ORIGINAL ARTICLE

Intraocular Lens Power Calculations in Short Eyes

Cálculo de Lentes Intraoculares em Olhos com Baixo Comprimento Axial

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ABSTRACT

INTRODUCTION: Our purpose was to comparatively evaluate the accuracy of newer intraocular lens (IOL) calculation formulas (Barrett Universal II, Kane and Hill-RBF 3.0) and common third-generation formulas with and without using a novel axial length (AL) adjustment in predicting refractive outcomes in eyes with short AL.

METHODS: Retrospective study including eyes with AL less than 22.0 mm submitted to uneventful cataract surgery and implantation of an AcrySof SN60AT IOL. All patients underwent optical biometry (Carl Zeiss IOLMaster 700) and the post-operative spherical equivalent for the same implanted IOL was estimated using SRK/T, Holladay 1, Hoffer Q, Haigis, Barrett Universal II, Kane and Hill-RBF 3.0 formulas. The Cooke-modified axial length (CMAL) method was used in the SRK/T, Holladay 1 and Hoffer Q formulas. Analysis was performed before and after lens constants optimization. Outcomes included the mean (ME) and median (MedE) prediction error, the mean absolute (MAE) and median absolute prediction error (MedAE) and the proportion of eyes within 0.50, 0.75 and 1.00 diopters (D) of the pre-operative prediction.

RESULTS: Sixty-four eyes with a mean axial-length of 21.54 ± 0.57 mm were included. Without adjustment the Hoffer Q was the only formula with a slightly myopic refractive prediction error –0.157D ± 0.60 and Hill-RBF 3.0 had the lowest standard deviation in the prediction error 0.031D ± 0.58. After optimization the mean absolute error in ascending order was Kane 0.43D, Hill-RBF 3.0 0.43D, Barrett 0.44D, Hoffer Q 0.45D, Haigis 0.45D, Holladay 1 0.48 and SRK/T 0.53D. The Kane formula, with the lowest MAE, yielded a prediction error within 0.50D, 0.75D and 1D in 71.9%, 84.4% and 90.6% of cases, respectively. Using CMAL did not improve predictions. The use of optional variables in the Kane (LT and CCT) and Barrett Universal II (LT and WTW) formulas changed the prediction error >0.1D in less than 30% of cases and most without further improvement.

CONCLUSION: Recent formulas like the Barrett Universal II, Kane, Hill-RBF v3.0 perform well, particularly after constant optimization. Without optimization the Hoffer Q is the only one with myopic prediction error which might explain its popularity in this subset of patients. The CMAL adjustment, originally developed for another optical biometer (OLCR device) did not improve outcomes. Also, the use of optional variables in the Kane and Barrett Universal II formulas did not further enhance predictions.

KEYWORDS: Axial Length, Eye; Lenses, Intraocular.

RESUMO

INTRODUÇÃO: O nosso objectivo foi avaliar comparativamente a previsão de fórmulas de terceira e nova geração (Barrett Universal II, Kane e Hill-RBF 3.0) no cálculo de lentes intraoculares (LIO) com e sem o uso de um novo ajuste de comprimento axial (CA) na previsão dos resultados refrativos de olhos com baixo CA.

MÉTODOS: Estudo retrospectivo que inclui olhos com CA inferior a 22,0 mm submetidos a cirurgia de catarata sem intercorrências e implante de uma LIO AcrySof SN60AT. Todos os doentes realizaram biometria óptica (Carl Zeiss IOLMaster 700) e o equivalente esférico pós-operatório para a LIO implantada foi calculado para as fórmulas SRK/T, Holladay 1, Hoffer Q, Haigis, Barrett Universal II, Kane e Hill-RBF 3.0. O ajuste do CA através do método de Cooke (CMAL) foi utilizado para as fórmulas SRK/T, Holladay 1 e Hoffer Q. Os dados foram analisados antes e após a otimização das constantes das LIOs. Os resultados incluíram o erro de previsão médio (ME) e mediano (MedE), o erro de previsão médio (MAE) e mediano absoluto (MedAE) e a proporção de olhos dentro de 0,50, 0,75 e 1,00 dioptrias (D) da previsão pré-operatória.

RESULTADOS: Incluíram-se 64 olhos com CA médio de 21,54 ± 0,57 mm. Sem ajustes, a fórmula Hoffer Q foi a única com um erro de previsão miópico –0,157D ± 0,60 e a Hill-RBF 3.0 teve o menor desvio padrão para o erro de previsão 0,031D ± 0,58. Após a otimização das constantes, o erro absoluto médio verificou-se em ordem ascendente nas fórmulas de Kane 0,43D, Hill-RBF 3.0 0,43D, Barrett 0,44D, Hoffer Q 0,45D, Haigis 0,45D, Holladay 1 0,48 e SRK/T 0,53D. A fórmula de Kane, com o menor MAE, produziu um erro de previsão dentro de 0,50D, 0,75D e 1D em 71,9%, 84,4% e 90,6% dos casos, respectivamente. A utilização do CMAL não melhorou as previsões. A introdução de variáveis opcionais nas fórmulas de Kane (LT e CCT) e Barrett Universal II (LT e WTW) alteraram o erro de previsão >0,1D em menos de 30% dos casos e maioritariamente sem melhoria adicional dos resultados.

CONCLUSÕES: Fórmulas recentes como a Barrett Universal II, Kane, Hill-RBF v3.0 apresentam um bom desempenho, principalmente após otimização das constantes. Sem otimização, a Hoffer Q é a única fórmula com erro de previsão miópico o que pode explicar sua popularidade neste subconjunto de doentes. O ajuste CMAL, originalmente desenvolvido para outro biómetro óptico (optical low-coherence reflectometry - OLCR), não melhorou os resultados. O uso de variáveis opcionais nas fórmulas de Kane e Barrett Universal II também não melhoraram as previsões.

PALAVRAS-CHAVE: Comprimento Axial do Olho; Lentes Intraoculares.

INTRODUCTION

Cataract surgery is the main refractive surgical procedure performed in adults and the prediction of its refractive postoperative outcome remains a challenge.[1,2]

The introduction of new generation intraocular lens (IOL) calculation formulas improved the ability to accurately predict its outcomes and recent studies show excellent results, with 83.1% of eyes within a prediction error of ±0.50 D.3 However, these results include a majority of eyes within the axial length (AL) of 22 to 25.5 mm.[3] When the AL is shorter than 22.0 mm, these results become less predictable and have been reported to be greater than > 1D in approximately 20% of all cases, with refractions tending to be unexpectedly myopic.[3-6]

Sources of error in eyes with short AL include a high power IOL, increasing the sensitivity to errors in the prediction of the effective lens position (ELP) and higher IOL manufacturer tolerances in this IOL range (more likely to diverge from their labelled power). Further motives include systematic errors in AL measurement and the additional probability of having a steep cornea and shallow anterior chamber depth (ACD), which remains a major source of miscalculation.[4,7,8]

To minimize these errors a few strategies have been employed, including the optimization of formula constants and the adjustment of the axial length.

Optical biometers have two different methods of calculating axial length (AL), one method is the traditional AL and the other is sum-of-segments AL.[9]

In traditional AL the segmented refractive indices of the eye are weighted in proportion to the segment lengths of the Gullstrand model and employed to acquire one representative average refractive index of the whole eye. Sum-of-segments contains the sum of geometric lengths of the ocular segments (cornea, aqueous, lens, and vitreous) to obtain AL.[9] Currently, the IOLMaster and Lenstar biometers measure axial length (AL) in the same traditional AL style.[9]

The Cooke-modified axial length (CMAL) is an adjustment developed by David Cooke allowing close approximation to sum-of-segments AL, using measurements available in optical biometers. It is reported to improve intraocular lens formulas originally developed with ultrasound, with this improvement more apparent in long and short eyes.[6]

Third-generation formulas (Hoffer Q, Holladay 1 and SRK-T) are based on the thin lens principle and calculate ELP with AL and corneal power variables only.[1,2] Fourth generation (Haigis) and fifth generation formulas (Barrett Universal II) include additional variables. Preoperative ACD is incorporated in the Haigis formula whereas ACD and optionally lens thickness (LT) and corneal white-to-white (WTW) are included in the Barrett Universal II.[1] Kane formula employs artificial intelligence and uses AL, corneal power, ACD, sex, LT and central corneal thickness (CCT), the latter as optional.[2] The Hill-Radial Basis Function (Hill-RBF) formula is a mathematical algorithm selecting the power of an IOL independent of a distinct effective lens position calculation. It uses pattern recognition and data interpolation requiring AL, corneal power, ACD, LT, CCT, sex and WTW.[10]

The purpose of the current study is to comparatively evaluate the accuracy of newer IOL calculation formulas (Barrett Universal II, Kane and Hill-RBF 3.0) and common third (Hoffer Q, Holladay 1 and SRK/T) and fourth (Haigis) generation formulas with and without using a novel AL adjustment (CMAL) in predicting refractive outcomes in eyes with short AL.

MATERIAL AND METHODS

STUDY DESIGN

Retrospective study of eyes submitted to uneventful cataract surgery and in the bag implantation of an AcrySof SN60AT IOL (Alcon Laboratories, Inc) between 2016 and 2021.

The data from 64 consecutive patients with ALs equal to or less than 22.0 mm were included. Exclusion criteria included incomplete data, ultrasonic biometry, combined or complicated phacoemulsification surgery, previous intraocular surgery (including previous refractive corneal surgery), intraoperative complications, any preexisting ocular pathology and postoperative best corrected distance visual acuity (BCVA) worse than 20/40.

The study followed the ethical tenets of the Declaration of Helsinki. All patients were fully informed and gave written consent.

CLINICAL EVALUATION AND DATA COLLECTION

In all patients, a complete ophthalmological evaluation was performed including, BCVA, comprehensive slit-lamp evaluation, measurement of intraocular pressure (Goldmann tonometry) and fundus examination.

Collected data included general demographic, preoperative CDVA and the implanted IOL model and power. Biometry was solely obtained with swept-source optical coherence tomography biometer (IOLMaster 700; Carl Zeiss Meditec AG, Jena, Germany). Manifest postoperative refraction was performed between 6 and 8 weeks after surgery. Refraction was first evaluated by an automatic kerato-refractometer (ARK-1, NIDEK CO.LTD, Japan) and afterwards the cylinder axis, power and Spherical Equivalent (SE) were verified with a Jackson cross-cylinder. The red-green duochrome test was used to refine the spherical refraction.

IOL POWER FORMULAS

Using the collected data, the predicted spherical equivalent for the IOL implanted was back-calculated for the following formulas hereunder:

- SRK/T, Haigis; Holladay 1 and Hoffer Q: Formulas programmed into Excel according to the author's recommendations[11-14]
- Radial Basis Function 3.0 (hill RBF 3.0): AI-based algorithm with radial basis function available online at https://rbfcalculator.com/
- Barrett Universal II: Unpublished formula available via an online calculator at: https://calc.apacrs.org/barrett_universal2105/
- Kane: Unpublished formula based on theoretical optics available at https://www.iolformula.com/

Two separate outcomes were included using the Barrett Universal II and Kane formulas.

Barrett Universal II (Full) and Kane (Full) denote the use of optional variables: LT and WTW in Barrett Universal II and LT and CCT in Kane. When simply named Barrett Universal II and Kane these formulas do not contain optional values.

In all formulas the optimized A-constant of the SRK/T formula from the User Group for Laser Interference Biometry (ULIB) website (http://ocusoft.de/ulib/c1.htm) was used.

The Cooke-modified axial length (CMAL) axial length adjustment was used in the SRK/T, Holladay 1 and Hoffer Q formulas, following the recommendations from the original article.[6]

CMAL= +1.23853+ 0.95855 x traditional AL – 0.05467 x lens thickness

STATISTICAL ANALYSIS

Prediction error was calculated as the difference between the spherical equivalent of the postoperative refractive error and the refractive error predicted by the IOL power calculation formula for the implanted IOL. A negative value specified a myopic prediction error.

Before lens factor optimization, outcomes included the mean numerical error and its standard deviation. To eliminate the formulas systematic refractive errors the recommendations described by Hoffer et al were followed by zeroing out the mean numerical error.[15] Subsequently the mean (ME) and median (MedE) prediction error, its standard deviation, the mean absolute (MAE) and median absolute prediction error (MedAE) and the proportion of eyes within eyes within a prediction error of 0.50, 0.75 and 1.00 diopters (D) were evaluated.

Statistical analysis was performed using STATA software (version 17, StataCorp LCC, College Station, TX, USA). Population demographics, preoperative biometry data and implanted IOL power were summarized using traditional descriptive statistical methods.

For comparisons between the MedAE, a paired signed rank test was performed, corrected for multiple comparisons using a Bonferroni method. A *p* value less than 0.05 was considered statistically significant.

RESULTS

A total of 64 eyes from 64 patients were included. The mean age was 70.27 ± 10.12 years (range 45-90) with a predominance of females (78.13%). Average keratometry was 45.74 ± 1.79D and mean AL 21.54 ± 0.57 mms. An AcrySof SN60AT IOL was implanted in all patients with a mean power of 26.30 ± 2.77D (range 23-40).

The demographic and preoperative data are summarized in Table 1.

Table 1. Demographic variables, preoperative biometric data and implanted IOL power [a]

Variables	Value
Demographics	
Patients (n)	64
Eyes (n)	64
Age (years)	70.27 ± 10.12
Female (%)	78.13
Biometry	
Keratometry (D)	
Average keratometry (D)	45.74 ± 1.79
K1 (D)	45.09 ± 1.67
K2 (D)	46.38 ± 1.95
Axial length (mm)	21.54 ± 0.57 (18.36 to 21.99)
Anterior chamber depth (mm)	2.77 ± 0.38
Central corneal thickness (µm)	544.69 ± 37.97
Lens Thickness (mm)	4.64 ± 0.43
White to White (mm)	11.38 ± 0.41
IOL	
Model SN60AT (n)	64
Power Implanted	26.30 ± 2.77 (23 to 40)

IOL = intraocular lens; D = diopters;

[a] Data presented as number and percentage or as mean ± standard deviation, with the exception of axial length and IOL power, which are presented as maximum and minimum;

Table 2 depicts results before constant optimization. The Hoffer Q was the only formula with a slightly myopic refractive prediction error –0.157D ± 0.60 and Hill-RBF 3.0 had the lowest standard deviation in the prediction error 0.031D ± 0.58.

Table 2. Mean numerical error in unoptimized formulas[a]

Formula	MNE	STDEV
Hoffer Q	-0,157	0,603
SRK/T	0,025	0,742
Hill-RBF 3.0	0,031	0,579
Holladay 1	0,033	0,678
Haigis	0,072	0,634
Kane (Full)	0,103	0,592
Hoffer Q CMAL	0,115	0,645
Barrett (Full)	0,163	0,588
SRK/T CMAL	0,266	0,799
Holladay 1 CMAL	0,290	0,734

MNE = mean numerical error; SDEV = standard deviation of the error

[a] Before optimization of formulas constants. Sorted by ascending order of MNE

Table 3 summarizes the overall accuracy of each IOL formula after constant optimization, sorted by MAE from lowest to highest. The Kane (Full) formula yielded the lowest mean absolute error of 0.43D, followed in ascending order by Hill-RBF 3.0 0.43D, Barrett (Full) 0.44D, Hoffer Q 0.45D, Haigis 0.45D, Holladay 1 0.48 and SRK/T 0.53D. Fig. 1 shows the box-and-whisker plots and the distribution around the MedAE value.

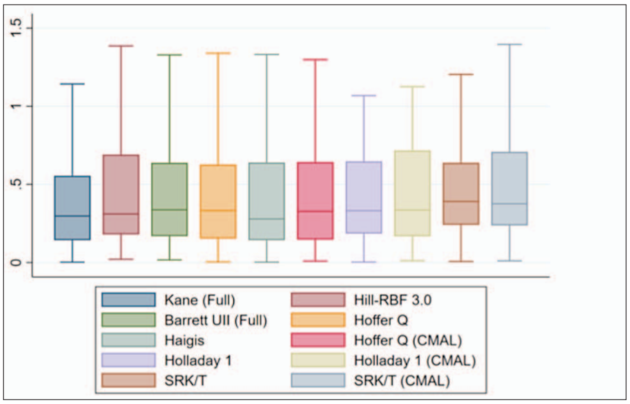

Figure 1. Median absolute prediction error by intraocular lens formula after constant optimization

Fig. 2 displays the proportion of eyes with an absolute prediction error within ±0.50, ±0.75, and ±1.00D for each IOL power calculation formula after constants were optimized. The Kane (Full) formula, with the lowest MAE, yielded a prediction error within 0.50D, 0.75D and 1D in 71.9%, 84.4% and 90.6% of cases, respectively. Similar performance was observed with the Hill-RBF 3.0 (70.3%, 79.7%, and 89.1%) and Barrett II (Full) (68.8%, 84.4%, and 90.6%) formulas. Overall, newer formulas achieved higher percentages compared to traditional ones. Using CMAL did not improve predictions in any of the tested formulas (SRK/T, Holladay 1 and Hoffer Q).

Table 3. **Overall accuracy of IOL power calculation formulas (N = 64)[a]**

					% of Eyes Within PE Range[b]				
Formula	**MeanAE**	**MedAE[b]**	**ME**	**STDEV**	**±0.50 D**	**±0.75 D**	**±1.00 D**	***p*-value[c]**	***p*-value[c] (Bonferroni)[c]**
Kane Full	0.428	0.298	0.000	0.405	71.9%	84.4%	90.6%	REF	REF
Hill-RBF 3.0	0.433	0.311	0.000	0.381	70.3%	79.7%	89.1%	.671	1.000
Barrett Full	0.443	0.337	0.000	0.383	68.8%	84.4%	90.6%	.936	1.000
Hoffer Q	0.449	0.332	0.000	0.399	65.6%	76.6%	90.6%	.862	1.000
Haigis	0.453	0.279	0.000	0.440	68.8%	78.1%	89.1%	.588	1.000
Hoffer Q CMAL	0.464	0.328	0.000	0.444	64.1%	78.1%	90.6%	.422	1.000
Holladay 1	0.482	0.332	0.000	0.473	67.2%	78.1%	89.1%	.226	1.000
Holladay 1 CMAL	0.504	0.335	0.000	0.530	60.9%	75.0%	90.6%	.099	0.887
SRK/T	0.538	0.391	0.000	0.508	60.9%	76.6%	89.1%	.009	0.082
SRK/T CMAL	0.551	0.376	0.000	0.574	60.9%	79.7%	87.5%	.010	0.090

IOL = intraocular lens; ME = mean error; MeanAE = mean absolute prediction error; MedAE = median absolute prediction error; PE = prediction error; STDEV = standard deviation of the error; D = diopters; CMAL=Cooke-modified axial length

[a] After optimization of formula constants. Sorted by ascending order of MeanAE.

[b] Proportion of eyes with absolute PEs within these diopters.

[c] Kane (Full) used as reference for paired comparisons using a sing rank test, *p*-value are shown both uncorrected and following multiple comparisons correction (Bonferroni)

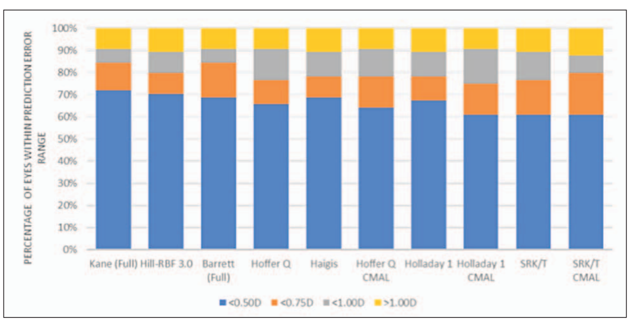

Figure 2. Proportion of eyes with an absolute prediction error within ±0.50, ±0.75, and ±1.00D after constant optimization

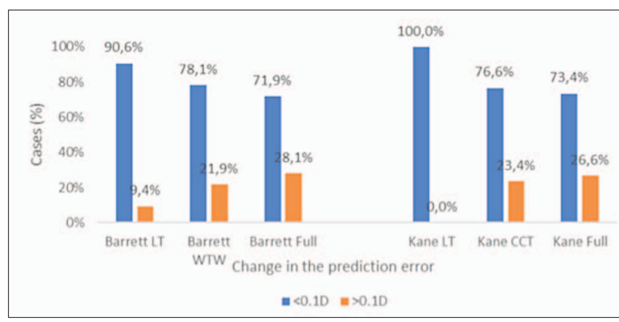

Figure 3. Change in the prediction error with optional variables in the Kane (LT and CCT) and Barrett Universal II (LT and WTW) formulas

The use of optional variables in the Kane (LT and CCT) and Barrett Universal II (LT and WTW) formulas changed the prediction error >0.1D in less than 30% of cases and most without further improvement. In Barrett formula when LT is the only optional the change in prediction error is >0.1D in 9.4% of cases, increasing to 21.9% when only WTW is inserted and achieving 28.1% when both variables are employed. In Kane formula the single use of LT does not change predictions, however using CCT and both variables changed the prediction error >0.1D in 23.4% and 26.6% of cases, respectively (Fig. 3). A subgroup analysis was performed when the prediction error changed >0.1D to evaluate if this modification provided further improvement in the overall prediction results (Fig. 4). Except for the marginal enhancement using CCT in the Kane formula, most optional variables had no overall improvement in the final prediction error.

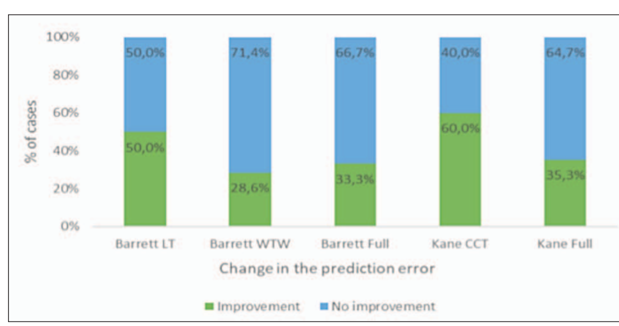

Figure 4. Overall improvement in the prediction error when changed >0.1D

DISCUSSION

This study represents a large sample of patients with short axial length exclusively implanted with a monofocal SN60AT IOL. In addition to common third and fourth generation formulas, newer intraocular lens (IOL) calculation formulas were also included, such as Barrett Universal II, Kane and Hill-RBF 3.0. The AL measurements, the IOL constants used and the chosen formula have been suggested as the three main sources of significant prediction errors.[16] Therefore, the main study goals were to determine if AL adjustment (CMAL), constant optimization and new IOL power prediction formulas improve outcomes. A secondary endpoint was analyzing the prediction error change employing optional variables in the Barrett and Kane formulas.

Without optimization the Hoffer Q is the only formula with myopic prediction error which might explain its popularity in this subset of patients. Some early studies suggested Hoffer Q has the most reliable formula in short eyes, however divergent results have been published.[1,17,18] These results might be explained by different axial length cut-offs, heterogenous selection of formulas and IOL types in addition to variability in samples selection and size. Studies by Carifi *et al* and Gökce *et al* also found a myopic refractive prediction error for the Hoffer Q formula of - 0.22 ±1.22D and - 0.22 ± 0.49D, respectively.[1,19] These results are comparable to ours -0.16 ±0.60D.

Before optimization Hill-RBF 3.0 had the lowest standard deviation in the prediction error 0.031D ± 0.58. Similar to our results Gökce *et al* also verified that prior to the adjustment of the mean refractive prediction error to zero, Hill-RBF formula had one of the lowest standard deviations in the prediction error + 0.05 ± 0.47.[1]

After constant optimization the Kane formula yielded the lowest MAE, followed by Hill-RBF v3.0 and Barrett Universal II. Overall, recent formulas perform well in this subset of patients. These formulas are followed by Hoffer Q, Haigis, Holladay 1 and lastly SRK/T. Gavin *et al* compared the accuracy of the Hoffer Q and SRK/T in 41 eyes with AL <22 mm and discovered Hoffer Q (MAE= 0.78D) was significantly more accurate than the SRK/T (MAE= 0.98D).[20] Our study confirms these results, since the Hoffer Q (MAE= 0.45D) was more accurate than the SRK/T (MAE= 0.54D).

Eom *et al* compared the accuracy of the Hoffer Q and Haigis formulas according to the ACD.[21] The Hoffer Q and Haigis formulas were found to be similarly accurate in eyes with ALs <22.0 mm. After performing a subgroup analysis, when the ACD was deeper than 2.40 mm no significant differences were found between the Hoffer Q or Haigis formula. However, Haigis formula was significantly more accurate than Hoffer Q in patients with an ACD less than 2.40 mm. In our study, the mean ACD was 2.77 ± 0.38 mm, explaining the similar MAE of Hoffer Q (MAE= 0.45D) and Haigis (MAE= 0.45D) formulas.

The Kane (Full) formula yielded a prediction error within 0.50D, 0.75D and 1D in 71.9%, 84.4% and 90.6% of cases, respectively. Similar performance was observed with the Hill-RBF 3.0 (70.3 %, 79.7%, and 89.1%) and Barrett II (Full) (68.8 %, 84.4%, and 90.6%) formulas. Unfortunately, these outcomes are still less accurate than the reports described in eyes with normal ALs. For example, Barrett II reports a prediction error within 0.50D, 0.75D and 1D in 80.8%, 93.7% and 97.8% of cases.[22] Therefore, we can conclude that in this subset of patients further improvement in IOL power calculation is necessary.

According to Cooke *et al* CMAL adjustment improves most of US-derived formulas and worsens most optical biometry derived formulas. However, in our study CMAL adjustment did not improve predictions in any of the tested US-derived formulas (SRK/T, Holladay 1 and Hoffer Q).[9] As stated by Cooke *et al* CMAL was developed with the optical low-coherence reflectometry (OLCR) device (Lenstar LS 900, Haag-Streit AG) machine, and it is not clear if it is transferable to other optical biometers with caution being advised.[6] In our study, all biometry was solely obtained with swept-source optical coherence tomography biometer (IOLMaster 700; Carl Zeiss Meditec AG, Jena, Germany), which may account as an explanation for the lack of improvement with CMAL.

Lastly, as a secondary endpoint in our study we concluded that the use of optional variables in the Kane (LT and CCT) and Barrett Universal II (LT and WTW) formulas did not further enhance predictions.

To the best of our knowledge, there is only one study showing the accuracy of IOL power calculation in the presence of partial biometry.[23] Using only the Barrett formula the authors concluded that the contribution of optional parameters was of little clinical importance in eyes with AL longer than 22 mm. However, in small eyes (AL ≤ 22 mm) there was a clinically significant difference in the calculated IOL power compared to the full biometry data. Interestingly, WTW and LT measurements had little to no effect and the most important parameter among the optional parameters was found to be ACD. When the ACD was not employed, results were identical to calculations based only on AL and K readings. Instead, when ACD was applied, the IOL power calculation was similar to that generated by all parameters with only 0.05 to 0.11 D mean absolute difference between them. Since ACD was not tested as optional parameter in this study, our results are comparable.

This study as several strengths. First, this is one of the largest reported case series in short eyes. Furthermore, the biometry data was collected using a single optical biometer (IOLMaster 700; Carl Zeiss Meditec AG, Jena, Germany). Lastly, we included a single eye per patient and implanted a single IOL model (AcrySof SN60AT)

We also recognize certain limitations. Our study has a retrospective design and surgeries were performed by different surgeons, in close relation with the reality found in a tertiary public hospital. Also, lens constants adjustment was performed to produce a mean numerical refractive prediction error of zero by adjusting all the prediction errors up or down, which is not the same as formally optimizing the lens constants, though this is acceptable according to best practices.[24]

In summary, our results demonstrate that recent formulas like the Barrett Universal II, Kane, Hill-RBF v3.0 perform well in eyes with short axial length, particularly after constant optimization. Without optimization the Hoffer Q is the only one with myopic prediction error. The CMAL adjustment did not improve outcomes and the use of optional variables in the Kane and Barrett Universal II formulas did not further enhance predictions.

CONTRIBUTORSHIP STATEMENT / DECLARAÇÃO DE CONTRIBUIÇÃO:

JC: Colheita de dados, análise estatística e redação do manuscrito.

MR, CL e JM: Análise estatística, revisão e aprovação do manuscrito final.

JC: Data collection, statistical analysis and writing of the manuscript.

MR, CL and JM: Statistical analysis, review and approval of the final manuscript.

RESPONSABILIDADES ÉTICAS

Conflitos de Interesse: Os autores declaram a inexistência de conflitos de interesse na realização do presente trabalho.

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Confidencialidade dos Dados: Os autores declaram ter seguido os protocolos da sua instituição acerca da publicação dos dados de doentes.

Proteção de Pessoas e Animais: Os autores declaram que os procedimentos seguidos estavam de acordo com os regulamentos estabelecidos pelos responsáveis da Comissão de Investigação Clínica e Ética e de acordo com a Declaração de Helsínquia revista em 2013 e da Associação Médica Mundial.

Proveniência e Revisão por Pares: Não comissionado; revisão externa por pares.

ETHICAL DISCLOSURES

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Confidentiality of Data: The authors declare that they have followed the protocols of their work center on the publication of data from patients.

Protection of Human and Animal Subjects: The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki as revised in 2013).

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REFERENCES

1. Gökce SE, Zeiter JH, Weikert MP, Koch DD, Hill W, Wang L. Intraocular lens power calculations in short eyes using 7 formulas. J Cataract Refract Surg. 2017;43:892-7. doi: 10.1016/j.jcrs.2017.07.004.
2. Röggla V, Langenbucher A, Leydolt C, Schartmüller D, Schwarzenbacher L, Abela-Formanek C, Menapace R. Accuracy of common IOL power formulas in 611 eyes based on axial length and corneal power ranges. Br J Ophthalmol. 2020 ;2020-315882. doi: 10.1136/bjophthalmol-2020-315882.
3. Melles RB, Kane JX, Olsen T, Chang WJ. Update on Intraocular Lens Calculation Formulas. Ophthalmology. 2019;126:1334-5. doi: 10.1016/j.ophtha.2019.04.011.
4. Voytsekhivskyy OV, Hoffer KJ, Savini G, Tutchenko LP, Hipólito-Fernandes D. Clinical Accuracy of 18 IOL Power Formulas in 241 Short Eyes. Curr Eye Res. 2021(in press). doi: 10.1080/02713683.2021.1933056.
5. Shrivastava AK, Behera P, Kumar B, Nanda S. Precision of intraocular lens power prediction in eyes shorter than 22 mm: An analysis of 6 formulas. J Cataract Refract Surg. 2018;44:1317-20. doi: 10.1016/j.jcrs.2018.07.023.
6. Cooke DL, Cooke TL. Approximating sum-of-segments axial length from a traditional optical low-coherence reflectometry measurement. J Cataract Refract Surg. 2019;45:351-4. doi: 10.1016/j.jcrs.2018.12.026. PMID: 30851808.
7. Kane JX, Melles RB. Intraocular lens formula comparison in axial hyperopia with a high-power intraocular lens of 30 or more diopters. J Cataract Refract Surg. 2020;46:1236-9. doi: 10.1097/j.jcrs.0000000000000235.
8. Hoffer KJ, Savini G. IOL Power Calculation in Short and Long Eyes. Asia Pac J Ophthalmol. 2017;6:330-1. doi: 10.22608/APO.2017338.
9. Cooke DL, Cooke TL. A comparison of two methods to calculate axial length. J Cataract Refract Surg. 2019;45:284-92. doi: 10.1016/j.jcrs.2018.10.039.
10. Wan KH, Lam TC, Yu MC, Chan TC. Accuracy and Precision of Intraocular Lens Calculations Using the New Hill-RBF Version 2.0 in Eyes With High Axial Myopia. Am J Ophthalmol. 2019;205:66-73. doi: 10.1016/j.ajo.2019.04.019.
11. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens implant power calculation formula. J Cataract Refract Surg. 1990;16:333–40;erratum: 528. doi:10.1016/ s0886-3350(13)80705-5.
12. Haigis W, Lege B, Miller N, Schneider B. Comparison of immersion ultrasound biometry and partial coherence interferometry for IOL calculation according to Haigis. Graefes Arch Clin Exp Ophthalmol. 2000;238:765–73. doi:10.1007/s004170000188.
13. Hoffer KJ. The Hoffer Q formula: a comparison of theoretic and regression formulas. J Cataract Refract Surg. 1993;19:700–12; errata 1994; 20:677 and Zuberbuhler B, Morell AJ. Errata in printed Hoffer Q formula [letter]. J Cataract Refract Surg 2007; 33:2; reply by KJ Hoffer, 2-3. doi:10.1016/s0886-3350(13)80338-0.
14. Holladay JT, Prager TC, Chandler TY, Musgrove KH, Lewis JW, Ruiz RS. A three-part system for refining intraocular lens power calculations. J Cataract Refract Surg. 1988;14:17–24. doi:10.1016/s0886-3350(88)80059-2.
15. Hoffer KJ, Aramberri J, Haigis W, Olsen T, Savini G, Shammas HJ, et al. Protocols for studies of intraocular lens formula accuracy. Am J Ophthalmol. 2015;160:403-5.e1. doi:10.1016/j.ajo.2015.05.029
16. Karabela Y, Eliacik M, Kocabora MS, Erdur SK, Baybora H. Predicting the refractive outcome and accuracy of IOL power calculation after phacoemulsification using the SRK/T formula with ultrasound biometry in medium axial lengths. Clin Ophthalmol. 2017;11:1143-9. doi:10.2147/OPTH.S136882
17. Hoffer KJ. Clinical results using the Holladay 2 intraocular lens power formula. J Cataract Refract Surg. 2000; 26:1233–7.
18. Kane JX, Van Heeden A, Atik A, Petsoglou C. Intraocular lens

power formula accuracy: comparison of 7 formulas. J Cataract Refract Surg. 2016; 42:1490–500.
19. Carifi G, Aiello F, Zygoura V, Kopsachilis N, Maurino V. Accuracy of the refractive prediction determined by multiple currently available intraocular lenspower calculation formulas in small eyes. Am J Ophthalmol. 2015; 159:577–83.
20. Gavin EA, Hammond CJ. Intraocular lens power calculation in short eyes. Eye. 2008;22:935–38. doi:10.1038/sj.eye.6702774.
21. Eom Y, Kang SY, Song JS, Kim YY, Kim HM. Comparison of Hoffer Q and Haigis formulae for intraocular lens power calculation according to the anterior chamber depth in short eyes. Am J Ophthalmol. 2014;157:818-824.e2. doi: 10.1016/j.ajo.2013.12.017.
22. Melles RB, Holladay JT, Chang WJ. Accuracy of Intraocular Lens Calculation Formulas. Ophthalmology. 2018;125:169-78. doi: 10.1016/j.ophtha.2017.08.027.
23. Vega Y, Gershoni A, Achiron A, Tuuminen R, Weinberger Y, Livny E, et al. High Agreement between Barrett Universal II Calculations with and without Utilization of Optional Biometry Parameters. J Clin Med. 2021;10:542. doi:10.3390/jcm10030542.
24. Koch DD, Hill W, Abulafia A, Wang L. Pursuing perfection in intraocular lens calculations: I. Logical approach for classifying IOL calculation formulas. J Cataract Refract Surg. 2017;43:717-8. doi: 10.1016/j.jcrs.2017.06.006.

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