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The accuracy of intraocular lens power calculation formulas for eyes longer than 25.00 mm and the correlation between method accuracy and eyeball axial length

Wiktor Stopyra

MW med Eye Centre, Krakow, Poland

ABSTRACT

Aim of the study: To compare the accuracy of intraocular lens power calculation formulas and examine the correlation of this accuracy with the axial length for eyes larger than 25.00 mm
Material and methods:. The data of myopic patients who underwent uneventful phacoemulsification between October 2015 and June 2019 were reviewed. The intraocular lens power for each patient was calculated using 6 formulas (Holladay1, SRK/T, Hoffer Q, Holladay 2, Haigis and Barrett Universal II) before cataract surgery. Postoperative refraction was measured and refractive prediction error was calculated 3 months after phacoemulsification. The correlation between axial length and absolute error was evaluated.
Results: Seventy patients (81 eyeballs with ocular axial length between 25.01 mm and 28.57 mm) were studied. The Barrett Universal II formula achieved the lowest level of mean absolute error of 0.08 ±0.08 D ($p < 0.001$). Significant correlations for the Holladay 1 ($r = 0.478$, $p < 0.001$), the Barrett Universal II ($r = 0.312$, $p = 0.005$) and for the Hoffer Q ($r = 0.293$, $p = 0.008$) formula were observed.
Conclusions:
1. The Barrett Universal II formula obtained the lowest absolute error and is recommended for intraocular lens power calculation for eyeballs with axial length exceeding 25.0 mm.
2. The correlation between axial length and absolute error is a factor which should be considered when calculating intraocular lens power, especially for eyeballs with an extremely large axial length.

KEY WORDS: intraocular lens power calculation formula, eyeball longer than 25.0 mm, Barrett Universal II formula, mean absolute error, correlation.

INTRODUCTION

It has been hotly debated which intraocular lens (IOL) power calculation formula best predicts actual postoperative refraction outcomes. This is due to patients' high expectations for precise vision after cataract surgery. Hence, many IOL power calculation formulas have been developed. They form five generations, which are shown in Table I [1-4].

Intraocular lens power calculation formulas are divided into theoretical (Fyodorov, Binkhorst, Hoffer – based on geometrical optics of eye) and empirical (SRK II, SRK/T, Haigis –

Table I. Generations of intraocular lens power calculation formulas

	Generation				
	1st	2nd	3rd	4th	5th
Formulas	Fyodorov SRK Binkhorst Colenbrander Clayman	SRK II Binkhorst II	Hoffer Q Holladay 1 SRK/T	Holladay 2 Haigis Olsen L-SRK Shammas	Barrett Universal Hill RBF Hoffer H-5 Ladas Super FullMonte

CORRESPONDING AUTHOR
Wiktor Stopyra, MD, PhD, MW med Eye Centre, 207 Dobrego Pasterza St., 31-416 Krakow, Poland, e-mail: wiktorstopyra@gmail.com

generated by averaging large numbers of postoperative clinical results). All theoretical formulas are based on the same fundamental following variables function f {AL, K, n, ACD} where:

AL – axial length,

K – corneal curvature,

n – refractive indices of aqueous and vitreous,

ACD – estimated postoperative anterior chamber depth.

In the particular case of the Sanders-Retzlaff-Kraff (SRK) formula, this gives the well-known equation:

$$P = A - 2.5AL - 0.9K$$

where

P – IOL power for emmetropia.

Usually most IOL power calculation formulas perform well for eyes of AL between 22.0 mm and 25.0 mm [5]. Only a few formulas obtain accurate results in the cases when an eyeball is shorter than 22.0 mm or longer than 25.0 mm [4, 6]. Eye surgeons are not sure, especially when choosing IOL power calculation formulas for eyes with AL exceeding 25.0 mm. Although the Barrett Universal II formula seems to be the most accurate in this respect [2, 6-8] there are still articles in which the advantage of the Haigis [5, 9], Holladay 1 [1, 9] Olsen [6] or Hill RBF [2] formula is shown.

Therefore the aim of this study was to evaluate the accuracy of IOL power calculation formulas for eyes longer than 25.0 mm. The correlation between accuracy of the formula and AL was also considered due to the large range of the myopic eyes' length.

MATERIAL AND MEHODS

Patients

The study was conducted adhering to the tenets of the Declaration of Helsinki. Each patient signed an informed consent form for routine cataract surgery. Seventy patients (81 eyeballs) were studied (36 men and 34 women at the mean age of 69.8 ±8.3; range 47-86).

Uneventful sutureless phacoemulsification and monofocal intraocular lens implantation with a 2.4 mm clear corneal incision was performed on all patients between October 2015 and June 2019. Axial lengths of the eyeballs were in the range between 25.01 mm and 28.57 mm. Cases with corneal astigmatism greater than 2.0 D or eyes having additional procedures such as vitrectomy or limbal relaxing incisions were not considered. Additionally, patients after corneal refractive surgery were excluded from the study.

Methods

Preoperatively, all patients underwent a full ophthalmological examination (best corrected Snellen visual acuity (VA), intraocular pressure, slit-lamp and fundus examination). Additionally, using the Zeiss IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany) keratometry and ocular biometry were performed in all eyes to measure K and AL with partial coherence interferometry and then to calculate IOL power using six different formulas (SRK/T, Holladay 1, Hoffer Q, Haigis, Holladay 2, Barrett Universal II) achieving theoretical postoperative emmetropia. All cataract operations were performed on the same equipment (Phacoemulsifier Infiniti, Alcon, Fortworth, TX, USA). Only monofocal, single-piece, hydrophobic, acrylic foldable IOLs were implanted. The manifest refraction was performed at the postoperative visit three months after phacoemulsification using an autorefractor keratometer tonometer (Nidek RKT-7700, Nidek Co Ltd, Tokyo, Japan). Based on postoperative refraction results the refractive prediction error was calculated as the difference between the real postoperative refractive outcome expressed as the spherical equivalent (the sum of spherical power and half of cylindrical power) and the residual refraction as the IOLMaster outcome for the power of the IOL actually implanted predicted by each formula. A positive value means a hyperopic prediction error and a negative value indicates myopic prediction error while absolute value (AV) refers to an absolute error (AE). Thus mean absolute error (MAE) for each formula was calculated as the average of the absolute value of the deviation from predicted postoperative refractive outcome for all cases. To determine whether AL correlates with postoperative refractive outcome, the correlation between AL and AE was evaluated using linear regression analysis.

Statistical analysis was performed using the Statistica 13.1 package. Data were analyzed using Excel spreadsheets (Microsoft Corp). A probability of less than 5% ($p < 0.05$) was considered statistically significant unless it was necessary to apply Bonferroni corrections for multiple comparisons, which reduced the significance level down to even 0.003. Data distribution for normality was checked using the Shapiro-Wilk test. The distribution of the variables was not normal so the non-parametric Kruskal-Wallis test was used to check statistically significant differences for between-group comparison. Then the Mann-Whitey *U*-test for quantitative variables was used for comparison between pairs of formula. Finally, using the Spearman rank test, the correlation between AL and AE was assessed for each formula.

RESULTS

Barrett Universal II and Holladay 2 formulas obtained the lowest (–0.34 D and –0.39 D, respectively) while Hoffer Q and SRK/T achieved the highest (–0.71 D and –0.67 D, respectively) value of the myopic refractive prediction error. Barrett Universal II and Haigis obtained the lowest (0.28 D and 0.29 D, respectively) while Holladay 1, Hoffer Q and SRK/T achieved the highest (0.61 D, 0.58 D, 0.58 D, respectively) value of the hyperopic refractive prediction error. Results of the calculated refractive prediction error are illustrated in Figure 1.

Barrett Universal II and Holladay 2 formulas obtained the lowest (0.05 and 0.12, respectively) while Hoffer Q and Holladay 1 achieved the highest (0.24 and 0.16, respectively) median value of AE. Similarly, Barrett Universal II and Holladay 2 formulas obtained the lowest (0.08 and 0.13, respectively) and Hoffer Q and Holladay 1 achieved the highest

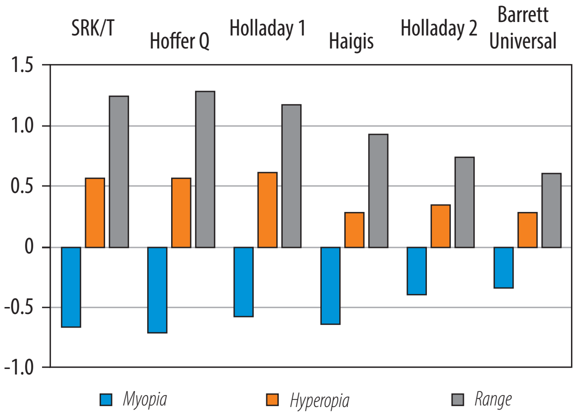

Figure 1. Refractive prediction error for each formula

(0.26 and 0.20, respectively) value of the MAE. Detailed AE outcomes for each formula were summarized using descriptive statistics (mean, standard deviation, median and range) and are shown in Figure 2.

Because of the non-normality of data distribution the nonparametric Kruskal-Wallis test was performed to compare AE results according to the six formulas. The test obtained $p < 0.001$ so outcomes were significant (probability less than 5%); therefore, it was checked between which pairs of formulas there were statistically significant differences. Due to multiple comparisons Bonferroni corrections were applied; therefore $\alpha = 0.05/15 = 0.003$. The nonparametric Mann-Whitney *U*-test was performed. The Barrett Universal II formula obtained the lowest level of mean absolute error of 0.08 ±0.08 D. For variables of Barrett Universal II versus each other formula as well as Hoffer Q versus Haigis, Holladay 2 and SRK/T formulas significant differences were found ($p < 0.001$).

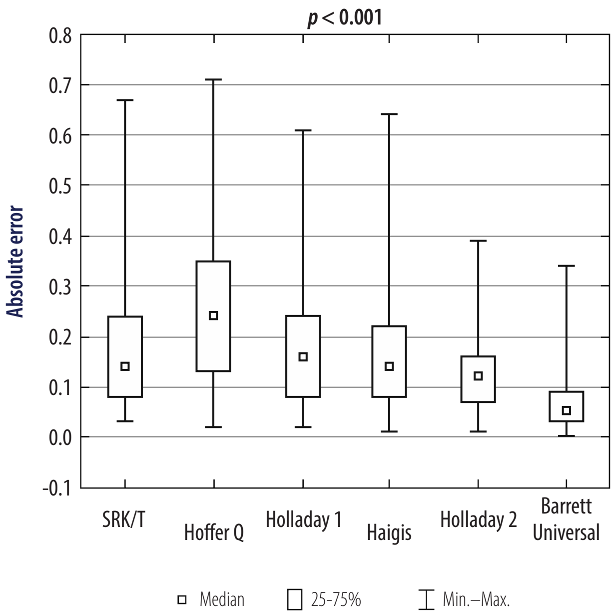

Figure 2. Descriptive statistics of absolute error for each formula

Next the correlation between AE and AL was evaluated. Significant correlation factors were obtained between AE and AL for the Holladay 1 formula as well as for the Barrett Universal II and the Hoffer Q formula. These correlations show that with the increase of axial eyeball length above 25.00 mm, AE increases, i.e. the accuracy of the formula decreases. For the Holladay 1 formula the correlation is moderate (Pearson correlation $r = 0.478$, $p < 0.001$), which is illustrated in Figure 3.

For Barrett Universal II ($r = 0.312$, $p = 0.005$) and for Hoffer Q ($r = 0.293$, $p = 0.008$) the correlation is low.

DISCUSSION

Due to widespread application of phacoemulsification postoperative refractive status is less associated with surgical factors. Meanwhile, accuracy of IOL power calculation formulas is the most important factor affecting the postoperative refractive status, and nowadays the choice of IOL formula is closely related to the accuracy of IOL power calculation [5]. However, the IOL power calculation's inaccuracy in eyes with long AL is well documented [6]. So, how to choose the most accurate IOL power calculation formula? We are currently even trying to use artificial intelligence for this purpose [10].

A meta-analysis of 4047 eyeballs longer than 24.5 mm published in 2018 showed the superiority of the Barrett Universal II formula over Holladay 1, Hoffer Q, SRK/T and Holladay 2 formulas but did not demonstrate a significant difference between Barrett Universal II and Haigis as well as the Olsen formula [6]. The highest correctness of the Barrett Universal II formula was also shown in the studies carried out by Zhang *et al.*, Liu *et al.*, as well as by Zhou, Sun, Deng [2, 7, 8]. The latter group obtained similar results to the present study. There too, the Barrett Universal II formula achieved the lowest MAE and the Hoffer Q formula the highest MAE (0.35 and 0.67, respectively). The results of the MAE in the present study are even smaller (0.08 and 0.26, respectively) and therefore even more accurate. However, Zhou *et al.* tested eyeballs much longer, up to 33.28 mm, which of course increased the MAE [8]. Moreover, Kane *et al.* observed that in

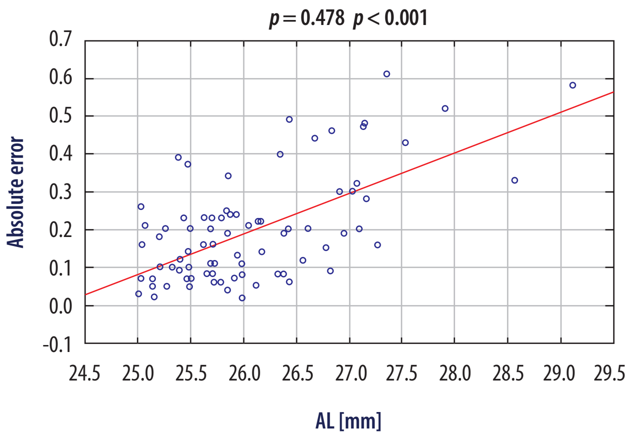

Figure 3. Correlation between absolute error and axial length for the Holladay 1 formula

eyes with an AL longer than 22.0 mm, the Barrett Universal II formula was a more accurate predictor of actual postoperative refraction than Haigis, Hoffer Q, Holladay 1, Holladay 2, SRK/T, and T2 formulas [11]. But Hoffer and Savini did not find a difference in the accuracy of Barrett Universal II, Haigis, Olsen and SRK/T formulas for long eyeballs [12]. David and Timothy Cook concluded that formulas gave different results depending on which machine measurements were used. The Olsen formula was the most accurate with optical low-coherence reflectometry measurements, significantly better than the best formula with partial coherence interferometry measurements. The Olsen was better, regardless of AL. If only partial coherence interferometry measurements (without lens thickness) were available, the Barrett Universal II performed the best and the Olsen formula performed the worst [13]. In turn, Chong and Mehta demonstrated that Barrett Universal II, Haigis and Holladay 1 formulas gave equally good calculation outcomes for eyes with AL exceeding 26 mm [9]. The most accurate predictions of actual postoperative refraction were achieved using the Barrett Universal II, Hill-RBF, Olsen, or T2 formula in the study of Shajari *et al.*, but only the quadrifocal IOLs were considered [14]. Rong *et al.* studying 79 eyes with AL longer than 26 mm comparatively evaluated Barrett Universal II, Haigis and Olsen formulas [15]. They obtained MAE of 0.41 for the Barrett Universal II formula and of 0.54 for Haigis, which is more than in the present study, but they tested eyeballs with an axial length up to 34.96 mm while the present study tested eyeballs with an axial length only up to 28.57 mm [15].

Bang *et al.* in their study proved the superiority of the Haigis formula over the others but it was performed only on 53 eyes longer than 27 mm [16]. Zheng *et al.* in their study involving 137 myopic eyes with AL greater than 26 mm found no differences in the accuracy of Haigis and SRK/T formulas [17]. It is interesting that the Haigis formula gave the best correctness of IOL power calculation in the study of Ghenam and El-Sayed but AL was measured using an A-scan ultrasonic biometer [18].

In my 2013 study, I observed the greatest accuracy of the Holladay 1 formula, but I did not use Barrett Universal II or Holladay 2 formulas at the time [1]. Nevertheless, Aristodemou *et al.* in their research with 1000 myopic eyes proved that the Holladay 1 formula used for calculating the IOL power for eyes with AL between 24.5 mm and 26.0 mm gave the best results, whereas the SRK/T formula was the most precise for eyes longer than 27.0 mm. Although the study was conducted on a large group, only three formulas – Hoffer Q, Holladay 1 and SRK/T – were considered [3].

The issue of correlation was not often considered in terms of IOL power calculation formulas' accuracy. Chen *et al.* proved that for SRK/T and Hoffer Q formulas, a 1 mm increase in AL increased AE by about 0.1 D when AL > 26 mm, while in the case of AL > 33 mm a 1 mm increase in AL increased the AE as much as about 1.1 D [4]. Zhou *et al.* made an interesting observation. In their study they found that the prediction error of Barrett Universal II and SRK/T formulas was less when the AL was between 24.5 and 30.0 mm in comparison to that calculated by Haigis, Holladay and Hoffer Q, while for AL greater than 30.0 mm, the prediction error of Barrett Universal II and Haigis formulas was smaller. They showed that the AE of SRK/T, Holladay, Hoffer Q and Barrett Universal II formulas was statistically significantly positively correlated with AL. That is, the longer the AL of the patient's eye was, the greater was the AE [8]. In the present study a statistically significant correlation was found between AL and AE for Holladay 1, Barrett Universal II, and Hoffer Q formulas when AL > 25.0 mm. Similarly to Chen, the present author found that with an increase of AL by 1 mm AE increased by 0.1 D, with the difference, however, that the range of AL was between 25.0 mm and 29.0 mm and the correlation applies to the Holladay 1 formula.

Thus, there is no single most exact IOL power calculation formula in the case of eyeballs with axial length exceeding 25.00 mm. The Barrett Universal II formula is considered generally as the most accurate [2, 6-8]. The present study supported a similar conclusion. The Barrett Universal II formula achieved the smallest result of AE as both a mean and a median and obtained the lowest refractive prediction error.

CONCLUSIONS

The Barrett Universal II formula obtaining the lowest AE is recommended for IOL power calculation for eyeballs with axial length exceeding 25.0 mm.

The observed positive correlation between AE and AL suggests that the accuracy of the IOL power calculation formula decreases with increasing eyeball length. This should be considered especially when using the Holladay 1 formula, for which the correlation is moderate.

DISCLOSURE

The author declares no conflict of interest.

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