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Comparative Performance Evaluation of Ten Intraocular Lens Power Calculation Formulas Based on Two Different Optimization Methods

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Abstract

Purpose

Comparison of the accuracy of 10 different intraocular lens power calculation formulas with two different optimization methods.

Methods

Data from 213 patients with normal axial length who underwent cataract surgery were retrospectively reviewed. SRK/T, Barrett Universal II (BUII), Hill-RBF 3.0, Hoffer Q, Haigis, Kane, EVO 2.0, PEARL-DGS, T2, and K6 formulas were used to calculate the mean prediction error (PE), mean absolute error (MAE), and median absolute error (MedAE) based on A-constants calculated according to the User Group for Laser Interference Biometry (Group 1) and three variable optimization (TVO) (Group 2). Additionally, the percentage of PE within ± 0.25 D, ± 0.50 D, ± 0.75 D, and ± 1.00 D was calculated.

Results

For all formulas, the mean PE in Group 2 was significantly lower than in Group 1. The lowest MAE and MedAE were calculated using the BUII formula in both groups. The MAE was found to be lower in both groups in BUII formula compared to Haigis formula ($p = 0.001$, $p = 0.03$). In group 1 the MedAE, in BUII formula was lower than the Haigis, Kane, and K6 formulas ($p < 0.05$ for all). In group 2 the MedAE was higher in Haigis formula compared to the BUII and Hill-RBF 3.0 formulas ($p < 0.05$ for both). In Group 2, the percentage of eyes with PE within ± 0.50 D using EVO 2.0 formula and the percentage of eyes with PE within ± 1.00 D using the Haigis formula were significantly higher compared to Group 1.

Conclusions

The TVO method yields successful results, and its ease of use is its most important advantage.

Introduction

Today, cataract surgery is used as a refractive surgery, and its success rates and prevalence are increasing with micro-incisional techniques and advancing technology.[1] The increasing desire of patients to lead a spectacle-independent life makes accurate intraocular lens (IOL) power measurements invaluable. Despite biometric devices and new IOL power calculation methods, up to 70% of patients achieve predictive refraction targets within ± 0.50 diopters (D).[2] Although high success rates are achieved, the number of patients who are not satisfied with these refractive results is not small.

The importance of optimization of lens constants to achieve successful postoperative refractive outcomes has been emphasized in many studies.[3–6] Lens constant optimization is mandatory for clinical trials and successful refractive outcomes, and its goal is to reduce the mean prediction error (PE) for the entire data set to zero and consequently eliminate systemic PE.[7] Constant optimization can be implemented with published formulas using the Goal/Seek function of Excel.[8] However, the constant optimization process is quite challenging for new biometric formulas with unpublished content. For unpublished formulas, optimization methods published in 2023 by Gatinel et al. and Lupardi et al. can be used.[3,9] Constant optimization is a time-consuming process that requires a large biometric dataset and technical knowledge. For these reasons, the application of optimization in clinical practice remains limited.

Recently, Buonsanti et al. introduced a constant optimization method called “three variable optimization (TVO)” which can be applied with only 3 variables.[10] These 3 variables are the mean power of all implanted IOLs, the mean PE for all patients and the lens constant used for preoperative calculations. The main advantages of the TVO method are its ease of application, free access, and small number of parameters. The aim of this study is to demonstrate the differences in refractive outcomes between the new constant optimization method with different formulas and the User Group for Laser Interference Biometry (ULIB), which includes optimized lens constants based on large databases.

Methods

The study is a retrospective analysis of the demographic and biometric data of 213 patients with axial lengths (AL) between 22.00–25.00 mm and Wisconsin grade 3 and 4 cataracts who underwent cataract surgery at Başkent University Adana Turgut Noyan Research and Application Center between August 2021 and October 2024. All cataract surgeries were performed through a 2.75 mm temporal clear corneal incision under topical anesthesia. Exclusion criteria were astigmatism greater than 2 diopters (D), previous ocular surgery (vitrectomy, corneal refractive surgery, ocular surface surgery) or trauma, any corneal pathology, glaucoma, uveitis, advanced diabetic retinopathy, vitreous hemorrhage and vitreomacular interface diseases. Patients who underwent uneventful sutureless cataract surgery, were followed up for at least 3 months and had postoperative best corrected visual acuity (BCVA) better than 0.8 were included in the study. The manifest refraction of each eye was evaluated 3 months after surgery.

The study was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from each patient for cataract surgery. Ethical approval for this study was obtained from Başkent University Medical and Health Units Research Board and Ethics Committee (Project number: KA25/95).

Preoperative biometric parameters were measured using optical low-coherence reflectometry (OLCR) (Lenstar LS900, Haag-Streit AG). The parameters evaluated were AL, anterior chamber depth (ACD: between corneal endothelium and lens anterior surface), keratometry (K), lens thickness (LT), corneal thickness and white-to-white (WTW) as corneal diameter. IOL power before cataract surgery was calculated with SRK/T, Hoffer Q and Haigis formulas. The implanted IOL power was randomly selected from these formulas.

All patients were implanted with the same acrylic foldable IOL (AcrySof IQ SN60WF, Alcon Laboratories, Fort Worth, TX, USA). The biometry formulas used in the study were SRK/T, Barrett Universal II (BUII), Hill-RBF 3.0, Hoffer Q, Haigis, Kane, EVO 2.0, PEARL-DGS, T2 and K6. For the IOL power calculation formulas of BUII (https://calc.apacrs.org/barrett_universal2105/), Hill-RBF 3.0 (https://rbfcalculator.com/online/index.html), Kane (https://www.iolformula.com), EVO 2.0 (https://www.evoiolcalculator.com/calculator.aspx), PEARL-DGS (https://iolsolver.com/regular), T2 (https://t2.iolpower.net), and K6 (https://cookeformula.com), calculations were performed by entering the parameters into web sources.

PE was calculated as the difference between the spherical equivalent of the postoperative refractive result (sum of spherical power and half of the cylindrical power) and the refraction predicted by each formula. A negative value is an indication of myopic prediction error. Mean absolute error (MAE) and median absolute error (MedAE) were calculated as the mean and median of prediction error magnitude, regardless of sign. The percentage of PE within ± 0.25 D, ± 0.50 D, ± 0.75 D and ± 1.00 D was calculated for each formula.

In our study, we calculated PE, MAE, and MedAE for each formula using the optimized lens constants obtained from large databases (> 5000 eyes) for AcrySof IQ SN60WF IOL on the ULIB (http://ocusoft.de/ulib/) website, which has been used in many previous studies.[11–13] The lens constants were then optimized on the website https://ioloptimization.com/calculator to apply the TVO method developed by Buonsanti et al. and refractive results (PE, MAE and MedAE) were obtained for each formula. The results obtained with the lens constants on the ULIB website were compared with the results obtained after applying the TVO method. In our study, we classified the refractive results obtained with ULIB constants as group 1 and the results obtained with TVO method as group 2.

Statistical Analysis

Statistical analyses were performed using SPSS Statistics software (version 25; IBM Corp., Armonk, NY, USA). The normality of data distribution was assessed using the Kolmogorov–Smirnov test. One-sample t-tests were used to determine whether the refractive prediction error (RPE) values of the lens formulas differed significantly from zero. Paired samples t-tests were applied to compare the mean RPE values for the same formulas between the two groups.

Within-group comparisons of MAE values were performed using repeated measures ANOVA when the assumption of normality was met, and Bonferroni-adjusted pairwise comparisons were conducted when significant differences were detected.

Within-group comparisons of MedAE values were performed using the Friedman test, followed by Bonferroni-adjusted Wilcoxon signed-rank tests for post hoc analyses. Comparisons of the percentage of eyes within different predictive error (PE) thresholds (± 0.25 D, ± 0.50 D, ± 0.75 D, ± 1.00 D) between groups were conducted using the Related-Samples Cochran's Q test for three or more categories, and the McNemar test for pairwise comparisons. A p-value < 0.05 was considered statistically significant.

Results

The study included 213 eyes of 213 patients. Of the patients, 58.69% (n = 125) were female and 41.31% (n = 88) were male. The mean AL of the eyes in the study was 23.41 ± 0.69 (range: 22.02 to 24.95) mm. Table 1 shows the demographic and biometric data for the patients included in the study.

Table 1
Demographic and biometric characteristics of the patients

Demographics	Mean ± SD	Range
Age (years)	68.58 ± 8.18	37–90
Gender M/F, %	88/125	41.31% / 58.69%
Axial length (mm)	23.41 ± 0.69	22.02–24.95
Corneal power (D)	43.83 ± 1.41	40.35–48.12
Corneal astigmatism magnitude (D)	0.77 ± 0.47	0.00-1.96
Anterior chamber depth (mm)	3.43 ± 0.41	2.38–4.74
Lens thickness (mm)	4.12 ± 0.40	2.93–5.41
Corneal diameter (mm)	11.94 ± 0.44	10.02–13.21
Central corneal thickness (mm)	533.9 ± 36.07	421–630
IOL power (D)	21.40 ± 1.76	15–26
D: Diopter		
SD: Standard Deviation		

In Group 1, we found myopic PE in all formulas, except PEARL-DGS formula, were in accordance with the general IOL calculation formula trends. The lowest PE was observed in SRK/T (-0.01 ± 0.45) and T2 (-0.01 ± 0.46) formulas. In group 1, PE was different from zero for the Hill-RBF 3.0, Hoffer Q, Haigis, Kane and EVO 2.0 formulas ($p = 0.019$, $p = 0.038$, $p < 0.001$, $p < 0.001$, $p < 0.001$, $p = 0.012$ respectively). In group 2, PE values of all formulas except Hoffer Q formula were slightly positive. The lowest PE values were found for T2 (0.000 ± 0.454), SRK/T (0.003 ± 0.453) and Haigis (0.004 ± 0.487) formulas. The PE values for Kane and PEARL-DGS formulas were significantly different from zero ($p = 0.045$, $p < 0.001$ respectively). In all formulas, the PE in Group 2 was statistically significantly lower than in Group 1 ($p < 0.05$ for each formula). Table 2 shows the optimized lens constants and Table 3 shows the PE values for all patients in Groups 1 and 2.

Table 2
Lens constant optimization based on TVO and ULIB methods

IOL (n = 213)	Alcon IQ SN60WF	
	Optimized constants	
Formula	Group 1 (ULIB)	Group 2 (TVO)
SRK/T	119.0	118.9
BUII	1.88	1.85
Hill-RBF 3.0	119.02	118.93
Hoffer Q	5.64	5.60
Haigis	− 0.769; 0.234; 0.217	-0.8946; 0.234; 0.217
Kane	119.0	118.87
EVO 2.0	119.0	118.93
PEARL-DGS	119.0	118.99
T2	119.0	118.99
K6	119.0	118.97

Table 3
Comparison of mean PE values between Group 1 and Group 2

	Group 1			Group 2			
	Mean PE	SD	p^1	Mean PE	SD	p^2	p^3
SRK/T	-0.01	± 0.45	0.721	0.003	± 0.453	0.924	**0.039**
BUII	-0.03	± 0.44	0.284	0.025	± 0.447	0.419	**< 0.001**
Hill-RBF 3.0	-0.07	± 0.44	**0.019**	0.018	± 0.449	0.554	**< 0.001**
Hoffer Q	-0.07	± 0.49	**0.038**	-0.014	± 0.489	0.674	**< 0.001**
Haigis	-0.19	± 0.50	**< 0.001**	0.004	± 0.487	0.912	**< 0.001**
Kane	-0.13	± 0.47	**< 0.001**	0.065	± 0.470	**0.045**	**< 0.001**
EVO 2.0	-0.08	± 0.46	**0.012**	0.020	± 0.458	0.522	**< 0.001**
PEARL-DGS	0.05	± 0.45	0.084	0.120	± 0.449	**< 0.001**	**< 0.001**
T2	-0.01	± 0.46	0.781	0.000	± 0.454	0.999	**0.001**
K6	-0.03	± 0.48	0.294	0.047	± 0.462	0.143	**< 0.001**

PE: Predictive Error

SD: Standard Deviation

p^1, p^2: One-Sample Test (Test Value = 0)

p^3: Paired Samples t Test

p^1: Comparison of PE values for formulas in Group 1 with zero

p^2: Comparison of PE values for formulas in Group 2 with zero

p^3: Comparison of mean PE values for Groups 1 and 2 with the same formula

In Group 1, the lowest MAE was obtained in BUII (0.35) and Hill-RBF 3.0 (0.35) formulas. Haigis formula (0.42) had significantly higher MAE than both BUII and Hill-RBF 3.0 ($p = 0.001$, $p = < 0.001$ respectively). In the Kane formula

(0.38), MAE was also significantly higher than Hill-RBF 3.0 ($p = 0.041$). In Group 1, the lowest MedAE was found for the BUII formula. The MedAE calculated for the Haigis formula (0.33) was significantly higher than the SRK/T (0.31), BUII (0.29), Hill-RBF 3.0 (0.32), PEARL-DGS (0.32) and T2 (0.31) formulas ($p = 0.012$; $p < 0.001$; $p < 0.001$; $p = 0.014$; $p = 0.002$, respectively). MedAE calculated for the Kane formula (0.31) was significantly higher than BUII (0.29) ($p = 0.015$). In addition, MedAE calculated for the K6 formula (0.34) was significantly higher than BUII (0.29) ($p = 0.040$). In Group 2, the lowest calculated MAE was for the BUII formula (0.35). The MAE of the Haigis formula (0.39) was significantly higher than BUII (0.35) and Hill-RBF 3.0 (0.36) ($p = 0.030$, $p = 0.006$ respectively). Similarly, MedAE was significantly higher for the Haigis formula (0.34) compared to BUII (0.29) and Hill-RBF 3.0 (0.32) ($p = 0.018$ for both). Tables 4 and 5 show the MAE differences in Groups 1 and 2 and Tables 6 and 7 show the MedAE differences. Figure 1 shows the MedAE values obtained using the same formula across groups.

Table 4
Comparison of mean absolute error values between formulas in Group 1

Formula	Mean ± SD	SRK/T	BUII	Hill-RBF 3.0	Hoffer Q	Haigis	Kane	EVO 2.0	PEARL-DGS	T2
SRK/T	0.36 ± 0.28									
BUII	0.35 ± 0.28	1.000								
Hill-RBF 3.0	0.35 ± 0.28	1.000	1.000							
Hoffer Q	0.39 ± 0.31	1.000	0.179	0.053						
Haigis	0.42 ± 0.33	0.204	**0.001**	**< 0.001**	1.000					
Kane	0.38 ± 0.29	1.000	0.124	**0.041**	1.000	1.000				
EVO 2.0	0.37 ± 0.28	1.000	1.000	1.000	1.000	1.000	1.000			
PEARL-DGS	0.36 ± 0.28	1.000	1.000	1.000	1.000	1.000	1.000	1.000		
T2	0.36 ± 0.28	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	
K6	0.38 ± 0.29	1.000	0.294	0.803	1.000	1.000	1.000	1.000	1.000	1.000
Repeated Measure ANOVA, $p < 0.05$ (p-value)										

Table 5
Comparison of mean absolute error values between formulas in Group 2

Formula	Mean ± SD	SRK/T	BUII	Hill-RBF 3.0	Hoffer Q	Haigis	Kane	EVO 2.0	PEARL-DGS	T2
SRK/T	0.36 ± 0.27									
BUII	0.35 ± 0.28	1.000								
Hill-RBF 3.0	0.36 ± 0.27	1.000	1.000							
Hoffer Q	0.43 ± 0.68	1.000	1.000	1.000						
Haigis	0.39 ± 0.29	1.000	**0.030**	**0.006**	1.000					
Kane	0.37 ± 0.29	1.000	1.000	1.000	1.000	1.000				
EVO 2.0	0.36 ± 0.28	1.000	1.000	1.000	1.000	1.000	1.000			
PEARL-DGS	0.36 ± 0.30	1.000	1.000	1.000	1.000	1.000	1.000	1.000		
T2	0.36 ± 0.27	1.000	1.000	1.000	1.000	0.984	1.000	1.000	1.000	
K6	0.37 ± 0.28	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Repeated Measure ANOVA, $p < 0.05$ (p-value)										

Table 6
Comparison of median absolute error values between formulas in Group 1

Formula	Median (Min.-Max.)	SRK/T	BUII	Hill-RBF 3.0	Hoffer Q	Haigis	Kane	EVO 2.0	PEARL-DGS	T2
SRK/T	0.31 (0.01–1.55)									
BUII	0.29 (0-1.68)	1.000								
Hill-RBF 3.0	0.32 (0-1.65)	1.000	1.000							
Hoffer Q	0.31 (-0.39-1.32)	1.000	0.203	0.804						
Haigis	0.33 (-0.45-1.47)	**0.012**	**< 0.001**	**< 0.001**	0.974					
Kane	0.31 (0.01–1.55)	1.000	**0.015**	0.081	1.000	1.000				
EVO 2.0	0.33 (0.01–1.54)	1.000	1.000	1.000	1.000	0.183	1.000			
PEARL-DGS	0.32 (0-1.68)	1.000	1.000	1.000	1.000	**0.014**	1.000	1.000		
T2	0.31 (0-1.49)	1.000	1.000	1.000	1.000	**0.002**	0.481	1.000	1.000	
K6	0.34 (0-1.76)	1.000	**0.040**	0.198	1.000	1.000	1.000	1.000	1.000	1.000
Friedman Test, $p < 0.05$ (p-value), BUII: Barrett Universal II										

Table 7
Comparison of median absolute error values between formulas in Group 2

Formula	Median (Min.-Max.)	SRK/T	BUII	Hill-RBF 3.0	Hoffer Q	Haigis	Kane	EVO 2.0	PEARL-DGS	T2
SRK/T	0.30 (0-1.56)									
BUII	0.29 (0.01–1.76)	1.000								
Hill-RBF 3.0	0.32 (0-1.72)	1.000	1.000							
Hoffer Q	0.32 (0.01–9.3)	0.914	0.179	0.179						
Haigis	0.34 (-0.03-1.68)	0.131	**0.018**	**0.018**	1.000					
Kane	0.33 (0.01–1.79)	1.000	0.858	0.858	1.000					
EVO 2.0	0.32 (0-1.63)	1.000	1.000	1.000	1.000	0.235				
PEARL-DGS	0.31 (-0.49-1.75)	1.000	1.000	1.000	1.000	1.000	1.000	1.000		
T2	0.31 (0-1.5)	1.000	1.000	1.000	1.000	0.293	1.000	1.000	1.000	
K6	0.32 (0-1.79)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Friedman Test, $p < 0.05$ (p-value), BUII: Barrett Universal II

In Group 1, SRK/T, Hill-RBF 3.0, and T2 had the highest percentage of formulas within ± 0.25 D PE (46.1% for all). PEARL-DGS had the highest percentage within ± 0.50 D PE (75.12%), followed by Hill-RBF (72.30%) and BUII (72.30%).

No difference was observed in the rate within ± 0.25 and ± 0.50 D PE between the 10 formulas ($p = 0.065$ and $p = 0.105$, respectively). The Haigis formula had the lowest rate within + 0.75 D PE (82.63%). This rate was significantly higher for T2 (92.96%), PEARL-DGS (92.02%), Hill-RBF (91.55%), EVO (90.61%), BUII (91.08%) and SRK/T (90.61%) formulas compared to the Haigis formula ($p < 0.001$, $p = 0.005$, $p < 0.001$, $p = 0.001$, $p = 0.001$, $p = 0.002$, $p = 0.005$ respectively). Within ± 1.00 D PE, the rate was highest for Hill-RBF 3.0 (99.06%) and lowest for Haigis (92.45%). This rate was significantly lower for the Haigis formula than for the Hill RBF 3.0, BUII (98.59%), SRK/T (98.12%) and T2 (97.65%) formulas ($p < 0.001$, $p = 0.002$, $p = 0.008$ and $p < 0.001$, respectively). In Group 2, the highest percentage of PE within ± 0.25 D was with the T2 formula (44.13%) and the highest percentage of PE within ± 0.50 D was with the PEARL-DGS formula (77.46%). However, there was no significant difference between the formulas with PE within ± 0.25 and ± 0.50 D ($p = 0.231$ and $p = 0.141$, respectively). Among the formulas with PE within ± 0.75 D, the lowest value was found for the Haigis formula (86.85%). This rate was significantly higher with the Haigis formula compared to BUII (92.49%), Hill-RBF 3.0 (92.02%), K6 (91.55%), T2 (91.55%), SRK/T (91.08%), EVO (91.08%) and PEARL-DGS (90.61%) ($p = 0.006$, $p = 0.003$, $p = 0.003$, $p = 0.012$, $p = 0.012$, $p = 0.012$, $p = 0.024$, $p = 0.024$ and $p = 0.045$ respectively). Among the formulas with PE within ± 1.0 D, the highest value was for SRK/T (98.12%) and the lowest value was for Hoffer Q (96.24%), but no significant difference was found between these 10 formulas. Table 8 shows the percentage of PEs within ± 0.25 D, ± 0.50 D, ± 0.75 D and ± 1.00 D for each formula in Groups 1 and 2 and the difference between the groups for the same formula. Figure 2 summarizes these percentages in graph form.

Table 8
Comparison of eyes within PE values between groups

	Eyes within PE (%)											
	≤ 0.25 D			≤ 0.50 D			≤ 0.75 D			≤ 1.0 D		
Formulas	Group 1	Group 2	p	Group 1	Group 2	p	Group 1	Group 2	p	Group 1	Group 2	p
SRK/T	46.01	43.19	0.180	71.36	71.83	1.000	90.61	91.08	1.000	98.12	98.12	1.000
BUII	45.07	43.19	0.523	72.30	74.65	0.383	91.08	92.49	1.000	98.59	97.65	1.000
Hill-RBF	46.01	42.72	0.248	72.30	73.71	0.678	91.55	92.02	1.000	99.06	97.65	0.375
Hoffer Q	42.25	38.50	0.186	69.01	70.42	0.648	86.85	88.26	0.508	95.31	96.24	0.625
Haigis	38.50	37.56	0.899	66.20	69.95	0.291	82.63	86.85	0.093	92.45	97.18	**0.021**
Kane	44.60	39.91	0.221	69.01	72.77	0.322	87.32	87.79	1.000	96.71	97.18	1.000
EVO 2.0	41.31	43.66	0.441	69.01	74.65	**0.031**	90.61	91.08	1.000	96.24	97.18	0.625
PEARL-DGS	39.91	38.50	0.710	75.12	77.46	0.302	92.02	90.61	0.453	96.71	96.71	1.000
T2	46.01	44.13	0.125	71.36	72.30	0.687	92.96	91.55	0.250	97.65	97.65	1.000
K6	39.91	40.85	0.832	71.36	74.18	0.238	89.20	91.55	0.180	96.71	97.65	0.500

Mc-Nemar Test, Related-Samples Cochran's Q Test, $p < 0.05$ (p-value), D: Diopter, PE: prediction error, BUII: Barrett Universal II

Discussion

In this study, population-based ULIB constants established with large patient groups for IOL power calculations were compared with the easy-to-use and easy-to-access TVO method, which allows the surgeon to optimize based on refractive outcomes obtained from their patient population.[12–14] Our results show that the mean PE was significantly lower with the TVO method for all formulas. The percentage of eyes with PE within ± 1.0 D for the Haigis formula and the percentage of eyes with PE within ± 0.50 D for the EVO formula were statistically significantly higher with the TVO method than the ULIB method. However, there was no difference between the two methods in terms of MAE and MedAE ($p > 0.05$ for all).

In our study, the lowest MAE and lowest MedAE were found for the BUII formula in Groups 1 and 2. In addition, the rate of PE within ± 0.50 D in Group 1 and Group 2 was highest with the BUII formula after the PEARL-GDS formula. In a study conducted by Yoon and Whang using BUII, EVO 2.0, Hill-RBF 3.0, Hoffer QST, Kane and PEARL-DGS formulas, the BUII formula was found to be the most successful formula.[15] In the same study, the MAE for the BUII formula was 0.340 D and MedAE was 0.467 D for patients with AL 22.5–25.5 mm.[15] In a study by Kane et al. using the same IOL as our study, the BUII formula was found to be the most successful formula in eyes with AL of 22.00-24.50 mm, while MAE was 0.383 D and MedAE 0.300 D.[16] In a study by Melles et al. including BUII, Olsen, Haigis, Holladay 1, Holladay 2, Hoffer Q, and SRK/T formulas, the lowest MAE (0.311 D) and MedAE (0.252 D) were observed for the BUII formula.[17] In the same study, the retention rate within ± 0.50 D PE was 80.0% for BUII, while the retention rate within ± 1.00 D PE was 97.3%.[17] These results were higher in terms of the rate of remaining within ± 0.50 D PE compared to our study, while the rate of remaining within ± 1.00 D PE was similar. In our study, the rate of remaining within ± 0.50 D PE with the BUII formula was 72.30% for Group 1 and 74.65% for Group 2. This percentage is 73.7% according to the European Registry of Quality Outcomes in Cataract and Refractive Surgery.[18] The success rate for BUII is acceptable in our study.

For the Hill-RBF 3.0 formula, which is one of the artificial intelligence-based formulas, we obtained MAE results very close to the BUII formula in Group 1 and Group 2. Natung et al. also used BUII, Hill-RBF 3.0, SRK/T, Hoffer Q, Haigis, and Holladay 1 formulas and included 185 eyes between 22-24.5 mm. Similar to our study, they found the lowest MAE value with the Hill-RBF 3.0 formula after the BUII formula.[19] In another study, in a subgroup including eyes between

22.5–25.5 mm, MAE was found to be 0.360 and MedAE 0.468 with the Hill-RBF 3.0 calculator.[15] In the same study, the rate of remaining within ± 0.50 D PE was 69.5% and the rate of remaining within ± 1.00 D PE was 92.1% with the Hill-RBF 3.0 calculator in patients in the entire AL range.[15] In our study, these rates were found to be 72.30% and 99.06% in Group 1 and 73.71% and 97.65% in Group 2 using the Hill-RBF 3.0 formula. Since the eyes included in our study were medium eyes, these ratios seem to be more successful in our study.

Although there was no significant difference between the PEARL-DGS formula and the other formulas, it had the highest rate within ± 0.50 D PE in Group 1 (75.12%) and Group 2 (77.46%). In the study by Lossada et al. including patients with AL 22.5–25.00 mm, similar to our study, successful results were obtained with the PEARL-DGS formula (86.89%) in terms of the rate within ± 0.50 D PE.[20] In another study that included medium-long eyes with AL 24.50-25.97 mm, the PEARL-DGS formula resulted in PE within ± 0.50 D PE of 85.05%.[21] These results are consistent with our study in terms of highly successful results of PEARL-DGS. MedAE, which is used to determine the accuracy of the formula in IOL power calculations as suggested by Hoffer, was calculated as 0.32 in Group 1 and 0.31 in Group 2 for PEARL-DGS in our study. This value was 0.21 in the study by Lossada et al. and 0.234 in the study by Stopyra et al.[20,21] This difference may be due to the more limited range of AL in other studies. In addition, the IOL used in Lossada's study was different from our study and this may have caused the difference in the results.[20]

The SRK/T formula had the highest ratio within ± 1.0 D PE in Group 2. In Group 1, it was slightly inferior to Hill-RBF 3.0 and BUII formulas. Although the SRK/T formula is one of the third generation formulas, there are studies with successful results for new generation formulas in medium eyes.[22,23] In the study by Paritekar et al. comparing the results of SRK/T, BUII and Kane formulas including eyes between 22–24 mm, MedAE was statistically significantly lower for SRK/T (0.25) and BUII (0.22) formulas compared to Kane (0.26).[23] In our study, MedAE for the Kane formula (0.31) was found to be significantly higher than the BUII formula (0.29) in Group 1, which is consistent with this study. In our study, although not statistically significant, MAE was also higher with the Kane formula compared to BUII and SRK/T formula in Groups 1 and 2.

In our study, the highest MAE in Group 1 was found for the Haigis formula (0.42 D), while this value was 0.39 D in Group 2. In Group 2, the highest MAE was detected with the Hoffer Q formula (0.43), while this value was 0.39 D in Group 1. The MAE for the Haigis formula was significantly higher than the MAE for the BUII and Hill-RBF 3.0 formulas in Groups 1 and 2. There was no difference between Hoffer Q formula and other formulas in terms of MAE in Groups 1 and 2. In the study by Kane et al. which included 7 different formulas, Haigis (0.415) and Hoffer Q (0.420) formulas had higher MAE values than the BUII, SRK/T and T2 formulas in our study.[22] In another study including 13 IOL power calculation formulas, the highest MAE and MedAE values were found for Hoffer Q and Haigis formulas, in parallel with our study.[24] In parallel with these data, in our study, the MedAE for the Haigis formula was significantly higher than BUII, Hill-RBF, SRK/T, PEARL-DGS and T2 formulas in Group 1 and BUII and Hill-RBF formulas in Group 2. For Hoffer's Q formula, no difference was found between the other formulas in terms of MedAE. In addition, percentage of eyes within ± 0.25 D, ± 0.50 D, and ± 0.75 D PE with the Haigis formula was the lowest among the formulas in Groups 1 and 2. In terms of percentage of eyes within ± 1.0 D PE, this formula was lowest in Group 1 and higher than Hoffer Q and PEARL-DGS in Group 2, and the same as Kane and EVO 2.0.

Although the T2 formula has been proposed as an improvement of the SRK/T formula, similar to other studies, we found no difference between the two formulas in terms of MAE and MedAE.[24,25] With the EVO 2.0 formula, no difference was found between the formulas we evaluated in terms of MAE and MedAE. For the K6 formula, MedAE was significantly higher in Group 1 compared to the BUII formula, whereas no difference was found in Group 2.

In our study, only PEARL-DGS (75.12%) in Group 1 exceeded the European Registry of Quality Outcomes in Cataract and Refractive Surgery's accepted rate of 73.7% for the percentage of eyes with PE within ± 0.50 D.[18] We found an increase in this rate in all formulas after TVO compared to before optimization. In Group 2, the percentage of eyes with PE within ± 0.50 D for the BUII, Hill-RBF 3.0, EVO 2.0, PEARL-DGS, and K6 formulas was more than 73.7%. After TVO application, the percentage of eyes with PE within ± 0.50 D using the EVO 2.0 formula and the percentage of eyes with PE within ± 1.0 D using the Haigis formula increased significantly. In this study, we compared the refractive results obtained with the easily applicable and accessible TVO method with those obtained with using ULIB constants based on large databases and used in many previous studies. Our results show that the refractive results obtained after the

application of TVO were generally more successful. We believe that this method, which is easy to apply and not time-consuming, will encourage ophthalmologists to optimize the formula constant.

Our study has some limitations. The limited number of patients and the fact that only medium eyes were included in the study prevented us from examining the performance of the TVO method in short and long eyes. The inability to perform triple optimization in the Haigis formula is also a limiting factor, as stated by Buonsanti et al.[10] Since IOL design can affect the effective lens position, the results may be different for different IOL designs.[11] Therefore, the use of a single type of IOL in the study may be a limiting factor. The small number of formulas evaluated in the study is another limiting factor.

Declarations

Conflicts of interest:

The authors of the study declare no conflicts of interest.

Ethics approval:

Local ethics committee approval was obtained.

Author Contribution

O.O and Z.K wrote this article.O.O, C.İ and A.İ prepared figures.OO, Z.K., A.İ. and C.İ. collected datas.C.İ. applied statistical analysis.A.P. and D.D.A both reviewed it and contributed during the writing process.All authors reviewed the manuscript.

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Figures

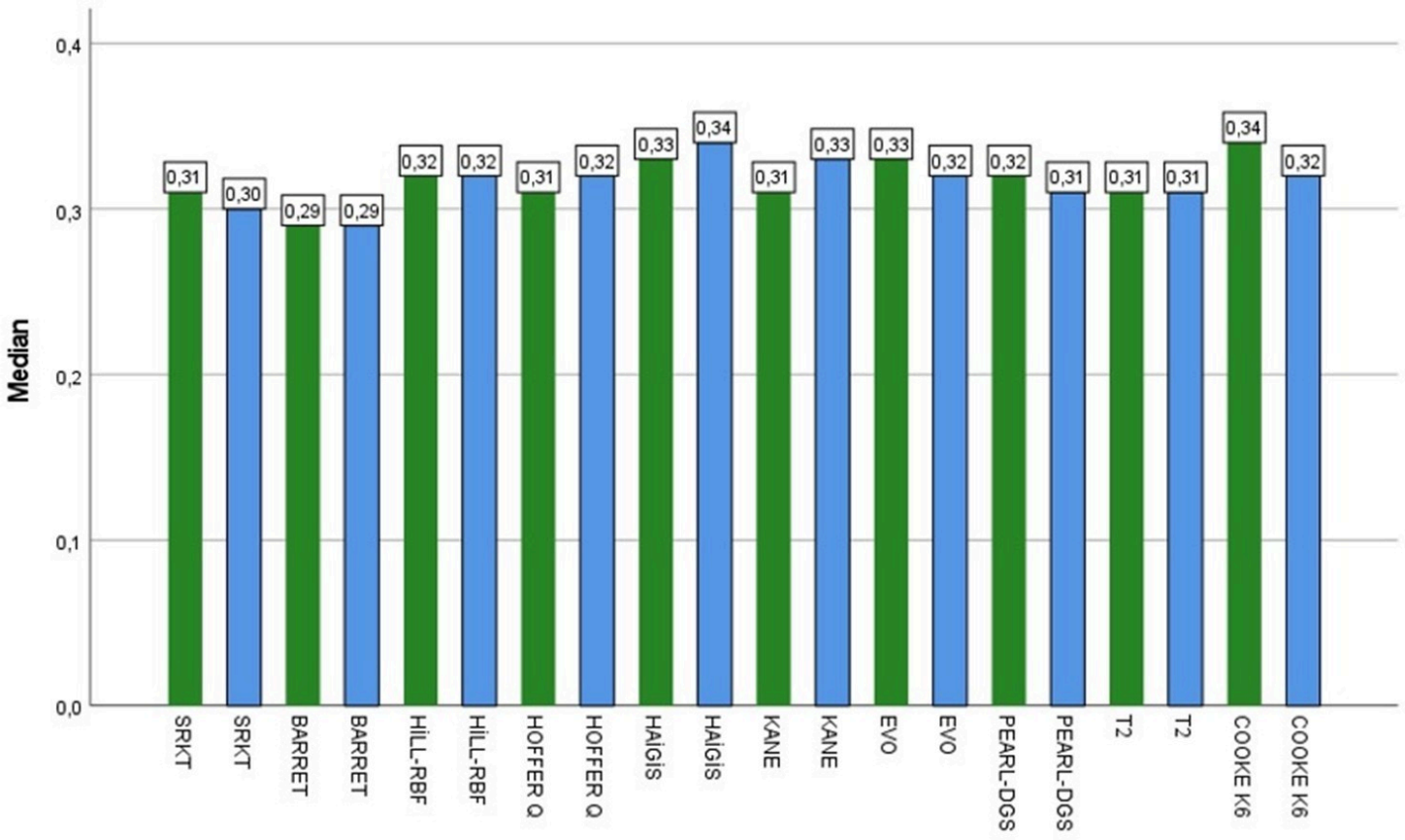


Figure 1

Median Absolute Error for the formulas (first constant and new constant respectively)

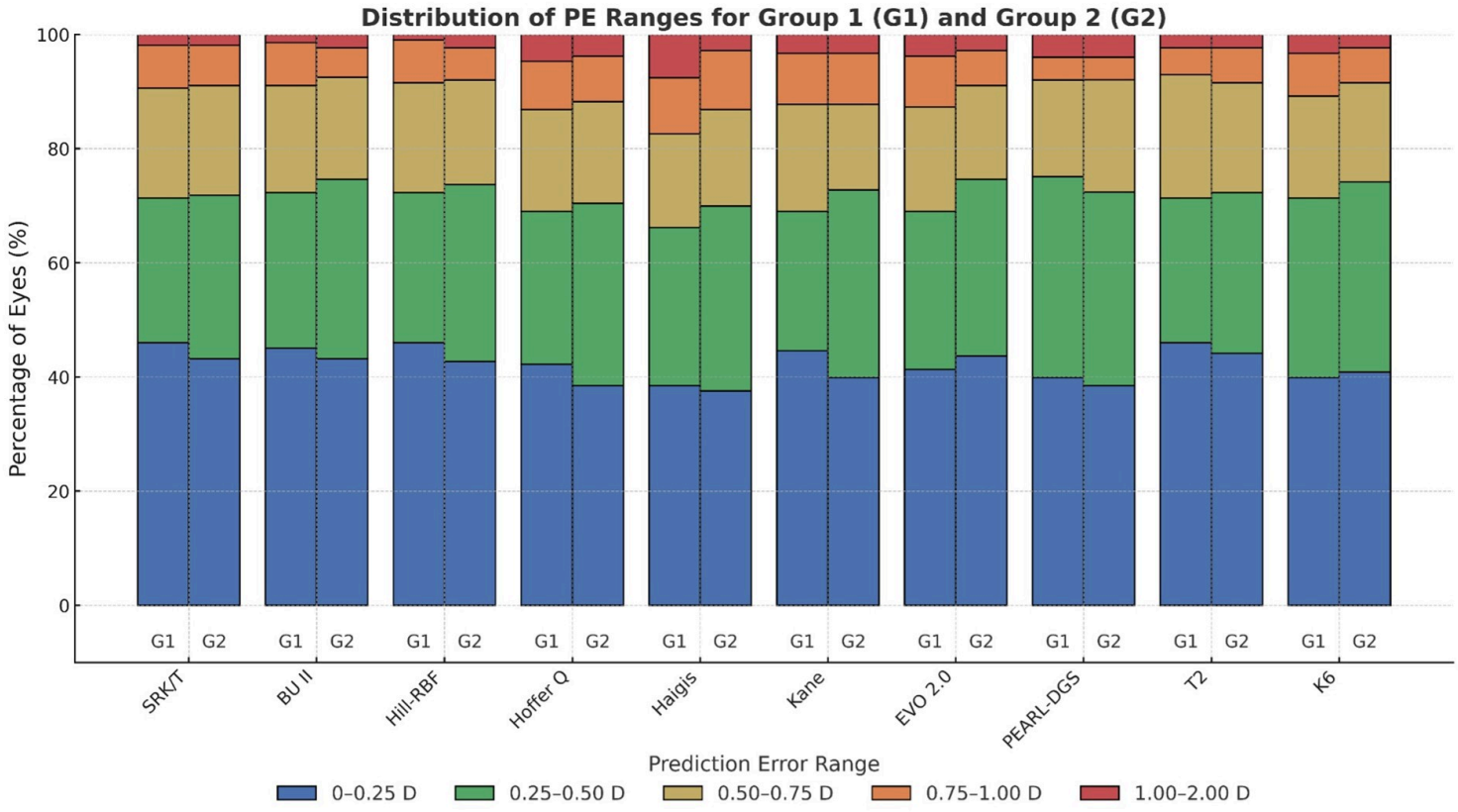


Figure 2

Percentage distribution of eyes with refractive errors within ±0.25, ±0.50, ±0.75, and ±1.00-2.00 D in Groups 1 and 2