LASIK keratometry and the amount of LASIK correction are key parameters when using the clinical history method. The larger variability of the clinical history method demonstrated in this study might be attributed to the fact that one more historical datum (pre-LASIK corneal power) is required than that in the $EffRP_{adj}$. Also, the clinical history method relies more heavily on preoperative values, whereas the $EffRP_{adj}$ method is primarily based on the corneal power measured at the time of the cataract surgery and is altered by only 0.15 D for every diopter of LASIK-induced refractive change.

The Maloney method converts the corneal central power obtained from corneal topography back to the anterior corneal power [central topographic power × (376/337.5)][19-21] and then subtracts the posterior corneal power (4.9 D), which is based on his own experience (Robert K. Maloney, MD, personal communication, October 2002). A major advantage is that historical data are not required. In our study, even with the double-K formulas, the Maloney method still consistently underestimated the IOL power and would have resulted in postoperative hyperopia. However, the variances of the IOL prediction error with all four formulas were significantly smaller than those by the clinical history method, indicating that with appropriate modification, this method might provide more consistent results. Based on the results of our 11 eyes, we suggest a modified Maloney method in which 6.1 D instead of 4.9 D is subtracted. In our series, this would have resulted in a mean deviation of –0.59 D ± 0.33 D (range, –1.04 D to –0.02 D) from the back calculated corneal power with the double-K Holladay 2 formula. Surprisingly, the posterior corneal power of 6.1 D found in our series is in good agreement with the average value of 6.2 D (range, 2.1 to 8.5 D) reported in a study by Seitz and colleagues,[22] in which the posterior corneal surface in vivo was assessed in 263 normal participants by the scanning slit topography technique. Nevertheless, our proposed offset value of 6.1 D was based on this small sample, and further studies are needed to validate this modified Maloney method.

We also compared the central Humphrey values to EffRP values from the EyeSys unit. Most EffRP values were lower than the central Humphrey values (mean difference, –0.49 ± 0.46 D; range, –1.30 to +0.27 D). If we recalculate the Maloney method using EffRP values and the double-K Holladay 2 formula, again aiming to have all eyes plano or myopic, remarkably, the new formula is unchanged: central power = [EffRP × (376/337.5)] –6.1. However, the variance for this calculation is slightly higher for EffRP than the central power of Humphrey (0.36 D^2 vs 0.11 D^2, respectively); also, the range was slightly greater (plano to –1.96 D for EffRP, vs plano to –1.04 D for Humphrey).

In contrast, for the 11 eyes, we calculated the effect of the LASIK-induced refractive change on the optimal Humphrey values and found a multiplier of 0.19 (vs the 0.15 value that we had found for EffRP).[9] Thus, the central power of Humphrey device can be adjusted by decreasing it by 0.19 D for every diopter of LASIK-induced refractive change. This would give mean deviation of –0.07 ± 0.20 D (–0.39 to 0.28 D) from the back calculated corneal power with the double-K Holladay 2 formula; note the low standard deviation.

Consistent with the finding reported by Argento and associates,[18] our results also revealed that the contact lens overrefraction was not reliable. This method was originally suggested to be used and found to be acceptable in eyes following refractive keratotomy;[7,23] in contrast, in eyes following ablative corneal refractive surgery (ie, PRK or LASIK), it is not accurate as theoretically demonstrated in a recent study by Haigis.[24] The Feiz-Mannis method yielded a mean IOL prediction error that was comparable with the double-K clinical history and $EffRP_{adj}$ methods, but the corresponding variances tended to be large, indicating poorer consistency. Similar findings were reported by Randleman and associates.[17]

As for the performance of the four double-K IOL formulas in eyes following myopic LASIK, the SRK/T formula yielded higher IOL powers than the corresponding IOL powers produced by Holladay 2 and Hoffer Q formulas, indicating that a lower amount of myopia should be targeted when the SRK/T formula is used; however, there were no significant differences in the variances of the IOL prediction error produced by these formulas. These findings indicate that in our series, the IOL formula used was less important than the method of calculating the appropriate corneal power, a finding that was also reported by Odenthal and colleagues.[25]

In conclusion, our results demonstrated that $EffRP_{adj}$ with double-K formulas predicted the most accurate IOL power and reduced the chances of hyperopic surprises. However, both methods that used Humphrey values (the modified Maloney method and the approach of reducing the central power by 0.19 D per D of LASIK-induced refractive change) are most promising. Although a larger study is indicated to validate the performance of these various approaches, our results suggest that an acceptable refractive outcome can be achieved in the majority of these challenging patients.

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DISCUSSION

Dr Christopher J. Rapuano. Keratorefractive surgery continues to be very popular in the United States and around the world. The number of patients who have had keratorefractive surgery is increasing every year. Eventually, these patients will need cataract surgery. There have been numerous improvements in cataract surgery over the recent past. Small-incision cataract surgery with minimal post-operative inflammation, minimal changes in corneal curvature, along with topical anesthesia have led to a very rapid visual recovery in most patients. These factors have combined to give cataract patients very high expectations!

Refractive surgery patients also have very high expectations. Most LASIK patients have "seen the light." They have enjoyed years of spectacle independence for distance and many for both near and distance. These refractive surgery patients expect similar results after cataract surgery. The problem is that refractive results of cataract surgery after refractive surgery have been suboptimal.

IOL calculations have traditionally required 1) corneal power (keratometry readings) and 2) axial length (A-scan). The basic intraocular lens power calculation formula is: IOL power = A constant - (2.5AL + 0.9K). The IOL power is adjusted according to the desired post-operative refraction.

IOL calculation methods have evolved greatly over the years. There are multiple additional variables to be considered including effective lens position, index of refraction, and different adjustments for myopic and hyperopic refractive surgery. The formulas are rather complex. There is even a small cottage industry of computer programs dealing with IOL calculations.

While there are many factors affecting the accuracy of IOL calculations after keratorefractive surgery, the primary problem is that current methods to measure the central corneal curvature (keratometry and topography) after keratorefractive surgery are inaccurate. They tend to overestimate corneal power (in previous myopes) causing the calculated IOL power to be too low, resulting in hyperopia.

There are a variety of potential solutions. Solution 1: Mathematically calculate the correct curvature. Taking the pre-operative K reading and subtracting the treatment effect perform this. This clinical history method has been touted as the best, but, not infrequently, results in mediocre refractive outcomes. It has the additional downside of requiring pre-operative, operative and stable post-operative data. Solution 2: Design a better instrument or method to directly measure corneal curvature. The hard contact lens (HCL) overrefraction method has many proponents, but it is time-consuming, does not work well for eyes with poor vision due to advanced cataract and also has mediocre refractive outcomes. New machines such as 3D topography or very high frequency ultrasonography may be able to directly measure corneal power in the future, but not as of yet. Solution 3: Use a fudge factor with an existing instrument, which is what Dr Koch and colleagues did.

The recent literature demonstrates no clear consensus as to which method of IOL calculation is best after refractive surgery. Ladas et al1 found corneal topography a poor method to measure central corneal power and concluded that the clinical history method was the best. Randleman et al[2] found corneal topography and K readings were poor methods; clinical history and HCL overrefraction were better methods, but an average of these last two was best. Kim et al[3] determined that the clinical history was the best method with the HCL overrefraction the second best method. Argento et al[4] found both HCL overrefraction and K readings poor methods to evaluate corneal curvature; they found the clinical history method the best, while adjusted K readings and corneal topography were second best. Stakheev and Balashevich[5] found no methods very good and suggested using multiple methods and selecting the lowest corneal power as determined by these methods in order to decrease the chance of post-operative hyperopia.

Dr. Koch and colleagues' study involved 11 eyes of nine patients after LASIK for myopia (mean –5.50 D). They found the clinical history and HCL overrefraction methods not reliable. Double "K" formulas were better than single "K" formulas, as they more accurately predicted the post-operative effective lens position. They found Humphrey corneal topography values, when adjusted, were the most promising method to measure central corneal power. The modified Maloney method (adjusting Humphrey corneal topography results) was also quite good and had the great advantage of not requiring any pre-operative data.

Do these results hold true for hyperopes? Will newer instrumentation make direct calculations of central corneal power more accurate, obviating the need for "fudge factors"? Will adjustable intraocular lenses, such as the light adjustable lens discussed by Dr. Daniel Schwartz earlier today, make accurate calculations less important?

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Dr Douglas Koch. I entirely agree with the comments made by Dr Rapuano. We need larger trials to better evaluate current approaches, but, more importantly, we need a methodology to measure true corneal refractive power or an approach that permits safe, accurate, and clinically feasible postoperative modification of intraocular lens power. Until then, our data suggest that the most accurate approaches are those that partially or totally rely upon corneal topographic measurements obtained just prior to cataract surgery.