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Comparison of Newer Intraocular Lens Power Calculation Methods for Eyes after Corneal Refractive Surgery

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Purpose: To compare the newer formulae, the optical coherence tomography (OCT)-based intraocular lens (IOL) power formula (OCT formula) and the Barrett True-K formula (True-K), with the methods on the American Society of Cataract and Refractive Surgery (ASCRS) calculator in eyes with previous myopic LASIK/photorefractive keratectomy (PRK).

Design: Prospective case series.

Participants: A total of 104 eyes of 80 patients who had previous myopic LASIK/PRK and subsequent cataract surgery and IOL implantation.

Methods: By using the actual refraction after cataract surgery as target refraction, predicted IOL power for each method was calculated. The IOL prediction error (PE) was obtained by subtracting the predicted IOL power from the power of the IOL implanted.

Main Outcome Measures: Arithmetic IOL PEs, variances of mean arithmetic IOL PE, median refractive PE, and percent of eyes within 0.5 diopters (D) and 1.0 D of refractive PE.

Results: Optical coherence tomography produced smaller variance of IOL PE than did Wang-Koch-Maloney (WKM) and Shammas ($P < 0.05$). With the OCT, True-K No History, WKM, Shammas, Haigis-L, and Average of these 5 formulas, the median refractive PEs were 0.35 D, 0.42 D, 0.51 D, 0.48 D, 0.39 D, and 0.35 D, respectively, the percentage of eyes within 0.5 D of refractive PE were 68.3%, 58.7%, 50.0%, 52.9%, 55.8%, and 67.3%, respectively, and the percentage of eyes within 1.0 D of refractive PE were 92.3%, 90.4%, 86.9%, 88.5%, 90.4%, and 94.2%, respectively. The OCT formula had smaller refractive PE compared with the WKM and Shammas, and the Average approach produced significantly smaller refractive PE than all methods except OCT (all $P < 0.05$).

Conclusions: The OCT and True-K No History are promising formulas. The ASCRS IOL calculator has been updated to include the OCT and Barrett True K formulas. Trial registration: Intraocular Lens Power Calculation After Laser Refractive Surgery Based on Optical Coherence Tomography (OCT IOL); Identifier: NCT00532051; www.ClinicalTrials.gov. *Ophthalmology 2015;122:2443-2449 © 2015 by the American Academy of Ophthalmology.*

Although corneal refractive surgery produces excellent visual outcomes, it creates difficulties in accurately calculating intraocular lens (IOL) power.[1−3] There are 2 major causes of error in IOL calculations in these eyes: (1) incorrect corneal refractive power estimation obtained from standard keratometers or corneal topographers because of incorrect measurements of anterior corneal curvature and change in the effective refractive index of the cornea after LASIK/photorefractive keratectomy (PRK), which is in turn caused by the alteration in the ratio of the anterior to posterior radius of curvature; and (2) incorrect estimation of effective lens position (ELP) as calculated by many IOL power calculation formulas.[4,5]

The internet-based IOL power calculator at the American Society of Cataract and Refractive Surgery (ASCRS) website (www.ascrs.org) has 3 modules for eyes with prior myopic LASIK or excimer laser PRK, hyperopic LASIK/PRK, or radial keratotomy. Another internet-based IOL power calculator is the Barrett True-K formula (True-K) and can be accessed from the Asia-Pacific Association of Cataract & Refractive Surgeons (www.apacrs.org) and ASCRS (www.ascrs.org) websites.

Optical coherence tomography (OCT) is a noncontact imaging technology that can measure both anterior and posterior corneal powers with high axial resolution. By using the RTVue (Optovue Inc., Fremont, CA), Tang et al[6] developed an OCT-based IOL calculation formula. Promising results for the OCT-based IOL formula were reported by Tang et al[6,7] and Huang et al.[8]

The purpose of this study was to compare the newer formulae, the OCT formula, and the True-K formula with the methods on the ASCRS calculator in a large case series of eyes with previous myopic LASIK/PRK from 2 study centers.

Methods

Patients

This is a study sponsored by the National Eye Institute and is registered with www.ClinicalTrials.gov (Identifier: NCT00532051).

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This prospective observational study was conducted at 2 academic eye centers (Cullen Eye Institute and Casey Eye Institute). Institutional Review Board approval was obtained for this study, and the study adhered to the tenets of the Declaration of Helsinki.

Prospectively, we enrolled patients who had previously undergone LASIK or PRK for myopia and underwent cataract surgery from November 2010 to January 2015. Inclusion criteria were eyes that (1) had no complications during or after the cataract surgery, (2) had manifest refraction performed at 3 weeks or later after the cataract surgery, and (3) had best spectacle-corrected visual acuity of 20/32 or better after cataract surgery.

Ocular biometry was measured using the partial coherence interferometer (IOLMaster, V.7.5, Carl Zeiss Meditec, Inc., Dublin, CA). The OCT scans were obtained using the RTVue device (Version 6, 8, 0, 27). In addition, corneal curvatures were measured using the Atlas (Zeiss, Oberkochen, Germany) and the EyeSys (EyeSys Vision, Houston, TX) devices at 1 center (Baylor College of Medicine, Houston, TX). All cataract surgeries were performed by 2 surgeons (D.H. and D.D.K.) using a temporal clear corneal incision, phacoemulsification, and implantation of IOLs in the capsular bag. Preoperatively, various methods were used for corneal power estimation and IOL power calculation. The surgeon selected the IOL power to be implanted depending on his judgment.

Intraocular Power Calculation Methods

Optical Coherence Tomography–Based Intraocular Power Calculation Formula. With the use of the RTVue device, 3 OCT scans were performed in each eye. Two scans were used in the OCT formula for IOL power calculation. The OCT formula uses 5 preoperative biometric measurements: axial length and anterior chamber depth (distance from the corneal epithelium to the crystalline lens) from the partial coherence interferometer, and net corneal power, posterior corneal power, and central corneal thickness from the OCT. On the basis of the anterior and posterior corneal powers and the central corneal thickness, net corneal power was calculated using the Gaussian thick lens formula. Then, for IOL power calculation, the net corneal power was converted to an effective corneal power based on linear regression analysis[8]: effective corneal power in post-myopic LASIK/PRK = 1.0208 × net corneal power − 1.6622.

The OCT IOL formula is based on an optical vergence model of the eye, that is, the paraxial approximation of Gaussian optics was used. The ELP was predicted using a regression-derived formula based on anterior chamber depth constant, posterior corneal power, and axial length of the eye.[8]

Barrett True-K Formula. The Barrett True-K formula was developed recently. There are 2 versions of the formula: one is based on knowing the refractive change induced by the refractive surgery ("True K"), and the other version relies only on data acquired at the time that the patient presents for cataract surgery (no historical data are required) ("True-K No History"). For IOL power calculation, the Universal II formula is used, which is a modified version of original universal theoretic formula.[9,10] Details regarding the design of the True-K and Universal II formulas are not published.

American Society of Cataract and Refractive Surgery Calculator. Depending on the use of historical data, the IOL calculator for eyes with prior myopic LASIK/PRK categorizes various methods into 3 groups: (1) methods using pre-LASIK/PRK keratometry (Ks) and change in manifest refraction (ΔMR) induced by LASIK/PRK, (2) methods using ΔMR and corneal measurements at the time of cataract surgery, and (3) methods using no prior data.

Because of reduced accuracy of IOL power prediction with methods using pre-LASIK/PRK Ks and ΔMR,[11] we did not evaluate methods in this group. In this study, 3 methods using no prior data were evaluated: the Wang-Koch-Maloney (WKM), Shammas,[12] and Haigis-L.[13] In a subgroup of 28 eyes with ΔMR data available, 4 additional methods using ΔMR were also assessed: Adjusted effective refractive power (EffRP),[14] Adjusted Atlas 0–3,[15] Masket,[16] and Modified Masket. Details regarding these methods were described in a previous study.[11]

Method Using Average Intraocular Lens Power. We also evaluated the method of averaging IOL powers predicted using various formulas and compared its performance with the single formula.

Intraocular Lens Prediction Error

The manifest refraction after cataract surgery was obtained at the most recent examination (range, 3 weeks to 3 months). By using the optimized lens constant in normal eyes for each surgeon and targeting the actual refraction after cataract surgery, the predicted IOL power for each formula was calculated. Then, the IOL prediction error (PE) was obtained by subtracting the predicted IOL power from the power of the IOL implanted. Thus, a positive value indicates that method predicts an IOL of lower power than the power of the implanted IOL; this would leave the patient hyperopic. Mean arithmetic IOL PE was calculated. Variance of the mean arithmetic IOL PE was assessed. A smaller variance indicates better consistency of the IOL prediction with that method; by adjusting to correct for the mean IOL PE, a better refractive outcome might be expected.

Refractive Prediction Error

By using the assumption that 1 diopter (D) of IOL PE produces 0.7 D of refractive error at spectacle plane,[17] the refractive PE was calculated on the basis of the IOL PE with each formula for each eye. Before calculating the refractive PE, the mean IOL PE may be compensated by adjusting the systemic error to zero or optimizing the lens constant for each IOL type. In this study, we did not adjust the mean IOL PE to zero for 2 reasons: (1) The magnitude of mean numeric IOL PE was small (≤0.67 D), equivalent to a refractive PE of ≤0.5 D; and (2) these data represent the normal clinical scenario in which surgeons routinely use their lens constants in patients with normal cataract and do not have specific optimized lens constants for eyes after LASIK/PRK.

The median absolute refractive PE was calculated. The percentage of eyes within refractive PE of ±0.50 D (IOL PE ± 0.71 D), ±1.00 D (IOL PE ± 1.43 D), and ±2.00 D (IOL PE ± 2.86 D) was computed for each method.

Statistical Analysis

For sample size, we want to detect a difference of one third of the standard deviation of differences between 2 groups. With a significance level of 5% and a test power of 80%, 88 eyes are required in each group. In this study, we enrolled 104 eyes.

To assess if the mean arithmetic IOL PEs produced by various methods were significantly different from zero, 1-sample *t* test or Wilcoxon 1-sample signed-rank test was used depending on the data distribution. The variances of mean arithmetic IOL PEs were tested using the F-test for variances to assess the consistency of the prediction performance by different methods. Nonparametric method Wilcoxon test was used to compare the absolute refractive PEs using different formulas. McNemar test was performed to compare percentage of eyes within 0.5 D, 1.0 D, and 2.0 D of refractive PEs. The Bonferroni correction was applied for multiple tests. The SPSS 15.0 for Windows (SPSS Inc., Chicago, IL) was

Table 1. Demographic Summary of 104 Eyes of 80 Patients

Parameter	No.	Mean ± SD	Range
Age	80 subjects	63±7 yrs	46–79 yrs
Pre-LASIK/PRK MRSE	28 eyes	−5.04±2.56 D	−11.38 to −1.50 D
Post-LASIK/PRK MRSE	28 eyes	−0.27±0.57 D	−1.38 to +0.50 D
Axial length	104 eyes	25.46±1.30 mm	22.59–28.67 mm
IOL power implanted	104 eyes	20.89±1.89 D	17.0–25.50 D
Post-cataract MRSE	104 eyes	−0.71±0.84 D	−2.75 to 0.88 D

D = diopters; IOL = intraocular lens; MRSE = manifest refractive spherical equivalent; PRK = photorefractive keratectomy; SD = standard deviation.

used for statistical analysis, and a probability of less than 5% ($P < 0.05$) was considered statistically significant.

Results

Patients' demographic data are shown in Table 1. A total of 104 eyes of 80 patients were included. The mean age was 63±7 years. Of the 104 eyes, 28 eyes had before and after LASIK/PRK manifest refraction data available.

Whole Group with Methods Using No Prior Data

The mean IOL PEs ranged from −0.34 D to −0.07 D (Table 2, Fig 1). The OCT and Shammas formulas produced slightly myopic IOL PEs ($P < 0.05$).

Variances of IOL PE were 0.53 diopter squared (D^2), 0.77 D^2, 0.79 D^2, 0.89 D^2, and 0.91 D^2 for the OCT, Haigis-L, True-K No History, Shammas, and WKM formulas, respectively. There were no significant differences among the first 3 formulas. The variances for the Shammas and WKM formulas were significantly greater than that of the OCT formula ($P < 0.05$) (Table 2).

Median absolute refractive PEs were 0.35 D, 0.39 D, 0.42 D, 0.48 D, and 0.51 D for the OCT, Haigis-L, True-K No History, Shammas, and WKM formulas, respectively (Table 3). There were no significant differences among the first 3 formulas, but the Shammas and WKM had significantly greater median absolute refractive PEs than did OCT ($P < 0.05$) and a significantly smaller percentage of eyes within ±1.0 D of refractive PE than did OCT ($P < 0.05$).

Averaging IOL powers predicted from all 5 formulas using no prior data produced a variance of IOL PE of 0.60 D^2 and median absolute refractive PE of 0.35 D, which was significantly smaller than the median absolute refractive PE using all formulas except OCT ($P < 0.05$). Averaging IOL powers predicted from the 3 best formulas (OCT, Haigis-L, and True-K No History) further reduced the variance to 0.55 D^2 with a range of IOL PEs within ±2.0 D and the median absolute refractive PE to 0.31 D, which was significantly smaller than the median absolute refractive PE using all formulas except OCT ($P < 0.05$).

Subgroup with Methods Using Change in Manifest Refraction and No Prior Data

The mean IOL PEs ranged from −0.67 D to +0.21 D with methods using ΔMR and from −0.51 D to −0.06 D with methods using no prior data (Table 4). With methods using ΔMR, variances of IOL PE were 0.97 D^2 for True-K, 1.15 D^2 for Masket, and 1.32 D^2 for Modified Masket; there were no significant differences among formulas using ΔMR. With methods using no prior data, variances of IOL PE were 0.56 D^2 for OCT, 0.82 D^2 for WKM, 0.85 D^2 for Haigis-L, and 0.91 D^2 for True-K No History; there were no significant differences among formulas using no prior data.

With methods using ΔMR, the median absolute refractive PEs were 0.30 D, 0.32 D, 0.33 D, 0.66 D, and 0.70 D for the Modified Masket, Masket, True-K, Adjusted EffRP, and Adjusted Atlas 0–3, respectively; there were no significant differences among the first 3 formulas (Table 5). Adjusted Atlas 0–3 had significantly greater median absolute refractive PE than the Modified Masket, Masket, and True-K formulas (all $P < 0.05$). With methods using no prior data, median absolute refractive PEs were 0.39 D, 0.44 D, 0.47 D, 0.60 D, and 0.65 D for the OCT, Haigis-L, True-K No History, WKM, and Shammas formulas, respectively; there were no significant differences among formulas using no prior data.

There were no significant differences among formulas using ΔMR and no prior data. Averaging IOL powers predicted from all formulas using ΔMR and no prior data produced a variance of IOL PE of 0.74 D^2 with all IOL PEs within ±2.0 D and median absolute refractive PE of 0.45 D.

Discussion

Reduced accuracy of IOL power calculation in eyes with previous corneal refractive surgery is a clinical challenge.

Table 2. Methods Using No Prior Data, Mean Arithmetic Intraocular Lens Prediction Error (Implanted Intraocular Lens Power − Predicted Intraocular Lens Power), and Variances of Arithmetic Intraocular Lens Prediction Errors (diopter squared)

Methods	No. of Eyes	Mean ± SD (D)	Range (D)	Variances (D^2)
OCT	104	−0.20±0.73*	−2.10 to 1.33	0.53†
True-K No History	104	−0.07±0.89	−1.86 to 2.65	0.79
WKM	84	−0.19± 0.95	−2.17 to 2.43	0.91†
Shammas	104	−0.34±0.94*	−2.09 to 2.99	0.89†
Haigis-L	104	−0.07±0.88	−2.15 to 2.04	0.77
Average using no prior data	104	−0.17±0.77	−1.93 to 2.14	0.60
Average OCT, Haigis-L, and True-K No History	104	−0.11±0.74	−1.92 to 1.83	0.55

D = diopter; D^2 = diopter squared; OCT = optical coherence tomography; SD = standard deviation; WKM = Wang-Koch-Maloney.
*Significantly different from zero.
†Significant different in variances of IOL PEs (all $P < 0.05$ with Bonferroni correction).

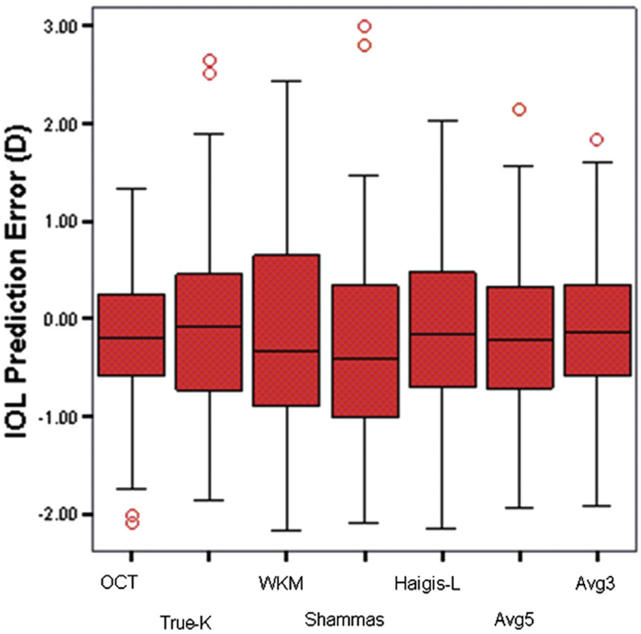

Figure 1. Box-plot of intraocular lens (IOL) power prediction errors (PEs) with optical coherence tomography (OCT)-based IOL formula (OCT), True K No History (True-K), Wang-Koch-Maloney (WKM), Shammas, Haigis-L, Average of the 5 formulas (Avg5), and Average of 3 formulas (OCT, Haigis-L, and True-K No History) (n = 104 eyes). D = diopters.

Newly introduced formulas include the OCT-based IOL formula and the Barrett True-K formula. In this study, we compared the performance of these 2 newly introduced formulas with methods on the ASCRS calculator in a case series of 104 eyes.

Our results showed that the OCT formula produced the smallest variance of IOL PE and smallest median absolute refractive PE, followed by the Haigis-L and the True-K No History formulas, although there were no significant differences among these 3 formulas. Compared with the WKM and Shammas formulas, the OCT had significantly smaller variances of IOL PE and refractive PE. Similar findings were observed in the subgroup with ΔMR data available.

By using the Holladay IOL Consultant Program (Holladay Consulting, Bellaire, TX) and the ASCRS IOL power calculator, Yang et al[18] compared the accuracy of IOL power calculation methods for patients after myopic excimer laser surgery without previous refractive surgery data. They reported that no statistically significant differences were observed among formulas using no prior data on the ASCRS calculator, specifically the WKM, Shammas No-History, Haigis-L, and ASCRS-Average, with mean absolute refractive PEs ranging from 0.79 D to 0.92 D. In our study, the median absolute refractive errors for these formulas tend to be lower with ranges from 0.35 D to 0.51 D.

We also evaluated the performance of averaging IOL powers predicted by various methods. Averaging IOL powers predicted by the OCT, True-K No History, WKM, Shammas, and Haigis-L produced a refractive PE that was significantly smaller than all methods using no prior data except OCT. Averaging IOL power predicted by the 3 best formulas (OCT, Haigis-L, and True-K No History) reduced the refractive PE further.

In 46 eyes with previous myopic LASIK/PRK, Huang et al[8] reported that the predictive accuracy of OCT was better than the Haigis-L and Shammas-PL formulas, with mean absolute refractive errors of 0.49 D for OCT, 0.65 D for Haigis-L ($P = 0.031$), and 0.62 D for Shammas-PL ($P = 0.044$). In 39 eyes with previous LASIK/PRK, Fram et al[19] compared the accuracy of intraoperative aberrometry technology (ORA; Alcon Labs, Fort Worth, TX) and the OCT and Haigis-L. The mean absolute refractive PEs were 0.34 D for ORA, 0.39 D for OCT, and 0.37 D for Haigis-L. In our study with a larger number of cases (104 eyes), we found a median absolute refractive PE of 0.35 D for OCT, 0.39 D for Haigis-L, and 0.48 D for Shammas; as did Fram et al,[19] we found no significant difference in outcomes between the OCT and the Haigis-L formula. Ianchulev et al[20] reported a median absolute refractive error of 0.42 D for ORA, 0.53 D for Haigis-L, and 0.51 D for Shammas.

The Barrett True-K formula is based on measured keratometry and ΔMR induced by the refractive surgery.[9,10] The True-K No History formula can be used when data for ΔMR are not available. We are unaware of studies

Table 3. Methods Using No Prior Data, Median Absolute Refractive Prediction Error, and Percentage of Eyes within 0.5 D, 1.0 D, and 2.0 D of Refractive Prediction Error by Assuming that 1 D of Intraocular Lens Prediction Error Produces 0.7 D of Refractive Error at the Spectacle Plane

Methods	No. of Eyes	Median (D)	%±0.5 D	%±1.0 D	%±2.0 D
OCT	104	0.35*	68.3	92.3	100.0
True-K No History	104	0.42	58.7	90.4	100.0
WKM	84	0.51*	50.0	86.9	100.0
Shammas	104	0.48*	52.9	88.5	99.0
Haigis-L	104	0.39	55.8	90.4	100.0
Average using no prior data	104	0.35†	66.3	94.2	100.0
Average OCT, Haigis-L, and True-K No History	104	0.31†	65.4	95.2	100.0

D = diopters; OCT = optical coherence tomography; WKM = Wang-Koch-Maloney.
*Significantly different in refractive PEs.
†Significantly smaller refractive PE than each single formula except OCT (all $P < 0.05$ with Bonferroni correction).

Table 4. Eyes with Change in Manifest Refraction Data Available, Mean Arithmetic Intraocular Lens Prediction Error (Implanted Intraocular Lens Power − Predicted Intraocular Lens Power), and Variances of Arithmetic Intraocular Lens Prediction Errors (diopter squared)

Methods	No. of Eyes	Mean ± SD (D)	Range (D)	Variance (D^2)
Using ΔMR				
Adjusted EffRP	23	−0.33±1.35	−2.73 to 2.15	1.82
Adjusted Atlas 0−3	22	−0.67±1.32	−2.47 to 3.42	1.75
Masket	28	+0.21±1.07	−1.30 to 3.61	1.15
Modified Masket	28	−0.21±1.15	−2.00 to 3.40	1.32
True-K	28	+0.06±0.98	−2.02 to 2.61	0.97
Using No Prior Data				
OCT	28	−0.23±0.75	−2.02 to 1.29	0.56
True-K No History	28	−0.10±0.95	−1.55 to 2.65	0.91
WKM	22	−0.37±0.90	−1.84 to 1.57	0.82
Shammas	28	−0.51±1.05	−1.97 to 2.99	1.10
Haigis-L	28	−0.06±0.92	−1.91 to 1.91	0.85
Average IOL power all methods	28	−0.21±0.86	−1.81 to 1.80	0.74

Adjusted EffRP = Adjusted effective refractive power obtained from EyeSys (EyeSys Vision, Houston, TX) corneal topography; D = diopter; D^2 = diopter squared; IOL = intraocular lens; ΔMR = change in manifest reaction; OCT = optical coherence tomography; WKM = Wang-Koch-Maloney.

comparing the True-K with other IOL calculation formulas. Our results demonstrated that the performance of True-K No History was comparable to that of OCT and Haigis-L.

The ASCRS calculator for eyes with previous myopic LASIK/PRK formerly included 3 groups of methods depending on the use of historical data. Because of the reduced accuracy with methods using pre-LASIK/PRK Ks and ΔMR,[11] these have been dropped from the calculator, and we did not evaluate the performance of this category of methods in our study. Similar to findings in our previous study, there were no significant differences among formulas using ΔMR or no prior data.

Traditionally, refractive PEs were calculated and compared in the published articles comparing the accuracy of IOL power formulas in normal virgin eyes. However, because the ASCRS calculator displays the IOL power in a decimal format and not in half-diopter steps, it is challenging to obtain the refraction predicted by the implanted IOL to calculate the refractive PE directly. With the ASCRS calculator, the exact IOL powers are calculated and displayed for the target refraction that the user enters. By entering the actual postoperative refraction after the cataract surgery, the IOL powers that would produce the postoperative refraction are calculated and displayed. These can then be compared with the IOL power implanted to obtain the IOL power PEs. This is a precise and readily reproducible method for evaluating calculation errors in these eyes. This method has been used by other authors who have evaluated outcomes using the ASCRS calculator.[11,18]

Table 5. Eyes with Change in Manifest Refraction Data Available, Median Absolute Refractive Prediction Error and Percentage of Eyes within 0.5 D, 1.0 D, and 2.0 D of Refractive Prediction Error by Assuming that 1 D of Intraocular Lens Prediction Error Produces 0.7 D of Refractive Error at the Spectacle Plane

Methods	No. of Eyes	Median (D)	%±0.5 D	%±1.0 D	%±2.0 D
Using ΔMR					
Adjusted EffRP	23	0.66	30.4	73.9	100.0
Adjusted Atlas 0−3	22	0.70*	45.5	68.2	95.5
Masket	28	0.32*	64.3	92.9	96.6
Modified Masket	28	0.30*	60.7	75.0	96.6
True-K	28	0.33*	67.9	89.3	100.0
Using No Prior Data					
OCT	28	0.39	60.7	92.9	100.0
True-K No History	28	0.47	53.6	85.7	100.0
WKM	22	0.60	45.5	86.4	100.0
Shammas	28	0.65	39.3	85.7	96.6
Haigis-L	28	0.44	53.6	92.9	100.0
Average IOL power all methods	28	0.45	53.6	89.3	100.0

Adjusted EffRP = Adjusted effective refractive power obtained from EyeSys corneal topography; D = diopter; IOL = intraocular lens; ΔMR = change in manifest reaction; OCT = optical coherence tomography; WKM = Wang-Koch-Maloney.
*Significantly different in refractive PEs (all $P < 0.05$ with Bonferroni correction).

Study Limitations

For the mean IOL PEs, we did not adjust the systemic error to zero or optimize the lens constant for each IOL type. We believe that this reflects the real-life situation, in which most surgeons do not have optimized lens constants for eyes with prior LASIK or PRK. We calculated the refractive PEs by assuming that 1 D of IOL PE produces 0.7 D of refractive error at spectacle plane.[17] We acknowledge that this ratio of 0.7 changes with very low or high IOL powers; the range of IOL powers implanted in our sample was 17 to 25.5 D. In this study, the majority of eyes had IOL PEs within 2 D, and the errors induced by this conversion were small. We included both eyes of some subjects. Subgroup analysis with each eye from each subject showed similar results as in the whole group (data not shown); therefore, we included all consecutive cases that met the inclusion criteria of this study. Postoperative refraction was obtained at 3 weeks to 3 months; this variability could affect outcomes because capsule bag changes within that time frame may influence those eyes with later refractions, although the stability of the postoperative refraction at 3 weeks after a small temporal clear corneal incision has been well documented.[21–23] Cleaning of lens epithelial cells was performed in 5 of the eyes (Baylor center only), and this could have affected their refractive outcomes. Although standard cataract surgery procedures were used by these surgeons, certainly some differences exist. Different IOL platforms were used, which may induce variation of ELP.

In summary, our results demonstrated that the OCT formula had a smaller refractive PE than the WKM and Shammas formulas and that the Average approach produced a significantly smaller refractive PE than did all methods except OCT. Based on the results of this study, both of the newly introduced formulas, the OCT and True-K formulas, have been added to the ASCRS calculator. Further studies are desirable, especially evaluation of IOL calculation using these formulas in eyes with prior hyperopic LASIK/PRK or radial keratotomy.

References

1. Koch DD, Liu JF, Hyde LL, et al. Refractive complications of cataract surgery after radial keratotomy. Am J Ophthalmol 1989;108:676–82.
2. Gimbel HV, Sun R. Accuracy and predictability of intraocular lens power calculation after laser in situ keratomileusis. J Cataract Refract Surg 2001;27:571–6.
3. Seitz B, Langenbucher A, Nguyen NX, et al. Underestimation of intraocular lens power for cataract surgery after myopic photorefractive keratectomy. Ophthalmology 1999;106: 693–702.
4. Koch DD, Wang L. Calculating IOL power in eyes that have undergone refractive surgery. J Cataract Refract Surg 2003;29: 2039–42.
5. Aramberri J. IOL power calculation after corneal refractive surgery: the double-K method. J Cataract Refract Surg 2003;29:2063–8.
6. Tang M, Li Y, Huang D. An intraocular lens power calculation formula based on optical coherence tomography: a pilot study. J Refract Surg 2010;26:430–7.
7. Tang M, Wang L, Koch D, et al. Intraocular lens power calculation after previous myopic laser vision correction based on corneal power measured by Fourier-domain optical coherence tomography. J Cataract Refract Surg 2012;38:589–94.
8. Huang D, Tang M, Wang L, et al. Optical coherence tomography-based corneal power measurement and intraocular lens power calculation following laser vision correction (an American Ophthalmological Society thesis). Trans Am Ophthalmol Soc 2013;111:34–45.
9. Barrett GD. An improved universal theoretical formula for intraocular lens power prediction. J Cataract Refract Surg 1993;19:713–20.
10. Barrett GD. Intraocular lens calculation formulas for new intraocular lens implants. J Cataract Refract Surg 1987;13: 389–96.
11. Wang L, Hill WE, Koch DD. Evaluation of IOL power prediction methods using the ASCRS post-keratorefractive IOL power calculator. J Cataract Refract Surg 2010;36: 1466–73.
12. Shammas HJ, Shammas MC, Garabet A, et al. Correcting the corneal power measurements for intraocular lens power calculations after myopic laser in situ keratomileusis. Am J Ophthalmol 2003;136:426–32.
13. Haigis W. Intraocular lens calculation after refractive surgery for myopia: Haigis-L formula. J Cataract Refract Surg 2008;34:1658–63.
14. Hamed AM, Wang L, Misra M, Koch DD. A comparative analysis of five methods of determining corneal refractive power in eyes that have undergone myopic laser in situ keratomileusis. Ophthalmology 2002;109:651–8.
15. Wang L, Booth MA, Koch DD. Comparison of intraocular lens power calculation methods in eyes that have undergone laser in-situ keratomileusis. Ophthalmology 2004;111: 1825–31.
16. Masket S. A simple regression formula for IOL power adjustment in eyes requiring cataract surgery following excimer laser photoablation. J Cataract Refract Surg 2006;32: 430–4.
17. Feiz V, Mannis MJ, Garcia-Ferrer F, et al. Intraocular lens power calculation after laser in situ keratomileusis for myopia and hyperopia: a standardized approach. Cornea 2001;20: 792–7.
18. Yang R, Yeh A, George MR, et al. Comparison of intraocular lens power calculation methods after myopic laser refractive surgery without previous refractive surgery data. J Cataract Refract Surg 2013;39:1327–35.
19. Fram NR, Masket S, Wang L. Comparison of intraoperative aberrometry, OCT-based IOL formula, Haigis-L, and Masket formulae for IOL power calculation after laser vision correction. Ophthalmology 2015;122:1096–101.
20. Ianchulev T, Hoffer KJ, Yoo SH, et al. Intraoperative refractive biometry for predicting intraocular lens power calculation after prior myopic refractive surgery. Ophthalmology 2014;121:56–60.
21. Lyle WA, Jin GJ. Prospective evaluation of early visual and refractive effects with small clear corneal incision for cataract surgery. J Cataract Refract Surg 1996;22:1456–60.
22. Masket S, Tennen DG. Astigmatic stabilization of 3.0 mm temporal clear corneal cataract incisions. J Cataract Refract Surg 1996;22:1451–5.
23. Naeser K. Incision size and corneal shape changes in sutureless cataract surgery. Ophthalmology 1995;102:1579–80.

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Abbreviations and Acronyms:
ASCRS = American Society of Cataract and Refractive Surgery; **D** = diopters; **D^2** = diopter squared; **EffRP** = effective refractive power; **ELP** = effective lens position; **IOL** = intraocular lens; **Ks** = keratometry; **ΔMR** = change in manifest refraction; **OCT** = optical coherence tomography; **PE** = prediction error; **PRK** = photorefractive keratectomy; **WKM** = Wang-Koch-Maloney.

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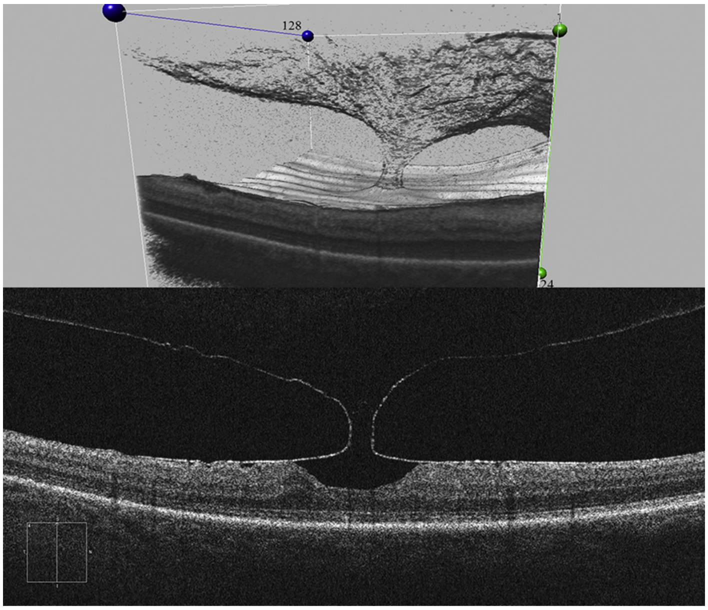
Pictures & Perspectives



Vitreous Vortex: A Unique Case of Vitreomacular Adhesion

A 69-year-old man with vitreomacular adhesion of an epiretinal membrane without foveal traction in the right eye. The images are en-face optical coherence tomography with 3-dimensional reconstruction (top) and a vertical cross-sectional B-scan of the fovea showing a unique "vortex" formation (bottom).

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