Assessing Accuracy of Okulix Ray-Tracing Software in Calculating Intraocular Lens Power in the Long Cataractous Eyes

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Abstract

Purpose: To investigate the accuracy of Okulix ray-tracing software in calculating intraocular lens (IOL) power in the long cataractous eyes and comparing the results with those obtained from Kane, Holladay 1 with optimized constant, SRK/T with optimized constant, Haigis with optimized constant, and Barret Universal 2 formulas.

Methods: The present study evaluates the refractive results of cataract surgery in 85 eyes with axial length > 25 mm and no history of ocular surgery and corneal pathology. IOL power calculation was performed using the Okulix software. The performances of Okulix software in comparison with the five other formulas were evaluated by predicted error, mean absolute error, and mean numerical error 6 months after surgery.

Results: The mean calculated IOL power by the Okulix software was +13.48 ± 4.19 diopter (D). The mean of the 6-month postoperative sphere and spherical equivalent were +0.18 ± 0.63 and -0.34 ± 0.78 D, respectively. Also, the 6-month spherical equivalent in 56.6% and 80% of eyes were within ±0.05 and ±1.00 D, respectively. The predicted error ($P < 0.001$) and the mean numerical error ($P < 0.001$) were different between the six studied methods; however, we were not able to find any significant differences in the mean absolute error among six studied methods (P: 0.211).

Conclusion: The present study showed acceptable performance of the Okulix software in IOL power calculation in long eyes in comparison with the other five methods based on the postoperative refractive error, calculated mean absolute error, and mean numerical error.

Keywords: Axial length, Cataract, Kane, Okulix, Ray-tracing, Refraction

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Introduction

The precise calculation of intraocular lens (IOL) power is an important step in producing optimal refractive results after cataract surgery. For nearly half a century, various formulas have been proposed to calculate IOL power. Currently, the most commonly used options are the third and fourth-generation formulas.[1] It is widely accepted that both sets of theories and regression formulas appropriately operate with axial lengths between 22 and 24.5 mm.[1] However, no equality exists between the results of different formulas at axial lengths shorter than 22 mm and longer than 25 mm.[2] The results of some studies shows that the third generation formulas in long eyes select the IOL with inadequate power compared to the actual

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required power, which results in hyperopic refractive outcomes after cataract surgery.[3]

To solve this problem, some practitioners used to specify some minus values for target refraction instead of Plano to reduce these refractive surprises in the long eyes, and some others employed the Wang-Koch adjustment method.[4,5] Since most of the IOL power calculation formulas are based on Gaussian optics (paraxial optics or the thin lens method), which is a poor estimation of the actual optical conditions of the human eye,[6] an attempt was made in axial length adjustment formulas to increase the accuracy of the calculated IOL power using predetermined coefficients.[5]

One of the growing IOL power calculation methods is Okulix software (Tedics Peric and Jöher GbR, Dortmund, Germany), which performs based on ray-tracing optics.[7] Okulix software calculates the path and the focal point of the entire beams passing through the pupils at each optical level in terms of Snell's law. Since the final focal point of the beams can be precisely calculated in this method, it is possible to calculate the IOL power more accurately.[7] Therefore, this software is expected to demonstrate acceptable performance in eyes with different conditions like long axial lengths. We found a limited number of studies evaluating the performance of Okulix software under various eye conditions. For instance, Nabil conducted a study to describe the refractive results after cataract surgery in long eyes without comparing them with other formulas.[8] However, in Ghoreyshi *et al*.'s study, Okulix software was compared with a few formulas in axial lengths between 21 and 26 mm.[9] Therefore, the needs of inspecting such an issue was crucially felt to compare the performance of Okulix software with those of some newer approaches such as Wang-Koch adjustment method and Kane's artificial intelligence-based formula in different eye types.

Considering the high incidence of cataract in people with high myopia,[10] the unequal results of different IOL power calculation formulas in axial lengths >25 mm, and the hyperopic refractive surprises of the patients after performing cataract surgery,[6,11] the present study attempted to investigate the refractive results of cataract surgery in eyes with axial length >25 mm, in which the IOL power was calculated using Okulix software. Furthermore, the obtained results were compared with the Kane, Holladay 1with optimized constant, SRK/T with optimized constant, Haigis with optimized constant, and Barret Universal 2 formulas to evaluate the performance of Okulix software.

Methods

In this retrospective study, eyes with axial lengths >25 mm were included. It should be noted that only one eye from each patient entered into the analysis, and in cases that needed cataract surgery in both eyes, only information of the first surgery was included in the final analysis. The Ethics Committee of the Iran University of Medical Sciences approved the study protocol. The study was conducted in terms of the tenets of the Declaration of Helsinki, and informed consent was obtained from all the included participants (IR. IUMS.REC.1398.1020).

The inclusion criteria were axial length >25 mm as well as the absence of any corneal pathology and retinal staphyloma. The exclusion criteria were having a history of any ocular surgery, dense nuclear cataract (any eye requiring ultrasound biometry), and the calculated IOL power <5.00 diopter (D).

Ocular examinations were performed between 2016 and 2019 at the BinaAfarin Ophthalmology Clinic in Tehran, Iran. First, the presence of cataract and the need for surgery were confirmed by a cornea specialist (M.J.) based on the patient's situation. Thereafter, ocular biometry was performed using OA-2000 (Tomey, Nagoya, Japan) biometry device, and biometrical components including axial length, anterior chamber depth, anterior flat and steep keratometry, lens thickness, pupil diameter, and white to white were also measured. Afterward, IOL power calculations were performed in all the studied eyes based on AMO TECNIS® Monofocal 1-Piece ZCB00 IOL information using Okulix software (A constant: 119.36). Refractive error components (sphere, cylinder, and axis) were also measured using Topcon KR 8900 (Topcon Corp., Tokyo, Japan), which were verified with a beta 200 streak retinoscope (Heine, Herrsching, Germany) followed by the subjective refraction in both preoperative examination and 6 months postoperative follow-up. Moreover, uncorrected and the best corrected visual acuity was recorded in logMAR criteria using the Snellen chart within 4 m distance in each examination. It is worth mentioning that the calculation of IOL power was carried out by Kane, Holladay 1 with optimized constant, SRK/T with optimized constant, Haigis with optimized constant, and Barret Universal 2 formulas as well as Okulix software for the above-mentioned IOL type. The calculation of the IOL power using Kane and Barret Universal 2 formulas was performed by referring to the following internet addresses: https://www.iolformula.com/(for Kane formula) and http://calc.apacrs.org/barrett_universal2105/(for Barret Universal 2 formula).

For all the enrolled cases, cataract surgery (phacoemulsification) was performed. The insertion of posterior chamber IOL in the capsular bag was done by a skilful physician (M.J.). Accordingly, the chosen IOL was AMO TECNIS® Monofocal 1-Piece ZCB00 IOL (A constant: 119.36) with Plano target refraction. Due to the predicted error of <0.25 D, the IOL power was exactly selected based on the calculated value by Okulix software.

Okulix software (Tedics Peric and Jöher GbR, Dortmund, Germany; Version 001-001) used in this study presents the optimum monochromatic optical capacity of the visual system and also examines the path of a single optical beam, which is merely limited by pupil size (exactly). The estimation of IOL placement can be done by Okulix software with the defined specifications inside each eye. In addition, this software calculates the postoperative anterior chamber depth, which is known as the most possible location for the IOL position based on the preoperative information, including axial length, position, and thickness of the crystalline lens and the selected IOL characteristics. Finally, to achieve the best results, it provides an accurate calculation of the IOL power via curvature radius (Okulix software measures the anterior corneal keratometry, and calculates posterior keratometry based on anterior values), refractive index, corneal asphericity, and central lens' thickness along with applying biometric information. Therefore, it is predicted that this software can calculate the IOL power with high accuracy in the eyes under different conditions.[7]

The Wang-Koch adjustment method is used to enhance the performance of some IOL calculation formulas in long eyes. In this method, specific coefficients are used to make changes in the axial length value for providing more accurate results.[5] The performance of this method was evaluated and then confirmed in various studies.[3,4] Moreover, the coefficients are different for each formula, which takes place in a certain range of axial lengths. The required parameters and the changes in the studied formulas are presented in Table 1.

Statistical analysis

The minimum required sample size was calculated based on the study by Nabil[8] in which the mean absolute error for eyes with axial length >26.5 mm using Okulix software was calculated as 0.45 ± 0.40. Therefore, 62 eyes were calculated as the minimum required sample size by considering the 95% confidence level, an acceptable error rate of 0.1, and the value 0.40 as the standard deviation. However, to increase the accuracy of the obtained results, all the patients who met the inclusion criteria in the above-mentioned time were inspected, and after excluding some of the individuals based on the exclusion criteria, 85 eyes were finally analyzed in this study.

Descriptive statistical information including mean, minimum, and maximum values (for qualitative variables) was calculated. Changes in refractive error components and visual acuity were checked with paired sample *t*-test. To compare the results of the Okulix software and the other five formulas, two parameters were defined for each one of them as follows: Mean numerical error (spherical equivalent-predicted error) and mean absolute error (absolute value of [spherical equivalent-predicted error]). Statistical analysis and comparison among the results of different formulas have been done by Friedman and Wilcoxon signed-rank tests. The significance level was considered at 0.05, and all analyses were performed by SPSS version 25 (SPSS, IBM corp., Armonk, NY, USA).

Results

In the present research, 85 eyes of 85 patients (including 47 men and 38 women) with the mean age of 59.77 ± 12.63 (31–87) years old were studied. The axial length of the evaluated ranged from 25.01 to 31.73 mm (mean of 26.41 ± 1.30 mm). The values of the biometric parameters of the studied eyes are presented in Table 2.

As shown in Table 3, the mean of uncorrected and the best corrected visual acuity improved 6 months after cataract surgery (mean difference: -0.80 ± 0.31 and −0.18 ± 0.20 logMAR, respectively). The mean of spherical and cylindrical refractive errors before surgery was −7.07 ± 4.38 D and −1.38 ± 0.90 D, respectively. Six months after cataract surgery and IOL implantation (the mean calculated IOL power by the Okulix software: +13.48 ± 4.19 D), the mean of spherical and cylindrical refractive errors reduced to +0.18 ± 0.63 D ($P < 0.001$) and −1.05 ± 0.79 ($P < 0.001$) D, respectively. Moreover, the mean change in spherical equivalent was +7.42 ± 4.54 D ($P < 0.001$) after surgery.

In Table 3, the values of preoperative and postoperative uncorrected and the best corrected visual acuity, sphere, cylinder, and spherical equivalents are shown.

Figure 1 shows the obtained spherical equivalent 6 months after surgery in different axial lengths.

Table 4 displays the frequencies of spherical refractive error and spherical equivalent obtained 6 months after cataract surgery. According to the values presented in this table, the spherical refractive error in 65.9% of the patients was within the range of ±0.50 D, and in 80% of them, it was within ±1.00 D after performing cataract surgery. Additionally, in 56.5% of the cases, the spherical equivalent was ±0.50 D by passing 6 months from surgery, and 80% of the eyes achieved a spherical equivalent of < ±1.00 D.

Tables 5 and 6 and Figure 2 can be used to compare the performances of the studied formulas. As can be seen, the mean of the calculated IOL powers is significantly different among formulas ($P < 0.001$). Therefore, if Okulix software is considered the basis, the results would differ <0.50 D in

Table 1: Axial length optimization

Formula	Axial length range	Required changes	Required factors[7,12]
Holladay 1with optimized constant	>26.5 mm	0.829×axial length+4.27	Adjusted AL, K
Haigis with optimized constant	>25 mm	0.929×axial length+1.56	Adjusted AL, K, ACD
SRK/T with optimized constant	>27 mm	0.854×axial length+3.72	Adjusted AL, K
Okulix	No axial length adjustment		AL, K, ACD, LT, CCT, WTW, RI, Q
Barret Universal 2	No axial length adjustment		AL, K, ACD, LT, WTW
Kane	No axial length adjustment		AL, K, ACD, sex, LT, CCT

Based on modified Wang-Koch method. AL: Axial length, K: Keratometry, ACD: Anterior chamber depth, LT: Lens thickness, CCT: Central corneal thickness, WTW: White to white, RI: Intraocular lens refractive index, Q: Asphericity

Table 2: Biometric parameters

	Mean±SD	Range
AL	26.41±1.30	25.01-31.73
ACD	3.33±0.40	2.57-4.74
Flat keratometry (diopter)	42.01±1.81	39.00-46.17
Steep keratometry (diopter)	43.39±2.21	39.75-48.49
WTW	12.13±0.49	11.46-13.50

SD: Standard deviation, AL: Axial length, ACD: Anterior chamber depth, WTW: White to white, D: Diopter

Table 3: Visual acuity and refractive error components, presurgery and postsurgery

	Presurgery (n=85)	6 months postsurgery (n=85)	*P**
UCVA (logMAR)			
Mean±SD	1.02±0.32	0.22±0.24	<0.001
Range	0.20-1.40	0.00-1.10	
BCVA (logMAR)			
Mean±SD	0.29±0.22	0.11±0.16	<0.001
Range	0.00-0.80	0.00-1.00	
Sphere (diopter)			
Mean±SD	−7.07±4.38	+0.18±0.63	<0.001
Range	−22.00 - −1.25	−1.25 - +1.75	
Cylinder (diopter)			
Mean±SD	−1.38±0.90	−1.05±0.79	<0.001
Range	−4.25-0.00	−4.00-0.00	
SE (diopter)			
Mean±SD	−7.76±4.51	−0.34±0.78	<0.001
Range	−23.63 - −1.63	−2.75 - +1.50	

*Paired sample *t*-test. Under-lined values are significant. P<0.05 is statistically significant. UCVA: Uncorrected visual acuity, BCVA: Best corrected visual acuity, SE: Spherical equivalent, SD: Standard deviation, D: Diopter

Table 4: Frequency distribution of sphere and spherical equivalent 6 months after surgery

	Frequency			
	−0.50-+0.50	−1.00-+1.00	−2.00-+2.00	−4.00-+4.00
Sphere (%)	65.9	80	100	-
Spherical equivalent (%)	56.5	80	96.5	100

the IOL power with the basis. In this regard, the biggest difference was found to be related to Haigis with optimized constant (which calculated the mean IOL power about 1.00 D more than Okulix software). Moreover, the obtained results from the Kane formula showed higher values in the predicted error (more negative) and lower values in the mean numerical error compared to others (both, P < 0.001). Figure 3 shows different obtained values for the mean numerical error.

The results of the other 5 formulas in terms of the predicted error and mean numerical error did not differ significantly from each other (both, P > 0.05). In addition, the statistical analysis showed that there was no significant difference in mean absolute error between the 6 studied formulas (P: 0.211). The calculated values of the mean absolute error frequency for each one of the formulas are indicated in Table 6 and Figure 4. As shown, in 53.6% of the studied eyes, the rate of the mean absolute error after performing cataract surgery was lower than +0.50 D, and in 83.4% of eyes, this was less than +1.00 D for Okulix software. The mean absolute error frequency lower than +0.50 D was higher for Okulix software in comparison with SRK/T with optimized constant, Haigis with optimized constant, Holladay 1 with

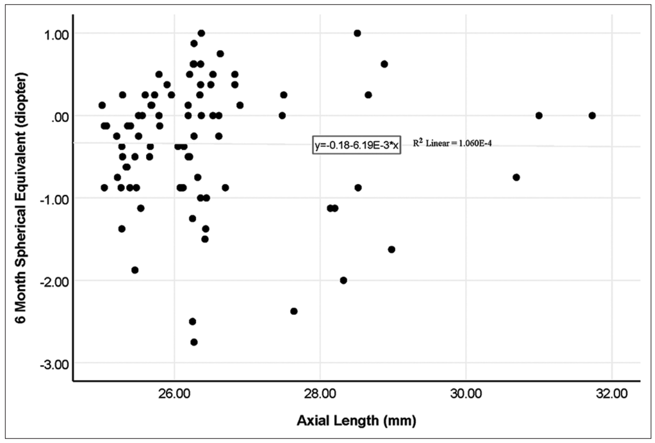

Figure 1: The correlation between spherical equivalent 6 months after surgery and axial lengths

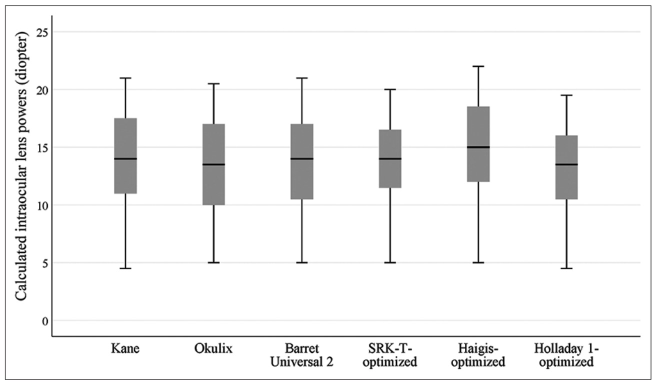

Figure 2: Calculated intraocular lens powers in each formula

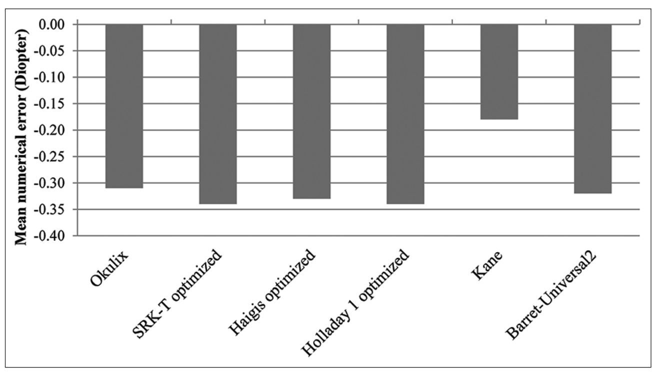

Figure 3: Mean numerical error of each formula

Table 5: Intraocular lens power values for each formula

	IOL power	Predicted error	MNE	MAE
Okulix				
Mean±SD	+13.48±4.19	−0.02±0.12	−0.31±0.75	+0.61±0.54
Range	+5.00 - +20.50	−0.23 - +0.21	−2.54 - +0.99	+0.01 - +2.54
SRK/T with optimized constant				
Mean±SD	+13.71±3.62	0.00±0.08	−0.34±0.79	+0.62±0.58
Range	+5.00 - +20.00	−0.17 - +0.17	−2.88 - +1.10	0.00 - +2.88
Haigis with optimized constant				
Mean±SD	+14.87±4.28	0.00±0.01	−0.33±0.79	+0.64±0.56
Range	+5.00 - +22.00	−0.30 - +0.17	−2.89 - +0.98	+0.01 - +2.89
Holladay 1 with optimized constant				
Mean±SD	+13.10±3.83	0.00±0.09	−0.34±0.78	+0.62±0.57
Range	+4.50 - +19.50	−0.16 - +0.18	−2.50 - +1.09	+0.01 - +2.59
Kane				
Mean±SD	+13.92±4.27	−0.15±0.09	−0.18±0.78	+0.60±0.53
Range	+4.50 - +21.00	0.00 - −0.32	−2.68 - +1.11	0.00 - +2.68
Barret universal 2				
Mean±SD	+13.67±4.20	−0.01±0.09	−0.32–0.77	+0.62±0.56
Range	+5.00 - +21.00	−0.17 - +0.16	−2.60 - +1.13	+0.01 - +2.60
*P**	<0.001	<0.001	<0.001	0.211

*Friedman test. Under-lined values are significant. *P*<0.05 is statistically significant. SD: Standard deviation, MAE: Mean absolute error, MNE: Mean numerical error, IOL: Intraocular lens

Table 6: Frequency distribution of mean absolute error 6 months after surgery in different formulas

	Mean absolute error frequency (%)				
	0.00 - +0.50	+0.50 - +1.00	+1.00 - +1.50	+1.50 - +2.00	+2.00 - +3.00
Okulix	53.6	29.8	9.5	3.6	3.6
SRK/T with optimized constant	52.9	27.1	12.9	2.4	4.7
Haigis with optimized constant	52.9	29.4	11.8	2.4	3.5
Holladay 1 with optimized constant	52.9	29.4	10.6	3.5	3.5
Kane	50.6	34.1	9.4	2.4	3.5
Barret-universal 2	48.8	28.8	13.1	3.6	4.8

optimized constant (all three, 52.9%), Kane (50.6%), and Barret Universal 2 (48.8%). Nevertheless, the calculated frequencies revealed that using the Kane formula results in more eyes with postoperative mean absolute error <1.00 D (83.4% of eyes).

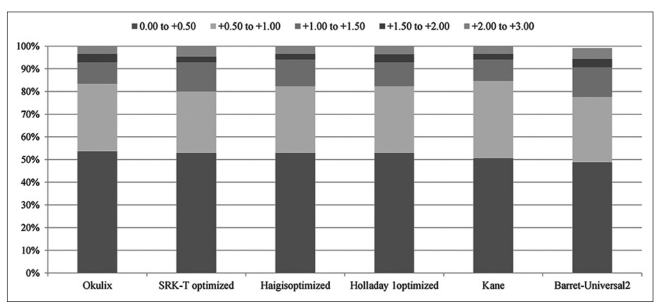

Figure 4: Mean absolute error frequency in each formula

Discussion

Ultrasound-based studies showed that 54% of the errors in the calculation of IOL power are due to incorrect axial length measurements, 38% to inaccurate estimates of postoperative anterior chamber depth, and 8% to an error in corneal power measurement.[12] Roessler *et al.* stated that the axial length of the eyeball before surgery and the postoperative anterior chamber depth are among the etiologic factors contributing to the incorrect IOL power calculation.[13] Any method that can reduce the error sources and calculate IOL power more accurately will result in achieving optimal postoperative refractive outcomes and appropriate uncorrected visual acuity and, finally, satisfying patients with the surgery.[9] In the present study, the performances of the ray-tracing method (Okulix software), the modified formulas (SRK/T, Haigis and Holladay 1, all with optimized constants), a combination of regression and artificial intelligence method (Kane formula), and Barret universal 2 formula to compare the performances of different methods are used to calculate the IOL power in the long eyes.

The refractive results obtained from the present study are in line with those of the studies performed by Zaldivar *et al*.,[14] Zuberbuhler *et al*.,[15] Petermeier *et al*.,[16] and Haigis,[17] who reported that people with high myopia end up with hyperopia after cataract surgery. Of interest, the mean spherical refractive error after cataract surgery (IOL powers calculated by SRK/T formula) was +0.45 ± 0.79 D in Yokoi's study (in eyes with axial lengths >26.5 mm),[18] and this result is more hyperopic than the achieved values in our study by passing 6 months from surgery (+0.18 ± 0.63 D). This observed difference could be due to a better performance of the Okulix software compared to the nonmodified SRK/T formula in IOL power calculations in eyes with axial lengths longer than 25 mm. On the other hand, the mean of 6 months postoperative spherical equivalent in the present study was −0.34 ± 0.78 D. Negative values in spherical equivalent after cataract surgery is definitely due to the presence of corneal astigmatism.

The results of the present study revealed that in 83.4% of the subjects, the mean absolute error after cataract surgery was < +1.00 and spherical refractive errors in 65.9% of subjects were in ±0.50 D range. In their study, Roessler *et al*. calculated the IOL power in people with high myopia (axial length >26.5 mm) using the Haigis formula as well as measuring biometric parameters by IOL-master. They observed that in 81% of subjects, the results of the spherical component were within the range of ±1.00 D, and in 54.1% of people, they were in ±0.50 D; 14.[13] Moreover, Nabil observed that in high myopic eyes (axial length > 26.5 mm) in which the power of the IOL was calculated by Okulix software, 88.33% of subjects had the mean absolute error < +1.00, and in 70% of patients, the postoperative spherical refraction was in ±0.50 D.[8] The percentage of eyes achieving refractive results within ±0.50 and ±1.00 D in comparison with other mentioned studies shows the acceptable performance of the Okulix software in IOL power calculations in long eyes.

According to the data presented in Table 5, the minimum of the mean numerical error was obtained by the Kane formula, while the obtained results revealed no difference among 5 other proposed methods. On the other hand, the biggest mean of the predicted error was seen in the Kane formula; however, other formulas had no significant difference in terms of this parameter. Besides the biometric information, Kane's formula employs the factors of gender, lens thickness, and corneal thickness to calculate IOL power [the required factors for each formula are shown in Table 1].[19] It seems that the use of different factors leads to obtaining acceptable results of this formula and Okulix software.

Considering the results of the mean absolute error, the performance of the 6 studied formulas was not statistically different. In our study, the observed mean absolute error values for the Okulix software were between +0.01 and +2.54, most of which were due to the placement of the spherical IOL and the lack of corneal astigmatism coverage. Wang's study indicated that the mean absolute error parameter can be considered an indicator of the evaluation of the accuracy of IOL power calculation formulas; hence, it was shown that the lower the mean absolute error, the greater the uncorrected visual acuity.[20] The above-mentioned results showed that Okulix software performs equally in calculating IOL power for cataract surgery (leading the uncorrected visual acuity to be higher) in axial length >25 mm. in comparison with the adjusted methods, artificial intelligence formula, and the well-known Barret Universal 2 formula.

Cheng *et al*. stated that modification in high axial lengths leads to weaker performance of SRK/T, but it is better for Holladay 1 formula. Moreover, they found that Holladay 1 formula acts better than Barret Universal 2 in axial lengths within 25–27 mm.[3] However, Popovic *et al*. in their study indicated that the adjustment for Holladay 1 formula should be done only in axial length >27 mm.[4] Of note in this study is that we did not evaluate the axial length classification due to the limited number of eyes with axial lengths >27 mm, which certainly affected the obtained results.

The current research has some potential limitations. One of the limitations we encountered in this study was that the Okulix software calculates posterior keratometry based on anterior values that might influence the IOL power calculation. Also, we used an old version of Okulix software that may have influenced the results. In addition, we had to eliminate the cases with the calculated IOL power <5 D, due to the lack of AMO TECNIS® Monofocal 1-Piece ZCB00 IOL power <5 D in markets. It is recommended to evaluate these eyes in future studies with different IOL brands. It is also suggested for further research to compare the performance of Okluix software and Kane formula with other formulas in eyes with axial lengths <22 mm as well as in the eyes with a history of keratorefractive surgery.

In conclusion, Okluix software has an acceptable and equal performance in calculating IOL power in eyes with axial lengths >25 mm in comparison with other investigated methods including Wang-Koch adjusted formulas, Kane formula, and Barret universal 2 formula.

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Conflicts of interest

There are no conflicts of interest.

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