Accuracy of the Barrett True-K formula for intraocular lens power prediction after laser in situ keratomileusis or photorefractive keratectomy for myopia

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PURPOSE: To compare the accuracy of the Barrett True-K formula with other methods available on the American Society of Cataract and Refractive Surgery (ASCRS) post-refractive surgery intraocular lens (IOL) power calculator for the prediction of IOL power after previous myopic laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK).

SETTING: Cullen Eye Institute, Baylor College of Medicine, Houston, Texas, and private practice, Mesa, Arizona, USA.

DESIGN: Retrospective case series.

METHODS: The accuracy of the Barrett True-K formula was compared with the Adjusted Atlas (4.0 mm zone), Masket, modified-Masket, Wang-Koch-Maloney, Shammas, and Haigis-L methods to calculate IOL power. A separate analysis of 2 no-history methods (Shammas and Haigis-L) was performed and compared with the Barrett True-K no-history option.

RESULTS: Eighty-eight eyes were available for analysis. The Barrett True-K formula had a significantly smaller median absolute refraction prediction error than all other formulas except the Masket, smaller variances compared with the Wang-Koch-Maloney, Shammas, and Haigis-L, and a greater percentage of eyes within $\pm$0.50 diopter (D) of predicted error in refraction compared with the Adjusted Atlas, Masket, and modified Masket methods (all $P < .05$). In eyes with no historical data, the Barrett True-K no-history formula had a significantly smaller median absolute refraction prediction error and a greater percentage of eyes within $\pm$0.50 D of the predicted error in refraction than the Shammas and the Haigis-L formulas (both $P < .05$).

CONCLUSION: The Barrett True-K formula was either equal to or better than alternative methods available on the ASCRS online calculator for predicting IOL power in eyes with previous myopic LASIK or PRK.

Financial Disclosures: Dr. Barrett has licensed the Barrett True-K formula to Haag-Streit. Dr. Hill is a paid consultant to Haag-Streit and Alcon Surgical, Inc. None of the other authors has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2016; 42:363–369 © 2016 ASCRS and ESCRS

Intraocular lens (IOL) power calculations for patients who have had refractive myopic correction surgery are a clinical challenge of growing importance.[1–4] The sources of the prediction errors in these eyes are well known.[1,5,6] Nevertheless, IOL power prediction for these eyes remains problematic.[7,8] The use of multiple formulas or calculations for these eyes can be difficult to execute and time consuming. The American Society of Cataract and Refractive Surgery (ASCRS) online calculator[A] was developed to facilitate this process. An evaluation of the post-myopic laser in situ keratomileusis (LASIK) or photorefractive keratectomy (PRK) ASCRS calculator[2] led to a recent revision that excluded methods that require pre-LASIK or PRK

Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.jcrs.2015.11.039

0886-3350

keratometry and included some new promising methods, such as the Potvin-Hill Scheimpflug device (Pentacam, Oculus),[8] optical coherence tomography (OCT)–based formulas,[7,9] and the Barrett True-K formula.[7,B]

The Barrett True-K formula is based on the Barrett Universal II formula.[10] It calculates a modified keratometry (K) value for patients who have had myopic or hyperopic LASIK or PRK or radial keratotomy (RK) and requires the measured keratometries and the before and after laser refraction values. It also provides a double-K solution[5,6] to address the problem of accurately calculating corneal height when central keratometries have been altered. In addition, the formula can predict the required power of the IOL when no refractive history is available (no-history formula).

The purpose of this study was to compare the Barrett True-K formula with the current methods available on the updated online ASCRS IOL power calculator.

PATIENTS AND METHODS

Study Groups and Protocol

This retrospective case series was performed with ethics committee approval. The case records of consecutive patients who had previously had LASIK or PRK for myopia and subsequently had cataract surgery between December 22, 2008, and February 28, 2013, at East Valley Ophthalmology, Mesa, Arizona, USA (Center 1, pooled data), and between January 2010 and November 2013 at the Baylor College of Medicine, Houston, Texas, USA (Center 2, 1 surgeon, D.D.K.), were reviewed. Inclusion criteria were no complications during or after cataract surgery, corrected distance visual acuity of 20/32 or better measured at least 3 weeks after surgery, and availability of manifest refraction values before and after LASIK or PRK (Center 1). Patients who had a Crystalens IOL (Bausch & Lomb) implanted were excluded from the study because of concerns about the predictability of the effective lens position. Cataract surgeries were performed using a temporal clear corneal incision and phacoemulsification. Various methods were used for corneal power estimation and IOL power calculation before surgery. The surgeon used his judgment to select the IOL power to be implanted.

Submitted: June 12, 2015.
Final revision submitted: November 9, 2015.
Accepted: November 22, 2015.

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METHODS

The Adjusted Atlas 9000 method (4.0 mm zone),[C] Masket formula,[11] Modified Masket formula,[D] Wang/Koch/Maloney formula,[C] Shammas with regression analysis,[12] Haigis-L formula,[13] Barrett True-K formula[7,B] and the average value of all formulas (average) were evaluated. The Potvin-Hill Scheimpflug device and the OCT-based formulas were not included because the data required for these methods were not available.

The Barrett True-K formula can be used with or without considering the surgically induced change in refraction (change in manifest refraction) because it uses an internal regression formula to calculate an estimated change in manifest refraction when those data are not entered. However, this internal regression formula was partly derived from data in the database of Center 1. Therefore, patients were divided into 2 groups; that is, Group A from Center 1 and Group B from Center 2. All formulas or methods were evaluated for Group A, and the Barrett True-K formula was compared with the Shammas and Haigis-L no-history formulas (ie, using no change in manifest refraction data) in Group B. A mean prediction error was calculated for each group.

The error in the predicted refraction was calculated as the difference between the actual postoperative refractive outcome and the predicted refraction for each formula or method. The mean numerical error, median absolute error, mean absolute error, and percentages of eyes within ±0.50 diopter (D) and ±1.00 D from the target refraction were calculated for each formula or method.

Statistical Analysis

The 1-sample *t* test was used to determine whether the mean numerical refraction prediction errors produced by the various methods were significantly different from zero. Analysis of variance was performed to compare differences in refractive prediction errors between methods. The variances in the mean numerical refractive prediction errors were tested using the Fisher F test for variances to assess the consistency of the prediction performance by different methods. The absolute refractive prediction errors were evaluated using the Wilcoxon signed-rank test. The percentages of eyes within certain refractive prediction errors were compared using the chi-square test or the Fisher exact test, as appropriate. The Bonferroni correction was applied for multiple tests. Statistical analyses were performed with the Xlstat (version 2014.2.03, Addinsoft) and Sigmaplot (version 12.5, Systat Software, Inc.). A P value less than 0.05 was considered statistically significant.

RESULTS

The study included 88 eyes of 66 patients. Group A had 58 eyes of 40 patients with an available change in manifest refraction data. Group B included 30 eyes of 26 patients. Table 1 shows the patients' demographics.

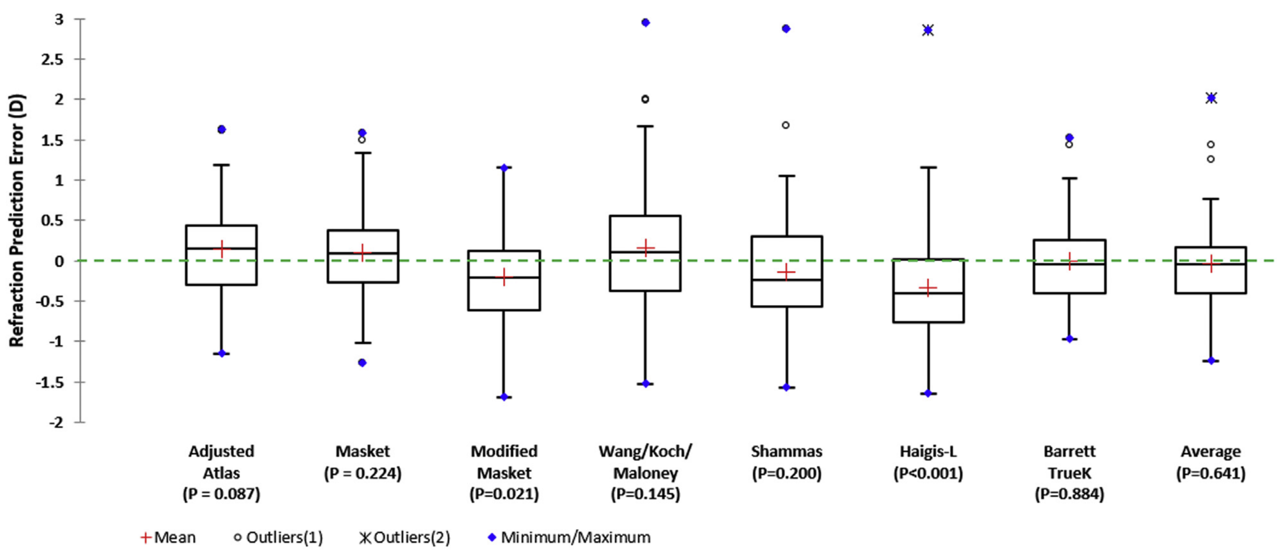
Refractive Prediction Error

Figure 1 shows boxplots of the refractive prediction errors according to the various methods. The mean

Table 1. Patient demographics.

	Group A (n = 58)		Group B (n = 30)	
Parameter	Mean ± SD	Range	Mean ± SD	Range
Age (y)	*	*	58 ± 7	34, 73
Pre-LASIK/PRK MRSE (D)	−5.49 ± 2.89	−13.38, −0.63	—	—
Post-LASIK/PRK MRSE (D)	−0.43 ± 0.84	−2.00, 2.50	—	—
Refractive correction (D)	5.06 ± 2.89	0.75, 14.00	—	—
Axial length (mm)	25.85 ± 1.35	23.22, 28.33	25.69 ± 1.25	23.22, 28.93
IOL power implanted (D)	19.83 ± 2.45	13.00, 26.50	20.27 ± 2.22	14.00, 25.00
Post-cataract MRSE (D)	−0.45 ± 0.85	−3.00, 1.25	−0.83 ± 0.90	−2.88, 0.75

IOL = intraocular lens; LASIK = laser in situ keratomileusis; MRSE = manifest refraction spherical equivalent; PRK = photorefractive keratectomy
*Data not available



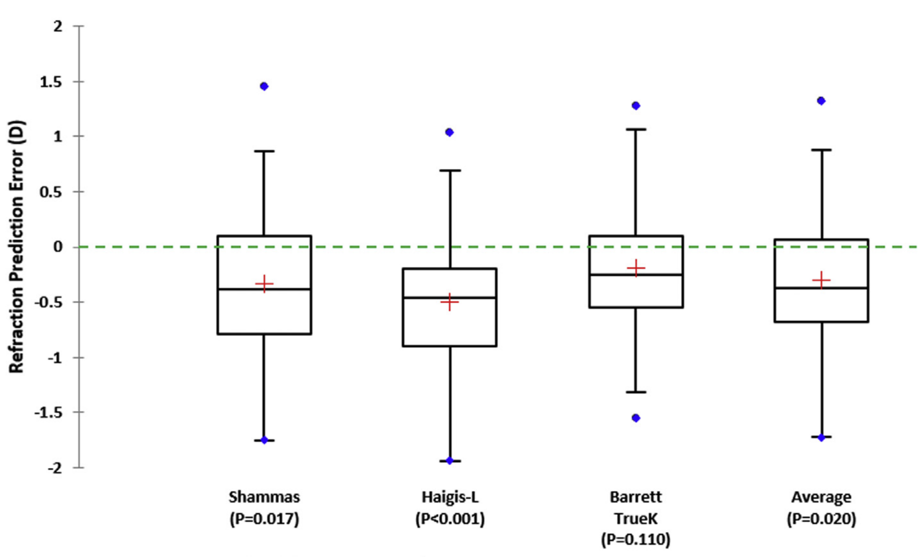


Figure 1. Refractive prediction errors with the various tested calculating methods in Group *A* (*top*) and Group *B* (*bottom*). The 1-sample *t* test was used to determine whether the mean numerical refraction prediction errors produced by the various methods were significantly different from zero (*P* values are presented for each method).

Table 2. Mean numerical errors, mean absolute errors, and median absolute errors in all eyes in Group A with inclusion of previous refractive data (n = 58).

	Refraction Prediction Error (D)				
	Numerical		Absolute		
Formula/Method	Mean ± SD	Range	Mean ± SD	Median	Range
Adjusted Atlas	0.15 ± 0.64	−1.15, 1.64	0.51 ± 0.41	0.38	0.01, 1.64
Masket	0.10 ± 0.64	−1.26, 1.59	0.48 ± 0.44	0.32	0.01, 1.59
Modified Masket	−0.20 ± 0.63	−1.69, 1.16	0.52 ± 0.41	0.48	0.01, 1.69
Wang/Koch/Maloney	0.16 ± 0.83	−1.52, 2.96	0.63 ± 0.56	0.53	0.02, 2.96
Shammas	−0.13 ± 0.77	−1.57, 2.87	0.60 ± 0.51	0.46	0.00, 2.87
Haigis-L	−0.34 ± 0.74	−1.65, 2.86	0.63 ± 0.51	0.58	0.00, 2.86
True-K	−0.01 ± 0.55	−0.96, 1.53	0.43 ± 0.36	0.33	0.00, 1.53
Average	−0.04 ± 0.62	−1.24, 2.02	0.46 ± 0.41	0.34	0.00, 2.02

numerical error values in Group A ranged from −0.34 to 0.16 D. The mean numerical errors were not significantly different from zero except for the modified Masket (P = .021) and the Haigis-L (P < .001) methods. The median absolute error ranged from 0.32 to 0.58 D. The Barrett True-K median absolute error was significantly lower than the median absolute errors of all other methods (range P = .002 to P = .031) and similar to the Masket formula (P = .09) and the average value (P = .486) (Table 2).

The mean numerical error values in Group B ranged from −0.20 to −0.50 D. The Shammas (P = .017), the Haigis-L (P < .001), and the average prediction error value (P = .020) produced a mean numerical error that was significantly different from zero. The median absolute errors ranged from 0.41 to 0.62 D. The Barrett True-K had the lowest median absolute error of all other tested methods (P = .01) (Table 3).

Variances in Refractive Numerical Prediction Error

The variance for the Barrett True-K formula in Group A was significantly lower than for the Wang/Koch/Maloney (P = .003), Shammas (P = .013), and Haigis-L (P = .034) formulas. There were no significant differences between the various methods in Group B (P = .905) (Table 4).

Refractive Prediction Error Within ±0.50 Diopter and ±1.00 Diopter

In Group A, the percentage of eyes with a refractive prediction error within ±0.50 D was significantly higher with the Barrett True-K formula than with the Adjusted Atlas, Masket, modified Masket, and average formulas (all P < .001). Also, the percentage of eyes with a refractive prediction error within ±1.00 D was significantly higher with the Barrett True-K formula than with the Adjusted Atlas (P = .001), Masket (P = .003), Wang/Koch/Maloney (P = .005), Shammas (P = .004), and average (P < .001) formulas (Table 5). In Group B, the percentage of eyes with a refractive prediction error within ±0.50 D was significantly higher with the Barrett True-K formula than with all other cited methods (P ≤ .002), whereas the percentage of eyes within ±1.00 D was highest using the average value (P < .001) (Table 5).

Table 3. Mean numerical errors, mean absolute errors, and median absolute errors in all eyes in Group B for which previous refractive data were not available (n = 30).

	Refraction Prediction Error (D)				
	Numerical		Absolute		
Formula/Method	Mean ± SD	Range	Mean ± SD	Median	Range
Shammas	−0.34 ± 0.72	−1.75, 1.46	0.63 ± 0.48	0.53	0.01, 1.75
Haigis-L	−0.50 ± 0.65	−1.94, 1.03	0.68 ± 0.45	0.62	0.14, 1.94
True-K*	−0.20 ± 0.64	−1.55, 1.28	0.52 ± 0.43	0.41	0.00, 1.55
Average (mean)	−0.31 ± 0.67	−1.72, 1.32	0.59 ± 0.44	0.53	0.02, 1.72

*Barrett true-K no history method

Table 4. Variances in numerical refractive prediction errors.

	Variance (D^2)	
Formula/Method	Group A (n = 58)	Group B (n = 30)
Adjusted Atlas	0.40	—
Masket	0.41	—
Modified Masket	0.39	—
Wang/Koch/Maloney	0.69	—
Shammas	0.60	0.51
Haigis-L	0.54	0.42
Barrett True-K	0.31	0.41
Average	0.38	0.45

DISCUSSION

Determining the most appropriate IOL power for eyes that had previous corneal refractive surgery is challenging. Various methods have been proposed to address the relative lack of predictability in post-LASIK or PRK myopic eyes.[1,2,4,6–8,11–20] Hill et al.[A] developed an Internet-based IOL power calculator for eyes with a history of LASIK, PRK, or RK to eliminate the need to perform multiple calculations for each case.[2] The online calculator has recently been updated, with less predictable methods having been eliminated and several new methods of calculation included. The purpose of the current study was to evaluate 1 of those methods, the Barrett True-K formula, in comparison with alternative formulas included in the online calculator.

All methods except for the modified Masket and Haigis-L produced mean numerical errors close to zero in Group A. Those 2 exceptions had a negative mean numerical error, with a tendency toward myopic outcomes. All methods except the Barrett True-K formula had a significant negative mean numerical error in Group B. Our data suggest that the IOL constants for those formulas might need minor adjustment for the 2 centers. Nevertheless, the spread of a refractive prediction error of a formula provides more meaningful information regarding its accuracy. In Group A, the variance for the Barrett True-K was significantly lower than for the Wang/Koch/Maloney, Shammas, and Haigis-L formulas. In Group B, there were no significant differences in the variance between the different methods. Our data therefore suggest that the Barrett True-K is at least as accurate as the other formulas tested.

The introduction of partial coherence interferometry technology[21] has improved the predictability of IOL power calculation formulas, yielding a low prediction error with a maximum absolute deviation from the target refraction of ±0.50 D in 71% of eyes and ±1.00 D in 93% of eyes.[22] The Barrett True-K formula with a change in manifest refraction data had the highest percentages of eyes with a refractive prediction error within ±0.50 D and ±1.00 D (67.2% and 94.8%, respectively) compared with all other methods. It was the only formula that was close to these updated benchmark criteria, suggesting that the prediction of the appropriate IOL power in this population is still far from optimum.

In general, in our study the percentage of eyes within ±0.50 D and ±1.00 D of the refractive prediction error seems to be slightly worse than the values reported in a study by Wang et al.[2] but slightly better than those in a study by Potvin and Hill.[8] In comparison with the figures in the literature, in our study the percentage of eyes within ±0.50 D and ±1.00 D of the refractive prediction error seems to be better than,[23] worse than,[13,18] or comparable to[3] those for the Haigis-L and the Shammas formulas. The differences are probably related to differences in the studied population groups. Different formulas have to be

Table 5. Percentage of eyes within ±0.50 D and ±1.00 D from the target refraction in Groups A and B.

	Percentage			
	Group A (n = 58)		Group B (n = 30)	
Formula/Method	Within ±0.50 D	Within ±1.00 D	Within 0.50 D	Within ±1.00 D
Adjusted Atlas	60.3	87.9	—	—
Masket	60.3	84.5	—	—
Modified Masket	53.4	86.2	—	—
Wang/Koch/Maloney	43.1	81.0	—	—
Shammas	55.2	82.8	50.0	80.0
Haigis-L	48.3	81.0	46.7	76.7
True-K	67.2	94.8	63.3	80.0
Average	58.6	91.4	46.7	83.3

compared on the same dataset for a valid analysis of relative predictability.

One limitation of our study is that the Barrett True-K formula was not tested both with and without a change in manifest refraction data for the same patients. This limitation arises from the retrospective nature of this study in which eyes from Center 1 were used to generate a regression analysis to determine a predicted refractive change of the procedure based on the measured parameters for the Barrett True-K formula when the change in manifest refraction is not available. Another limitation of our study is that new formulas that use direct measurements of the posterior cornea were not evaluated because those data were not available for our study population. A third limitation of our study is that it was confined to formulas and methods available on the ASCRS online calculator. Further studies that compare the Barrett True-K formula with and without a change in manifest refraction information with additional formulas and methods including ray tracing[15] and intraoperative aberrometry[4,14] are warranted. Finally, no subgroup prediction analysis was performed for eyes with different axial lengths and mean K values.

In conclusion, our results show that for eyes with previous myopic LASIK or PRK correction, the Barrett True-K formula gave results better than or similar to those of various methods and formulas from the ASCRS online calculator. Further studies are needed to evaluate the Barrett True-K formula in eyes that had previous RK or hyperopic LASIK or PRK.

WHAT WAS KNOWN

- Determining IOL power for eyes that have had corneal refractive surgery is difficult compared with current accuracy standards for virgin eyes.
- Methods that use corneal measurements at the time of presentation for cataract surgery, either with or without knowledge of surgically induced changes in refraction, are more accurate than methods that rely solely on pre-LASIK or PRK K values and surgically induced changes in refraction for calculating corneal power.

WHAT THIS PAPER ADDS

- The Barrett True-K formula was applicable for eyes with or without previous data of the surgically induced changes in refraction.
- The Barrett True-K formula gave better or similar results to those with various methods and formulas from the ASCRS online calculator.

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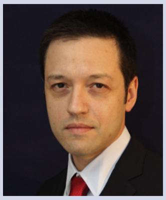

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