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Intraocular lens power calculation for eyes with high and low average keratometry readings: Comparison between various formulas

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Purpose: To compare the accuracy of intraocular lens power prediction for eyes with average keratometry (K) readings greater than 46.00 diopters (D) and lower than 42.00 D.

Setting: Ein-Tal Eye Center, Tel-Aviv, Israel.

Design: Retrospective case series.

Methods: Eyes having cataract extraction surgery with steep and flat preoperative corneal curvatures determined with the Lenstar-LS900 device were enrolled. Refractive prediction errors for the Barrett Universal II, Haigis, Hill-RBF, Hoffer-Q, Holladay 1, Holladay 2, Olsen, and SRK/T formulas were compared. Optimized K values for the SRK/T formula were back-calculated for each group. Validation was performed using an additional dataset.

Results: The study comprised 171 eyes (79, K reading >46.00 D; 92, K reading <42.00 D). For K readings greater than 46.00 D, myopic errors were noted using the SRK/T and Hill-RBF formulas and hyperopic errors using the Olsen C-constant and Haigis (−0.31 D, −0.17 D, 0.18 D, and 0.17 D, respectively). The percentage of eyes with an absolute error within ±0.50 D from target refraction ranged from 60.8% (SRK/T) to 83.0% (Hill-RBF). For K readings lower than 42.00 D, myopic errors were seen using the Haigis, Hill-RBF, Hoffer-Q, and Olsen-C formulas (−0.31 D, −0.14 D, −0.22 D, and −0.17 D, respectively) and a hyperopic error using the SRK/T formula (0.16 D). The refractive prediction within ±0.50 D ranged between 75.0% (Haigis) and 96.7% (Barrett Universal II).

Conclusions: Power calculation for eyes with flat corneas and steep corneas requires the use of specific formulas for accurate postoperative results. An adjustment method of the SRK/T formula is proposed.

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Modern cataract surgery is considered a combined rehabilitative and refractive procedure, allowing spectacle independency postoperatively. The accuracy and precision in biometric measurements and intraocular lens (IOL) power calculation formulas are 2 essential factors that affect postoperative refractive outcomes.[1] Most currently used IOL power calculation formulas show similar accuracy in average eyes.[2] However, the performance of these formulas can vary in eyes with different ocular features.[3]

The third-generation formulas Hoffer Q,[4,5] Holladay 1,[6] and SRK/T[7] predict the effective lens position (ELP) of the implanted IOL based on the axial length (AL) and corneal curvature using a thin-lens model. Although they share mathematic similarities, their ELP estimation differs. Newer formulas include more variables for ELP prediction. The Haigis formula[8,9] assumes the postoperative position of the theoretical thin lens as a function of 3 constants that are tied to the preoperative measurements of AL and anterior chamber depth (ACD). The Olsen[10] is a ray-tracing thick-lens formula that uses 5 variables consisting of AL, ACD, keratometry (K), lens thickness, and the patient's age. It also has the option of using only the ACD and lens thickness to calculate the ELP; that is, the C-constant function. The Holladay 2 formula[A] uses 7 variables consisting of AL, K, ACD, white-to-white (WTW) distance, lens thickness, preoperative refraction, and the patient's age. The Barrett Universal II formula[11,12,B] is based on paraxial ray tracing (Gaussian/thick lens), which takes into account the change in the principle planes encountered with different powered IOLs. It has the option to use up to 5 variables consisting of AL, K, ACD, lens thickness, and WTW. Recently, Hill[C] proposed a new method of

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IOL calculation, the Hill-Radial Basis Function (Hill-RBF) calculator. It uses pattern recognition and data interpolation to predict the postoperative refraction. The calculator features a self-validating method by providing a boundary model to exclude cases in which the calculator is likely to be inaccurate.

Depending on the individual ocular features and the optics of the IOL model, some formulas might estimate better postoperative refraction than others. As such, it could be argued that different formulas should be preferred for certain eyes. It has been widely discussed in the literature that for axial myopia, third-generation formulas tend to select IOLs of insufficient power, leaving patients with postoperative hyperopia.[13] Refractive outcomes for hyperopic patients with short ALs have also been shown to be less accurate, with the prediction error increasing with increasing hyperopia.[13]

To our knowledge, the performance of commonly used IOL power calculation formulas has not been studied in a subgroup of eyes with steep and flat corneal geometry. The aim of this study is to compare the accuracy of the earlier-cited IOL power formulas for eyes with high K readings and eyes with low K readings.

PATIENTS AND METHODS

The study was approved by the Institutional Ethics Committee, Meir Medical Center, Kfar Saba, Israel. All research and data collection adhered to the tenets of the Declaration of Helsinki.

Consecutive medical records of patients who had cataract extraction by 2 surgeons (E.I.A, G.K.) at the Ein-Tal Eye Center, Tel Aviv, Israel between August 2011 and December 2016 were retrospectively reviewed. All surgical procedures were performed using phacoemulsification through a small clear corneal incision (2.2 to 2.4 mm).

Eyes with K readings greater than 46.00 diopters (D) or lower than 42.00 D as measured by optical low-coherence reflectometry (OLCR) (Lenstar, Haag-Streit AG) were enrolled in this study. Manifest refraction was recorded at the postoperative follow-up visit at least 3 weeks after surgery. Only eyes with a corrected distance visual acuity of 6/9 or better were included in the study. Exclusion criteria were previous ocular pathology that might have affected the accuracy of biometry measurements, previous refractive correcting procedures, perioperative complications, and incomplete biometric or refractive data.

Preliminary Data Analysis

Preoperative refraction, patient age, AL, K values, ACD, lens thickness, WTW, and central corneal thickness were recorded. Intraocular lens power calculations for all formulas were performed using measurements with the OLCR device. The dual-zone autokeratometry of the OLCR device measures the anterior cornea using 32 reference points at 1.65 mm and 2.30 mm, each composed of an average of 4 measurements. Using the recommended 5 scans, this device displays K values based on 640 measuring points.[14,15] All biometric measurements were compatible with the strict validation criteria described by Hill.[D] In cases in which the OLCR device failed to measure AL values, these measurements were obtained by partial coherence interferometry (PCI) (IOLMaster, Carl Zeiss Meditec AG). Keratometric corneal power was calculated using a keratometric index of 1.3375.

A predicted refraction for the IOL power that had been implanted was calculated for the Hoffer Q,[4,5] Holladay 1,[6] Holladay 2,[A] SRK/T,[7] Haigis,[8,9] Olsen,[10] Barrett Universal II,[11,12,B] and Hill-RBF[C] formulas. Calculations were performed using an Excel software spreadsheet (Microsoft Office 2013, Microsoft Corp.) for the Haigis, Hoffer Q, Holladay 1, and SRK/T formulas. The Olsen formula was evaluated using the standard A-constant (Olsen-A) and C-constant (Olsen-C) outputs of the Phacooptics program (version 1.10.100.2020) or integrated in the OLCR device's Eyesuite IOL package. Predicted refraction for the Holladay 2 formula was calculated with the Consultant Surgical Assessment Outcomes Program.[A] Calculations with the Barrett Universal II formula and the Hill-RBF method were performed using the online calculators.[B,C] Eyes were excluded from the Hill-RBF analysis if the ocular measurements were classified as "out-of-bounds" or had a myopic target refraction that was not obtainable by the calculator. The User Group for Laser Interference Biometry[E] constants were used in calculation with the Haigis, Hoffer Q, Holladay 1, Holladay 2, Olsen, and SRK/T, except for Physiol IOLs (Physiol S.A.), for which the company's optical constants recommendation was used for calculations. The Barrett Universal II and Hill-RBF formulas were used with the recommended constants in their online software, when available. The formulas were not optimized to detect systemic prediction errors in this population of eyes. The manifest refraction was measured at least 3 weeks after surgery. A prediction error for each formula was calculated by subtracting the predicted refraction from the actual postoperative spherical equivalent refraction. An absolute error was defined as the absolute value of the prediction error. The differences in the mean prediction errors and mean and median absolute errors of the predicted refraction were analyzed. Thereafter, the percentages of eyes within ± 0.50 D and ± 1.00 D from the target refraction were calculated for each formula.

Eyes were divided into 2 groups. The first group included eyes with steep corneas (K reading >46.00 D), and the second group included eyes with flat corneas (K reading <42.00 D). Data analysis was performed separately for each group.

Optimizing Keratometry Values for the SRK/T Formula

For each eye in the 2 groups, an optimized K value yielding a prediction error of zero for the SRK/T formula was calculated using the Excel software. Linear regression was applied to evaluate the relationship between the optimized and the measured K values. Adjustment equations were developed for K values greater than 46.00 D and lower than 42.00 D separately.

To assess the accuracy of this adjustment method, an additional dataset was included. Consecutive cases with K values of more than 46.00 D and less than 42.00 D that had uneventful cataract extraction by the same surgeon (E.I.A) between August 2010 and November 2016 were reviewed. Biometry was performed with the PCI device. The manifest refraction at least 3 weeks postoperatively was required. Using the regression equations described above, an optimized average K value was calculated for each eye. A predicted refraction for the IOL model and power that had been implanted was then calculated with the SRK/T formula.[7] The numerical and absolute prediction errors with and without the optimization method were compared.

Statistical Analysis

Statistical analysis was performed with the SPSS software (version 21.0, IBM Corp.). A sample-size calculation was performed to detect a prediction error of 0.125 D assuming a standard deviation of 0.30 D. Forty-six eyes were required for a significance level (α) of 0.05 and a test power of 0.80. Data were checked for normality using the Shapiro-Wilk test. A 1-sample *t* test was used to assess whether the refractive prediction error for each formula was different from zero. The differences between the absolute errors of formulas were compared using the Friedman test. The Wilcoxon signed-rank test was applied for post hoc analysis. A Bonferroni

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