

Comparison of prediction accuracy of five different biometric formulas

Comparaç o da acur cia preditiva de cinco f rmulas biom tricas diferentes

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ABSTRACT**Objective:** To compare the performance of Sanders-Retzlaff-Kraft/Theoretical, Hoffer Q, Barrett Universal II, Kane, and Hill-radial basis function formulas to calculate intraocular lens power in eyes with normal axial length, in terms of predicting target refraction by using partial coherence interferometry technology.**Methods:** Phacoemulsification and intraocular lens implantation were performed in 135 eyes of 135 patients with an axial length between 22 and 24.5 mm. Axial length, keratometry, and anterior chamber depth were measured by intraocular lens Master 500. Sanders-Retzlaff-Kraft/Theoretical, Hoffer Q, Barrett Universal II, Kane, and Hill-radial basis function formulas were used for intraocular lens power calculations. The difference between the expected postoperative refraction and the mean absolute prediction error was calculated for each eye. Statistical significance was evaluated at the level of $p < 0.05$.**Results:** The study included 135 subjects. The mean axial length, anterior chamber depth, keratometry, and intraocular lens power were 23.2 ± 1.2 (22 to 24.5) mm, 3.2 ± 0.4 (2.4 to 4.4) mm, 43.5 ± 1.5 (40.8 to 46.2) diopter, 21.5 ± 1.8 (18.5 to 25.5) diopter, respectively. The mean absolute prediction error for Sanders-Retzlaff-Kraft/Theoretical, Hoffer Q, Barrett Universal II, Kane, and Hill-radial basis function was 0.306 ± 0.291 , 0.312 ± 0.257 , 0.314 ± 0.268 , 0.299 ± 0.206 and 0.308 ± 0.280 , respectively ($p > 0.05$).**Conclusion:** The study showed the third-generation (Sanders-Retzlaff-Kraft/Theoretical and Hoffer Q), fourth-generation (Barrett Universal II) and new-generation (Kane and Hill-radial basis function) intraocular lens power calculation formulas had similar performances regarding calculation of intraocular lens power to predict target refraction after phacoemulsification in eyes with normal axial length.**RESUMO****Objetivo:** Comparar o desempenho das f rmulas Sanders-Retzlaff-Kraft/Te rica, Hoffer Q, Barrett Universal II, Kane, e Hill-radial basis function (RBF) para c culo de poder di ptrico das lentes intraoculares, em olhos com comprimento axial normal, em termos de prediç o da refraç o alvo, utilizando a tecnologia de interferometria de coer ncia parcial.**M todos:** Facoemulsificaç o e implante de lentes intraoculares foram realizados em 135 olhos de 135 pacientes com comprimento axial entre 22 e 24.5 mm. Comprimento axial, ceratometria, e profundidade da c mara anterior foram medidos por lente intraocular Master 500. As f rmulas Sanders-Retzlaff-Kraft/Te rica, Hoffer Q, Barrett Universal II, Kane, e Hill-radial basis function foram empregadas para c culo de poder di ptrico das lentes intraoculares. A diferenç a entre a refraç o esperada no p s-operat rio e a m dia dos erros absolutos preditivos foi calculada para cada olho. Os valores de $p < 0,05$ foram considerados estatisticamente significativos.**Resultados:** O estudo incluiu 135 sujeitos. As m dias de comprimento axial, profundidade da c mara anterior, ceratometria, e poder di ptrico das lentes intraoculares foram $23,2 \pm 1,2$ (22 a 24,5) mm, $3,2 \pm 0,4$ (2,4 a 4,4) mm, $43,5 \pm 1,5$ (40,8 a 46,2) dioptria, $21,5 \pm 1,8$ (18,5 a 25,5) dioptria, respectivamente. A m dia de erro absoluto preditivo para as f rmulas Sanders-Retzlaff-Kraft/Te rica, Hoffer Q, Barrett Universal II, Kane, e Hill-radial basis function foi $0,306 \pm 0,291$, $0,312 \pm 0,257$, $0,314 \pm 0,268$, $0,299 \pm 0,206$ e $0,308 \pm 0,280$, respectivamente ($p > 0,05$).**Conclus o:** O estudo mostrou que as f rmulas de terceira geraç o (Sanders-Retzlaff-Kraft/Te rica e Hoffer Q), de quarta geraç o (Barrett Universal II) e as da nova geraç o (Kane e Hill-radial basis function) para c culo de poder di ptrico das lentes intraoculares, t m desempenhos semelhantes para c culo do poder di ptrico das lentes intraoculares, para prever a refraç o alvo ap s facoemulsificaç o em olhos com comprimento axial normal.

INTRODUCTION

Cataract surgery is one of the most common and successful surgical interventions in modern medicine.⁽¹⁾ Every year, intraocular lenses (IOLs) are implanted in millions of eyes worldwide.⁽²⁾ One of the most important factors affecting the success of this surgical procedure is the implantation of an IOL of appropriate power.⁽³⁾ The precision of clinical measurements and the accuracy of IOL calculations have become essential factors to achieve satisfactory refractive results after surgery.⁽⁴⁾ Obtaining the target refractive result has become an integral part of cataract surgery.⁽⁵⁾ Furthermore, with the advances in optical biometry and the introduction of new-generation IOL calculation formulas, the refractive outcomes of cataract surgery can now be more accurately predicted.^(6,7)

This study aimed to compare the success of five different IOLs power calculation formulas – Sanders-Retzlaff-Kraft/Theoretical (SRK/T), Hoffer Q, Barrett Universal II, Kane, and Hill-radial basis function (RBF). In addition, to evaluate the prediction accuracy differences of Kane formula, as compared to the other four formulas in obtaining the planned refractive value before cataract surgery.

METHODS

The study with an observational and cross-sectional design was conducted at the Department of Ophthalmology, Faculty of Medicine, Istanbul University, Turkey, between September 2016 and April 2018. Approval was obtained from the Ethics Committee of the university, and detailed informed consent was taken from all participants after informing them about the study. The study complied with the principles of the Declaration of Helsinki.

Settings and participants

The demographic and clinical data of the 312 eyes of 190 patients, who underwent phacoemulsification surgery, were recorded. A total of 135 eyes of 135 patients who met the inclusion criteria were included the study. Emmetropia or minimal myopia was targeted in the patients. We obtained the target refraction value using the biometric measurement results by partial coherence interferometry (IOL Master 500, Carl Zeiss AG, Germany). The Infiniti Vision System (Alcon, Inc.) was used in all surgical procedures.

Gender, age at the time of surgery, surgical side, uncorrected and best-corrected visual acuity (BCVA) before and after surgery, and degree of existing cataract were

recorded by an anterior segment examination under a biomicroscope. The expected postoperative refraction (EPR) was calculated according to the Kane, Barrett Universal II, Hoffer Q, SRK-T, and Hill-RBF formulas, preoperatively. The prediction error was then calculated as the actual postoperative refraction minus the refractive result predicted by each formula. The mean absolute prediction error (MAPE), standard deviation (SD) of the MAPE, maximum spherical equivalent (SE) of MAPE as well as the percentage of eyes that had a prediction error within ± 0.25 , 0.50, 0.75 and 1.00 diopter (D) were calculated for each formula.

In the postoperative period, patients used topical moxifloxacin four times daily for one week and topical prednisolone sodium phosphate, 4 to 6 times daily, for one month. In the examinations performed at three months after surgery, the refractive results of the patients were evaluated, and the SE of the refractive value was calculated. The differences between the target refractive and resulting refractive values, as well as the absolute values of these differences were recorded. Anterior and posterior segment examinations were performed under a biomicroscope in all controls after surgery.

Inclusion criteria

Inclusion criteria were patients aged 18 years and over, having uncomplicated conventional cataract surgery performed by the same experienced surgeon. Capsulotomies were centred on the pupil with implantation of an AcrySof SN60WF IOL (Alcon Laboratories, Inc, Fort Worth, TX) inserted through a temporal 2.4-mm clear corneal incision. The phacoemulsification techniques of ‘stop and chop’ or ‘chip and flip’ were employed in all procedures. In all cases, phacoemulsification surgery was successfully completed, and no corneal suturing was required.

Exclusion criteria

Patients who had undergone any previous eye surgery (keratoplasty, refractive surgery, vitrectomy, etc.) and those with amblyopic eyes or eyes with any condition in the optic axis, macula or optic disc that would affect refraction were excluded from the study. Eyes with an abnormal axial length were also not included in the study (normal axial length was accepted as 22 mm to 24.5 mm). Intraoperative complications, including anterior or posterior capsule tear, vitreous prolapse or zonular dehiscence, and postoperative complications, such as persistent corneal edema, were also exclusion criteria. If both eyes of

one patient met the inclusion criteria, one eye was randomly excluded from the study. Lastly, patients who did not attend regular follow-up for at least 3 months after surgery were excluded.

Intraocular lens calculation formulas

The Kane formula (available at www.iolformula.com) is based on theoretical optics, and incorporates regression and artificial intelligence components to further refine its predictions. It uses axial length, keratometry, anterior chamber depth, and patient gender along with optional variables of lens thickness and central corneal thickness to predict the refractive outcome.⁽⁶⁾ Hill-RBF uses an artificial intelligence regression method to predict postoperative refraction and has been updated to version 2.0 based on additional training data.

A third-generation formula refers to a combination of theoretical and regression formulas. This concept was introduced in 1988 and involves the use of two variables, namely K and AL values, allowing a more accurate measurement of the effective IOL position. As an example of third-generation formulas, SRK/T represents a combination of a theoretical eye model and a linear regression method. Based on nonlinear terms of theoretical formulas, SRK/T also includes empirical regression methodology for optimization, which provides greater precision.⁽⁸⁾ Another third-generation formula, Hoffer Q, was developed to estimate the pseudophakic anterior chamber depth (ACD) for theoretical IOL power formulas. Personalized ACD is based on axial length and corneal curvature.

Lastly, the Barrett Universal II formula was developed based on a theoretical model eye, in which ACD is related to axial length and keratometry. In this formula, the relation between the A-constant and a lens factor is also used to determine ACD. The refractive principle of the IOL, the position of its planes is preserved as a corresponding variable in the formula, and the user does not need to know the material, structure and constant of the lens.^(9,10)

Statistical analysis

The chi-squared test was used to compare the nominal data. The distribution of data was examined using the Shapiro-Wilk test. Continuous variables were expressed as mean±standard deviation for the normally distributed data, and as median, mode or range if the data were not normally distributed. Categorical variables were obtained as frequency and percentages. In the analysis comparing the groups, analysis of variance and one-sample t-tests

were performed for continuous variables with normal distribution, and the Mann-Whitney U test was used to compare the data without normal distribution. The differences in absolute error between formulas were assessed using the Friedman test. In the event of a significant result, *post-hoc* analysis was undertaken using the Wilcoxon signed ranks tests for paired comparisons with Bonferroni correction. Statistical significance was evaluated at the level of $p < 0.05$. The Statistical Package for the Social Sciences (SPSS) version 23.0 was used for the statistical analysis of data.

RESULTS

The demographic data and ophthalmological examination findings of patients are given in Table 1. Of the patients in the study, 69 were male and 66 were female. The mean age of patients was 63.5 ± 8.3 (49 to 86) years. The mean axial length value was 23.2 ± 1.2 (22 to 24.5) mm. The mean BCVA was 0.71 ± 0.43 (0.45 to 2) LogMAR preoperatively, and 0.01 ± 0.03 (0 to 0.1) LogMAR at 3 months after surgery. The mean ACD value was 3.2 ± 0.4 (2.4 to 4.4) mm. The mean IOL power was 21.5 ± 1.8 (18.5 to 25.5) D, and the mean preoperative K value was 43.5 ± 1.5 (40.8 to 46.2) D. The mean lens thickness was 4.5 ± 0.5 (3.8 to 5.5) mm. Horizontal white to white (WTW) was 11.9 ± 0.5 (11.2-12.7) mm. Target and resulting refractive values measured with the partial coherence interferometry (IOL Master) device are presented in Table 2. The prediction power differences of the four biometric formulas compared to Kane formula are shown in Table 3. There was no difference between the five biometric formulas in obtaining the planned refractive values ($p > 0.05$). Stacked histogram comparing the percentage of eyes within a given diopter range of predicted SE refraction outcome is presented in Figure 1.

Table 1. Demographic and ophthalmological characteristics of the study participants

Characteristics	
Gender (male/female)	69/66
age	63.5±8.3
Axial length	23.2±1.2
preoperative bcva	0.71±0.43
postoperative bcva	0.01±0.03
acd	3.2±0.4
iol power	21.5±1.8
Preoperative mean k value	43.5±1.5
Postoperative mean k value	43.5±1.6
lens thickness	4.5±0.5
wtw	11.9±0.5
Preoperative astigmatism	-0.34±0.19
Postoperative astigmatism	-0.39±0.22

Results expressed as mean ± standard deviation.

BCVA: best-corrected visual acuity, ACD: anterior chamber depth, IOL: intraocular lens; WTW: wide-to-wide.

Table 2. Target and resulting refractive values measured with the partial coherence interferometry (intraocular lens master) device

Formula	EPR	MAPE	SD of MAPE	Maximum SE of MAPE	±0.5 D (%)*	±1 D (%)*
Hoffer Q	-0.07	0.312	0.257	1.46	86.7	98.7
Kane	-0.10	0.299	0.260	1.38	88.0	100.0
Barrett	-0.10	0.314	0.268	1.43	85.3	98.7
Hill-RBF	-0.06	0.308	0.280	1.44	86.7	97.3
SRK/T	-0.11	0.306	0.291	1.50	85.3	96.0

*Eyes within ±0.5D/±1D MAPE.

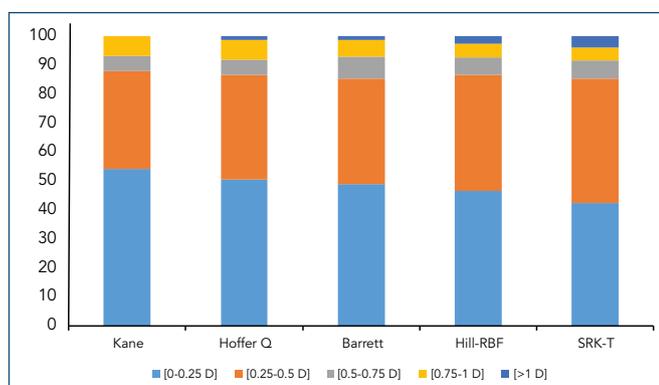
EPR: expected postoperative refraction; MAPE: mean absolute prediction error; SD: standard deviation; SE: spherical equivalent; D: diopter; RBF: radial basis function; SRK/T: Sanders-Retzlaff-Kraft/Theoretical.

Table 3. Prediction power differences of four biometric formulas compared to the Kane formula

Formula	MAPE ± SD	Maximum SE of MAPE	±0.5 D (%)*	±1 D (%)*
Hoffer Q	0.312±0.257	1.46	86.7	98.7
p-value	0.254	0.678	0.796	0.387
SRK-T	0.306±0.291	1.50	85.3	96.0
p-value	0.984	0.812	0.485	0.699
Barrett	0.314±0.268	1.43	85.3	98.7
p-value	0.198	0.375	0.999	0.387
Hill-RBF	0.308±0.280	1.44	86.7	97.3
p-value	0.527	0.411	0.796	0.387

*Eyes within ±0.5D/±1D MAPE.

MAPE: mean absolute prediction error; SD: standard deviation; SE: spherical equivalent; D: diopter; SRK/T: Sanders-Retzlaff-Kraft/Theoretical; RBF: radial basis function.



RBF: radial basis function; SRK/T: Sanders-Retzlaff-Kraft/Theoretical; D: diopter.

Figure 1. Stacked histogram comparing the percentage of eyes within a given diopter range of predicted spherical equivalent refraction outcome.

DISCUSSION

Today, one of the most important goals of cataract surgery is to reach the targeted refractive value. There are many publications showing that new-generation biometry formulas are successful in reaching target refraction values.^(11,12) Connell *et al.* found the Kane formula was the most successful to determine the target refractive value.⁽¹³⁾

In our study, although there was no statistically significant difference, it was observed the lowest resulting refractive estimation error was obtained with the Kane formula in eyes with normal axial length. In addition, it was determined that the refractive estimation error of all eyes remained within ± 1D when the Kane formula was

used. Melles *et al.* found the most effective of ten different IOL calculation formulas was the Kane formula.⁽⁶⁾ In the same study, the Hill-RBF formula was described as more accurate than the third-generation formulas.⁽⁶⁾

In another study evaluating six different biometry formulas, including Hoffer Q and SRK/T using two different biometry devices (IOL master and Lenstar LS 900), it was reported these two formulas had similar success, and suggested the SRK-2 formula should not be used due to the low prediction accuracy of the SRK-2 formula.⁽¹¹⁾ In our previous study comparing the SRK/T and SRK-2 formulas, we also demonstrated the SRK/T formula to be more successful.⁽⁵⁾

Nemeth *et al.* showed the Barrett Universal II and Hill-RBF methods performed better, as compared to the SRK/T formula in achieving the planned refractive values in 186 cataractous eyes.⁽¹⁴⁾ In our study, there was no difference between these IOL power calculation formulas in attaining the planned refractive values. This may be due to the limited number of study participants and absence of abnormal axial lengths in our study. Kuthirummal *et al.* found the Barrett Universal II formula was more accurate than the SRK-2, SRK/T, and Olsen IOL power calculation formulas.⁽¹⁵⁾

The limitations of our study include the exclusion of eyes with an abnormal (short or long) axial length. The Hoffer Q formula had been previously reported to be more successful in eyes with short axial length.^(16,17) However, since our study did not include eyes with a short axial length, we were not able to compare our results. In addition, there is a need to increase the number of patients and make an evaluation in a wider population. Lastly, our study was performed on cases in which only Alcon SN60WF IOLs were used, and different lens models should be investigated in future studies.

In conclusion, our study showed the third-generation (SRK/T and Hoffer Q), fourth-generation (Barrett Universal II) and new-generation IOL power calculation formulas (Kane and Hill-RBF) provided successful results in calculating the target refractive values before cataract surgery.

CONCLUSION

The third-generation (Sanders-Retzlaff-Kraft/Theoretical and Hoffer Q), fourth-generation (Barrett Universal II), and new-generation (Kane and Hill radial basis function) formulas have similar performances in terms of calculating intraocular lens power to predict target refraction after phacoemulsification in eyes with normal axial length.

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