Factors Affecting Prediction Error after Cataract Surgery with Implantation of Various Multifocal IOLs in Patients with Previous Refractive Laser Surgery

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Abstract

This study aimed to compare the clinical outcomes of implantation of various multifocal intraocular lenses (mIOLs) and the prediction accuracy of two intraocular lens (IOL) power calculation formulas for eyes that underwent previous corneal refractive surgery. Four types of mIOLs (TECNIS Symfony (Group I), AcrySof IQ PanOptix (Group II), LENTIS Mplus (Group III), and TECNIS mIOL (Group IV)) were used and the IOL power was calculated with the two no-history methods, Shammas-PL and Barrett True-K. Visual acuity and refractive outcomes including manifest refraction, prediction error (PE), absolute error (AE), and median absolute error (MedAE) were evaluated at three months after the cataract surgery. For all groups the Barrett True-K formula produced a narrower range of PEs and lower MedAE than Shammas-PL. Eyes of lower predictive accuracy (group B, AE > 0.5D) showed weak uncorrected distance visual acuity resulting from myopic refractive error and target refraction when compared to that of higher predictive accuracy (group A, AE ≤ 0.5 D). Targeting emmetropia using the Barrett True-K is recommended in patients undergoing mIOL implantation with prior corneal refractive surgery. Additionally, history of prior large amount of laser ablation seems to be an important factor related to low predictive accuracy.

Introduction

With the popularization of refractive surgery, many patients have undergone refractive surgeries, and as the age of patients has increased, the number of cataract surgeries after refractive surgery has increased. There are many reports that intraocular lens (IOL) power calculation for eyes that have previously undergone refractive surgery is less accurate than that for virgin eyes[1–3]. IOL power calculations for patients who have had corneal refractive surgery are clinically challenging because it is difficult to accurately predict corneal power and effective lens position[1,2]. Many formulas are used to accurately calculate IOL power for eyes that have previously undergone corneal refractive surgery. When the refractive surgery parameters (pre-refractive surgery K-readings, amount of myopia corrected, or both) are known, many methods are available to correct the K-values and more accurately estimate the lens position[4,5]. However, when the refractive surgery data is not available, the no-history method is a viable alternative for IOL power calculation after myopic refractive surgery[4].

In the absence of refractive surgery data, several formulas have been proposed to accurately calculate IOL power, including the Shammas post-LASIK (Shammas-PL) and Barrett True-K formulas[1,6]. The Shammas-PL formula calculates IOL power based upon anterior chamber depth (ACD), axial length (AL) and post-refractive surgery keratometry[1]. The Barrett True-K formula (version 2.0) is based on the Barrett Universal II formula and is accessed online[7,8]. Many studies have been published on monofocal IOL power calculation after refractive surgery, but to the best of our knowledge there have been few reports on multifocal IOL (mIOL) power calculation after refractive surgery. Although several studies have shown good refractive outcomes and visual acuity results, the use of mIOLs for eyes that have undergone corneal refractive laser surgery is controversial because of the assumption that the laser alteration of the cornea could cause vision to deteriorate after mIOL implantation[9,10].

To our knowledge, there are few studies that have evaluated refractive and visual outcomes and analyzed factors affecting prediction error (PE) for various mIOLs for patients who have had myopic refractive laser surgery. This retrospective study aimed to compare the clinical outcomes of four mIOLs and to evaluate predictive accuracy of two IOL power calculation formulas for patients that have previously undergone corneal refractive surgery. Additionally, preoperative characteristics that could lead to low predictive accuracy of IOL power calculation were evaluated.

Results

There was no difference in patient sex between the four groups (Table 1). Although the optical power of the implanted mIOLs was not different between the groups, group I showed younger age, flatter corneal curvature, and longer axial length than the other three groups (all $P < 0.05$). From the preoperative biometry of group I, it can be inferred that the extended depth of focus (EDOF) IOL was used in cataract patients with prior higher degrees of myopic laser correction.

Table 1
Subject demographics

	Group I	Group II	Group III	Group IV	*P* value
Number	59	25	26	21	
Age	48.7 ± 6.2[c]	50.4 ± 4.8	52.5 ± 4.6	50.5 ± 6.1	0.031[a]
Female (%)	40 (67.8%)	15 (60.0%)	18 (69.2%)	17 (81.0%)	0.499[b]
Visual Acuity (LogMAR)					
UDVA	0.56 ± 0.37	0.29 ± 0.20	0.25 ± 0.33	0.37 ± 0.30	0.225[b]
UNVA	0.40 ± 0.26	0.34 ± 0.28	0.41 ± 0.21	0.32 ± 0.24	0.453[b]
Manifest Refraction (D)					
Spherical Equivalent	−0.73 ± 1.97	−0.49 ± 0.92	−0.84 ± 1.17	−0.75 ± 1.36	0.563[b]
Refractive Sphere	−0.43 ± 2.02	−0.22 ± 0.91	−0.35 ± 0.49	−0.44 ± 1.37	0.223[b]
Refractive Astigmatism	−0.60 ± 0.61	−0.53 ± 0.71	−0.36 ± 0.35	−0.61 ± 0.59	0.479[b]
Keratometry (D)	39.92 ± 2.47[c]	41.30 ± 1.65	41.66 ± 2.16	40.61 ± 2.52	0.010[b]
Central Corneal Thickness (μm)	483.0 ± 41.4[c]	514.5 ± 33.2	482.4 ± 42.4	479.8 ± 34.0	0.007[b]
Anterior Chamber Depth (mm)	3.42 ± 0.31	3.52 ± 0.25	3.32 ± 0.32	3.38 ± 0.32	0.051[b]
Axial Length (mm)	26.23 ± 1.99[c]	25.21 ± 1.07	24.92 ± 1.33	25.48 ± 1.79	0.003[b]
IOL Power (D)	20.11 ± 4.64	20.28 ± 3.52	19.98 ± 2.07	21.12 ± 2.78	0.462[a]

[a] *P* value by Kruskal–Wallis H test

[b] *P* value by chi-squared test

[c] Group I showed statistically different values compared to each of groups II, III, and IV.

UDVA: uncorrected distance visual acuity; UNVA: uncorrected near visual acuity; IOL: intraocular lens

Both postoperative UDVA and UNVA were improved in all groups compared with those before cataract surgery (all $P < 0.001$). Both postoperative mean UDVA and UNVA were logMAR 0.1 or less in groups II, III, and IV (Table 2). UDVA was better for groups II, III, and IV than for group I, and UNVA was better for groups II and III than for groups I and IV. Postoperative mean MR for four groups were − 0.37 ± 0.64, − 0.14 ± 0.24, − 0.16 ± 0.26, and − 0.050 ± 0.44 D in groups I, II, III, and IV, respectively. There was no difference in SE based on MR between the four groups (P = 0.106). Groups I and III showed myopic refractive error in mean AR compared to their mean MR. More than 60% of eyes in each group showed MR between − 0.25 and + 0.25 D (67.8, 84.0, 73.1, and 66.7% in group I, II, III and IV, respectively; Fig. 1). More than 80% of eyes showed MR within 1 D in all groups (84.7, 100.0, 92.3, and 95.2% in group I, II, III and IV, respectively).

Table 2
Postoperative visual and refractive outcomes after cataract surgery in patients with prior refractive laser surgery.

	Group I	Group II	Group III	Group IV	*P* value[a]
Number	59	25	26	21	
Visual Acuity (LogMAR)					
UDVA	0.11 ± 0.16[b]	0.076 ± 0.14	0.043 ± 0.10	0.072 ± 0.10	0.047
UNVA	0.13 ± 0.12[c]	0.051 ± 0.077	0.030 ± 0.061	0.10 ± 0.11[c]	< 0.001
Spherical Equivalent (D)					
Manifest Refraction	−0.37 ± 0.64	−0.14 ± 0.24	−0.16 ± 0.26	−0.050 ± 0.44	0.106
Auto Refraction	−1.41 ± 0.63[d]	−0.27 ± 0.48	−1.50 ± 0.45[d]	−0.51 ± 0.49	< 0.001

[a] *P* value by Kruskal–Wallis H test

[b]Group I showed statistically different values compared to each of groups II, III, and IV.

[c]Groups I and IV showed statistically different values compared to each of groups II and III.

[d]Groups I and III showed statistically different values compared to each of groups II and IV.

UDVA: uncorrected distance visual acuity; UNVA: uncorrected near visual acuity

Target refractions calculated from Barrett True-K showed no difference between all groups (P = 0.355, Table 3). PEs based on Barrett True-K were closer to zero than those based on Shammas-PL in groups I and II (P = 0.017 and 0.007, respectively; Fig. 2). Although groups III and IV showed no difference in PE between Barrett True-K and Shammas-PL, mean PE values of Shammas-PL (0.050 ± 0.40 and − 0.29 ± 0.65 D in groups III and IV, respectively) and Barrett True-K formulas (0.19 ± 0.22 and − 0.012 ± 0.60 D in groups III and IV, respectively) were within 0.50 D of each other. For all groups, the Barrett True-K formula yielded lower MAE and MedAE than Shammas-PL. More eyes had MAE within 0.25 and 0.50 D when using the Barrett True-K formula (45.8, 68.0, 65.4, 42.9% and 76.3, 84.0, 88.5, 66.7% in group I, II, III, and IV, respectively) compared to Shammas-PL (23.8, 44.0, 50.0, 38.1% and 72.9, 84.0, 76.9, 66.7% in group I, II, III, and IV, respectively; Fig. 3).

Table 3
Prediction accuracy of IOL power calculated using Shammas-PL and Barrett True-K formulas for four multifocal intraocular lenses.

	Group I	**Group II**	**Group III**	**Group IV**	***P* value[a]**
Number	59	25	26	21	
Target Refraction (D)					
Shammas-PL	−0.39 ± 0.34	0.067 ± 0.29	−0.13 ± 0.31	−0.34 ± 0.35	< 0.001
Barrett True-K	−0.20 ± 0.65	−0.16 ± 0.37	0.027 ± 0.22	−0.062 ± 0.33	0.355
Absolute Error (D)					
Shammas-PL	0.44 ± 0.30	0.47 ± 0.33	0.32 ± 0.24	0.49 ± 0.50	0.284
Barrett True-K	0.41 ± 0.50	0.29 ± 0.19	0.24 ± 0.17	0.45 ± 0.39	0.155
MedAE (D)					
Shammas-PL	**0.37**	**0.35**	**0.27**	**0.34**	
Barrett True-K	**0.28**	**0.28**	**0.22**	**0.29**	
MedAE: median absolute error					
[a] *P* value by Kruskal–Wallis H test					

Postoperative mean UDVA in eyes with postoperative MR between 0.25 and − 0.25 D were 0.053 ± 0.082, 0.044 ± 0.11, 0.0072 ± 0.017, and 0.058 ± 0.094 in group I, II, III, and IV, respectively (Fig. 4). Although there was no difference in UDVA between four groups in case with postoperative MR between + 0.25 and − 0.25 D ($P = 0.056$), UNVA at 40 cm was better in groups II and III than groups I and IV (all $P < 0.001$). Group I achieved UNVA better than 0.1 logMAR in wider range of postoperative MRs than other groups, showing the EDOF properties. In subgroup analysis based on postoperative MR, Group II, III, and IV showed the best UDVA and UNVA in postoperative MR between + 0.25 and − 0.25 D.

Twenty-three of the 131 subjects (17.56%) showed an absolute value of PE (AE) of 0.5 D or more based on the calculation with Barrett True-K formula (Table 4); these subjects were grouped as Group B. Their UDVA was lower ($P < 0.001$) and their postoperative refraction error was more myopic ($P = 0.001$) than subjects having AE less than 0.5 D (Group A). Both SE and refractive sphere based on MR were closer to emmetropia for group A (− 0.16 ± 0.36 and − 0.0049 ± 0.38 D, respectively) than for group B (− 0.58 ± 0.85 [$P = 0.016$] and − 0.40 ± 0.87 D [$P = 0.028$], respectively). Lower K-values ($P = 0.002$) and longer axial length ($P = 0.010$) were found in group B compared to group A. It is supposed that subjects who experienced more ablation during laser refractive surgery before cataract surgery fell into the higher-PE group B. Target refraction preoperatively calculated with Barrett-True-K was more myopic for group B than group A ($P < 0.001$). However, target refraction calculated with Shammas-PL did not show any difference between group A (− 0.22 ± 0.36D) and group B (− 0.36 ± 0.41D, $P = 0.090$). Regardless of which IOL formula was used, group B showed myopic refractive error compared to group A. For the high-AE group B, IOL power selection targeting myopic seems to have resulted in postoperative myopic PE after cataract surgery.

Table 4

Factors related to absolute value of prediction error after cataract surgery in patients with prior refractive laser surgery. All subjects were divided into two groups: those having prediction error of 0.5 D or less (Group A) or prediction error more than 0.5 D (group B). Prediction error was calculated by using the Barrett True-K formula.

	Group A (AE ≤ 0.5 D)	**Group B AE > 0.5 D**	***P* value**
Number	108	23	
Postoperative Values			
Visual Acuity (LogMAR)			
UDVA	0.061 ± 0.10	0.19 ± 0.22	0.001[a]
UNVA	0.090 ± 0.11	0.10 ± 0.12	0.645[a]
Manifest Refraction (D)			
Spherical Equivalent	−0.16 ± 0.36	−0.58 ± 0.85	0.016[a]
Refractive Sphere	−0.0049 ± 0.38	−0.40 ± 0.87	0.028[a]
Refractive Astigmatism	−0.31 ± 0.38	−0.35 ± 0.32	0.367[a]
Target Refraction (D)			
Barrett True-K	−0.069 ± 0.25	−0.36 ± 1.05	< 0.001[a]
Preoperative Values			
Age	50.1 ± 5.8	50.0 ± 5.8	0.702[a]
Female (%)	40 (67.8%)	15 (60.0%)	0.922[b]
Keratometry (D)	40.96 ± 2.27	39.13 ± 2.30	0.002[a]
Central Corneal Thickness (μm)	489.6 ± 37.1	481.4 ± 54.8	0.843[a]
Anterior Chamber Depth (mm)	3.43 ± 0.32	3.34 ± 0.23	0.363[a]
Axial Length (mm)	25.46 ± 1.66	26.59 ± 1.97	0.010[a]

[a] *P* value by Mann–Whitney test

[b] *P* value by chi-squared test

AE: absolute value of prediction error; UDVA: uncorrected distance visual acuity; UNVA: uncorrected near visual acuity; IOL: intraocular lens

	Group A (AE ≤ 0.5 D)	Group B AE > 0.5 D	*P* value
IOL Power (D)	20.3 ± 3.4	20.3 ± 5.1	0.227[b]
[a] *P* value by Mann–Whitney test			
[b] *P* value by chi-squared test			
AE: absolute value of prediction error; UDVA: uncorrected distance visual acuity; UNVA: uncorrected near visual acuity; IOL: intraocular lens			

Discussion

MIOL implantation yielded good distant and near visual acuity in post-refractive surgery eyes, and the emmetropia target is also recommended for good near and distance visual acuity. In calculating mIOL power after refractive surgery, the Barrett True-K formula, which considers posterior corneal curvature as well as anterior corneal curvature, was more accurate than the Shammas-PL formula. However, eyes with history of larger amount of laser ablation in corneal refractive surgery (39.13 D and 26.59 mm were the mean values of K and AL in the present study, respectively) seems to show weaker predictive accuracy of IOL power calculation when using the Barrett True-K formula.

The predictive accuracy of the Barrett True-K formula was higher than that of the Shammas-PL formula, which is thought to be due to the fact that the Barrett True-K formula showed more hyperopic PE than Shammas-PL formula[6]. Although conventional formulas such as Shammas-PL and Haigis-L calculate IOL power based upon preoperative keratometry measuring only the anterior curvature, supplemental factors have been added to these formulas to reduce PE for eyes with prior corneal refractive surgery[4,11]. Specific methods for corneal power correction have been used with both Shammas-PL and Haigis-L to compensate for overestimated keratometry in eyes with prior corneal refractive surgery. However, the keratometry used in both formulas were not measured values, but expected values developed by using regression analysis (a no-history method). As a result, IOL power calculations with Shammas-PL and Haigis-L have shown more myopic PE in eyes with prior corneal refractive surgery than those preoperatively expected[7].

The Barrett True-K formula more accurately calculates IOL power, representing the curvature of the entire cornea by including the posterior corneal curvature measurement[6,11–13]. In clinical studies reporting the results of cataract surgery after corneal refractive laser surgery, IOL power calculation using total keratometry which considers both anterior and posterior corneal curvature showed better results than conventional calculation using only the anterior corneal curvature[14–19]. Additionally, Shammas-PL based on total keratometry measured with an IOLMaster 700 biometer showed improved accuracy compared to that based on anterior keratometry in clinical studies by Lawless et al. and Yeo et. al.[20,21] Recently, formulas using a ray-tracing method developed directly by the research institute were presented for more accurate IOL power calculation considering the anterior and posterior corneal curvature as well as the corneal thickness[15,22–24]. Keratometry calculated from directly measured corneal curvatures of both the anterior and posterior surfaces would improve refractive outcomes due to the correction of myopic refractive error along with conventional IOL power calculations in eyes with prior corneal refractive surgery.

In the present study, eyes with extreme biometry (mean K value of 39.13 D and mean AL of 26.59 mm) showed greater PE as calculated using Barrett True-K. IOL power calculation formulas for eyes with prior corneal refractive surgery are divided into history methods, which consider pre-refractive surgery data, and no-history methods, which are used when data from the refractive surgery are not available. Although there was no significant difference between the two methods[4,11,25], there has been no single formula showing high accuracy in various biometry conditions including eyes after corneal refractive surgery[26,27]. Recently, Whang et al. reported in a retrospective study that the predictive accuracy of no-history IOL formulas depends on AL[28]. Barrett True-K was most accurate for AL less than 28 mm, Triple-S was most accurate for AL between 28 and 30 mm, and Shammas-PL was most accurate for AL 30 mm or more. In the present study, mean preoperative AL was 25.84 ± 1.81 mm and only two eyes had a preoperative AL of more than 30 mm; thus, further evaluation of prediction accuracy in the case of extremely long eyes requires further study.

Eyes with high PE as calculated by Barrett True-K (group B in Table 4) showed preoperative characteristics of lower K-values and longer axial length. These biometry results correspond to eyes that experienced larger amount of ablation during refractive laser surgery. Additionally, both IOL power selection targeting myopic refraction and postoperative myopic refractive outcome resulted in PE being myopic. Previous studies with earlier formulas recommended targeting myopic due to hyperopic refractive surprise when calculating IOL power in eyes with previous corneal refractive surgery[27–31]. Recent studies have reported that it is good to make the postoperative MR close to emmetropia in eyes having general corneal curvature, and the same results were reported for eyes which have undergone corneal refractive surgery[32,33]. However, targeting slightly myopic may improve near vision without compromising distant vision, especially in high myopic patients, which is the case in the real world practice. Based on our result, we recommend aiming emmetropia when using Barrett True-K formula for implanting mIOL in eyes that have undergone corneal refractive surgery. Moreover, this study shows that predictive accuracy is more important than mIOL type for postoperative visual outcomes of patients with prior corneal refractive surgery.

To measure postoperative refractive power of the eye, MR is recommended after mIOL implatation[34]. Pseudophakia with a diffractive multifocal IOL (Tecnis ZM900 or ReSTOR) showed similar refraction between autorefraction and MR measurements, including both spherical and astigmatic values[34,35]. However, for eyes with a refractive multifocal IOL (ReZoom and Lentis LS-312 MF30), spherical values were found to be underestimated by autorefraction compared to MR[34,36,37]. Interestingly, in the present study both EDOF IOL (Tecnis Symfony) and rotationally asymmetric multifocal IOL (Lentis LS-312 MF30) also led to underestimation of spherical power by means of autorefraction compared to MR. Postoperative refraction in patients with refractive or EDOF mIOL should be measured by MR.

However, there were some limitations in this study. IOL power calculation formulas with no-history methods were not compared to history methods in this retrospective study. Type of corneal refractive surgery was not identified due to a lack of information in some medical records. Although this was a relatively large-scale study comparing the results of different types of mIOLs, further prospective study based on a larger number with same type of mIOL is needed in order to improve the predictive accuracy of each IOL power calculation, especially in eyes that have undergone a large amount of corneal ablation.

In conclusion, MIOL implantation after corneal refractive laser surgery showed good refractive and visual outcomes. The Barrett True-K formula, which considers both anterior and posterior corneal curvature, was more accurate than the Shammas-PL formula, which considers only anterior corneal curvature. Targeting emmetropia is recommended when implanting mIOL in eyes that have undergone corneal refractive surgery. Especially in eyes that have undergone extensive corneal ablation, the previously large amount of laser ablation for cornea seems to be an important factor causing low predictive accuracy of IOL power calculation in cataract surgery.

Methods

Subjects

This retrospective study included 131 eyes of 131 patients who underwent cataract surgery with mIOLs from January 2018 to July 2019 and had previously undergone myopic refractive surgery. Exclusion criteria were previous ocular surgeries except corneal refractive procedures such as LASIK or LASEK, corneal diseases, pseudoexfoliation, zonular weakness, corneal astigmatism greater than 1.00 diopter (D), glaucoma, macular disease, and amblyopia. Eyes with best-corrected distant vision less than 20/40 in the postoperative state were also excluded. The study protocol adhered to the tenets of the Declaration of Helsinki for the use of human participants in biomedical research. The Institutional Review Board (IRB #2020-09-079) for Human Studies at Samsung Medical Center approved this study and informed consent was exempted by IRB of Samsung Medical Center.

Surgical technique

All procedures were performed by one experienced surgeon (TYC) under topical anesthesia. Phacoemulsification was performed through a 2.75 mm temporal clear corneal incision. After performing continuous curvilinear capsulorhexis with intended diameter 5.0 mm and hydrodissection, phacoemulsification of the nucleus and bimanual aspiration of the residual cortex were performed using a cataract surgery phacoemulsification device (Centurion Vision System, Alcon, Fort Worth, TX, USA). The mIOL was implanted into the capsular bag using an injector and disposable cartridge system before removing the ophthalmic viscosurgical device (OVD). Four types of mIOLs were used: extended range of vision (Group I; TECNIS Symfony, ZXR00, Johnson & Johnson Vision Care, Inc. Santa Ana, CA, USA), quadrifocal (Group II; AcrySof IQ PanOptix, TNFT00, Alcon, Fort Worth, TX, USA), asymmetric zonal refractive bifocal (Group III; LENTIS Mplus, LS-313 MF30, LS-313 MF30, Oculentis GmbH, Berlin, Germany), and traditional diffractive bifocal (Group IV; TECNIS multifocal IOL, ZLB00, Johnson & Johnson Vision Care, Inc., Santa Ana, CA, USA). Finally, a balanced salt solution was injected into the incision site to close the corneal incision, causing edema. After the surgery, postoperative antibiotic and corticosteroid eye drops were used four times daily and tapered over a month.

Patient examinations

Before cataract surgery, visual acuity was measured, including uncorrected distance visual acuity (UDVA) and uncorrected near visual acuity (UNVA). Manifest refraction (MR) testing was also conducted. To calculate mIOL power during cataract surgery, preoperative biometry of the eye was measured, namely the keratometry of the anterior and posterior surface, central corneal thickness, anterior chamber depth, and axial length, using both a swept-source optical coherence tomography (SS-OCT) biometer (ARGOS, Suntec, Inc., Aichi, Japan) and a Scheimpflug camera (Pentacam, Oculus, Wetzlar, Germany). Three months after the cataract surgery, visual acuity (UDVA and UNVA) and ocular refraction (MR and autorefraction [AR] with autorefractor) were measured. UDVA and UCVA were measured at 4 m and 40 cm respectively.

Main measurement outcomes

Differences were compared between the predicted refractive value for each mIOL calculated by using different formulas and the refractive value measured three months after cataract surgery. The IOL power was calculated using two methods, the Shammas-PL formula, which is built into the biometer used, and the Barrett True-K formula (version 2.0, http://calc.apacrs.org/Barrett_True_K_Universal_2105/), which can be computed using a website. To calculate IOL power, the Shammas-PL uses only the anterior corneal curvature measured by the biometer, whereas the Barrett true-K formula uses both this curvature and the posterior corneal curvature. The IOL constants of each formula were as follows; In Shammas-PL (TECNIS Symfony (Group I); 118.8, PanOptix (Group II); 119.1, LENTIS Mplus (Group III); 118.5, TECNIS ZLB00 (Group IV); 118.8), in Barrett True-K formula (TECNIS Symfony (Group I); 119.39, PanOptix (Group II); 119.1, LENTIS Mplus (Group III); 118.5, TECNIS ZLB00 (Group IV); 119.39).

Prediction error (PE) in refraction was defined as the predicted spherical equivalent (SE) from an IOL formula minus the actual postoperative SE, whereas the mean error (ME) was the mean of the PEs. Positive and negative signs of PE respectively represent myopic and hyperopic errors of postoperative refraction. The mean absolute error (MAE) and median absolute error (MedAE) were the mean and median of the absolute values of the MEs. We also calculated the percentage of eyes having MEs of ± 0.25, ± 0.50, and ± 1.00 D or less. Additionally, PE for each mIOLs were analyzed based on postoperative MR. After these refractive outcomes were calculated, the predictive accuracies of the two formulas were evaluated.

Statistical analysis

Visual acuity and refractive outcomes including MR, AR, and PE were compared between four mIOLs using the Kruskal–Wallis H test. The refractive outcome measures MAE and MedAE of the Shammas-PL and Barrett True-K formulas were compared for each of the four mIOL groups. Box plots were used to compare the PEs of the Shammas-PL and Barrett True-K formulas. Statistical analyses were performed using SPSS statistical software (version 23.0, SPSS, Inc., Chicago, IL, USA) and statistical significance was defined as $P < 0.05$.

Declarations

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None

Author Contributions:

Y.S.Y. and M.C.K. contributed equally to this work and wrote the main manuscript. D.H.L. and T.Y.C. made substantial contributions to the conception or design of the work and revised it. J.Y.P. analyzed the data. H.G.K and E.S.C. contributed to interpretation of data. All authors reviewed the manuscript.

Competing Interest:

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Figures

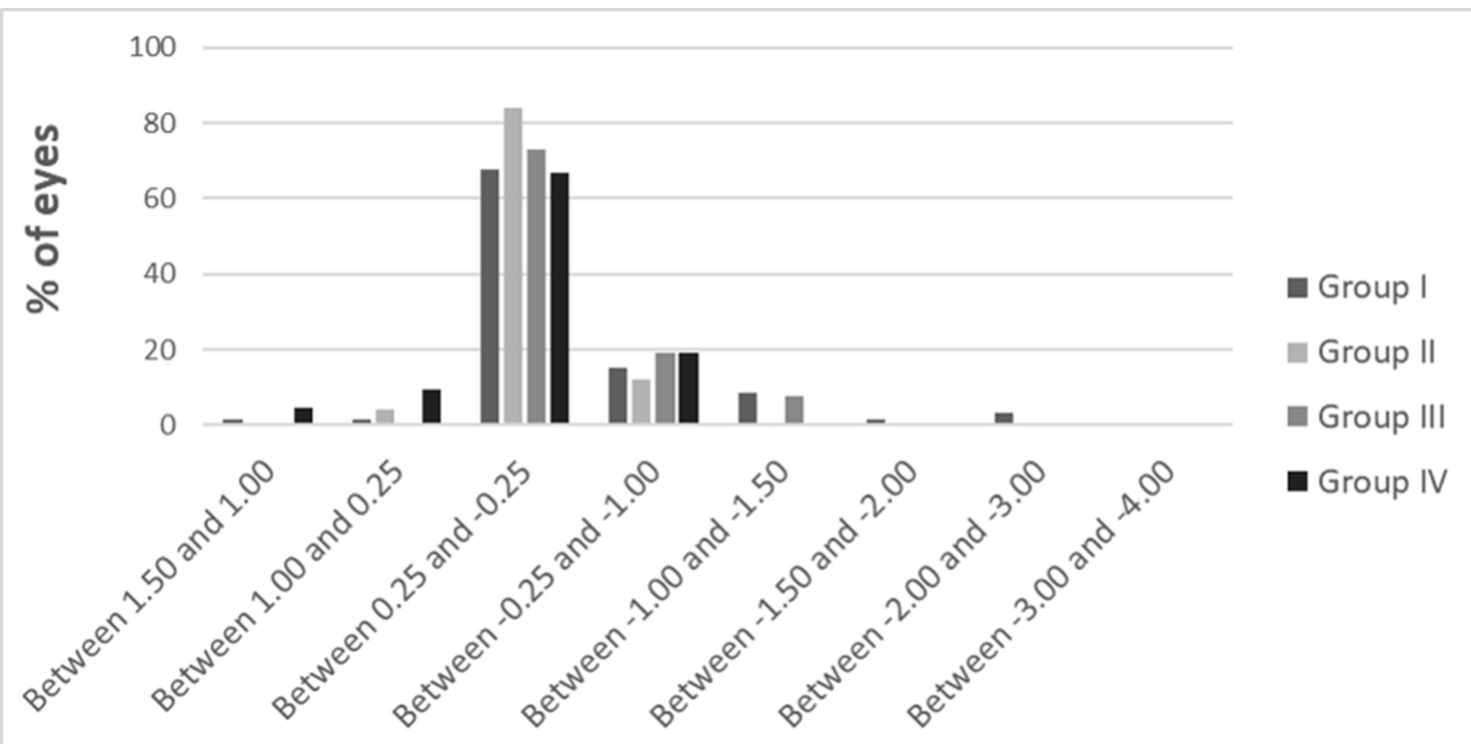

Figure 1

Postoperative manifest refractions of subjects implanted with various multifocal intraocular lenses.

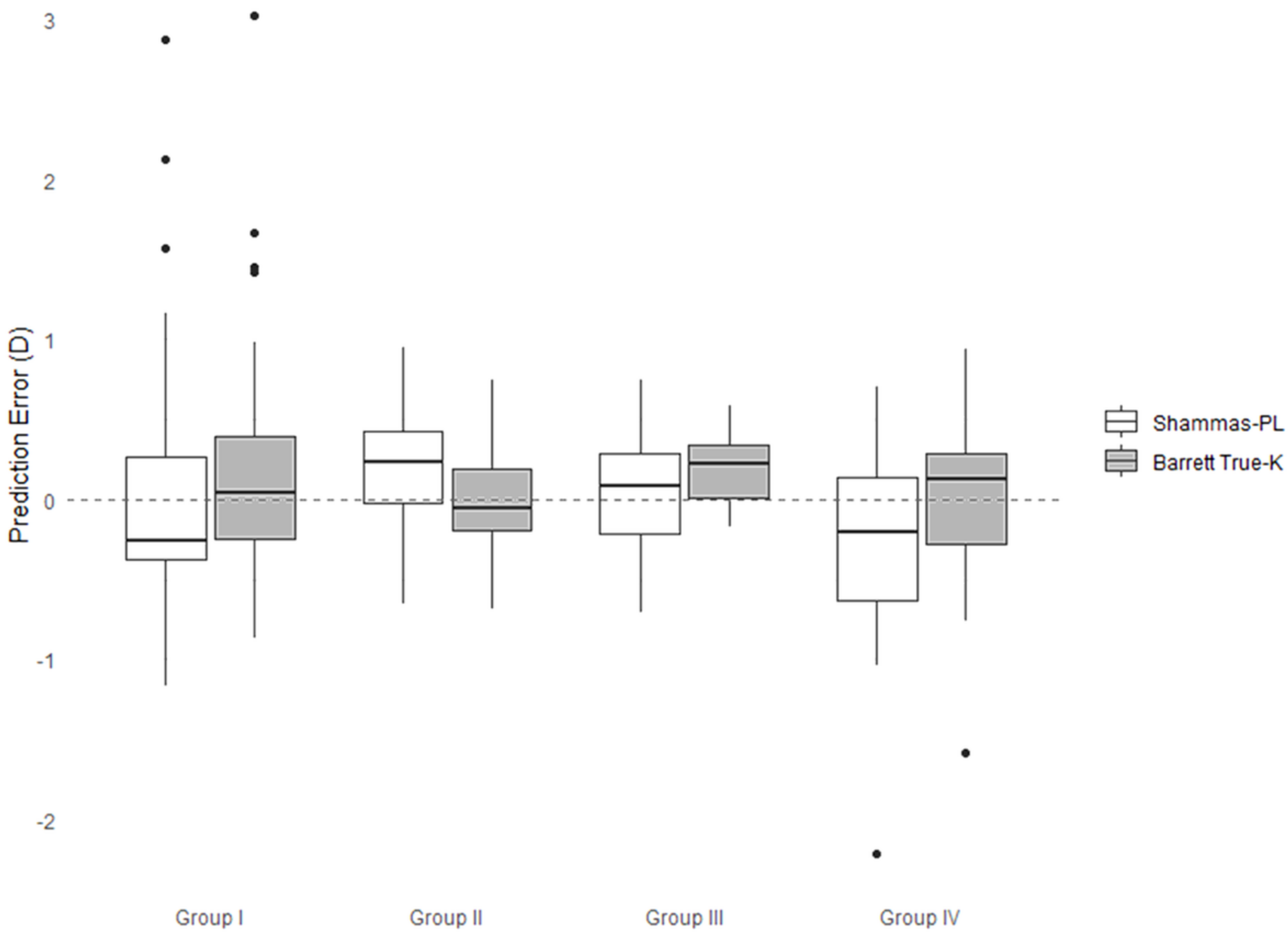

Figure 2

Prediction errors of Shammas-PL and Barrett True-K formulas. (Prediction error = predicted spherical equivalent (SE) − postoperative SE)

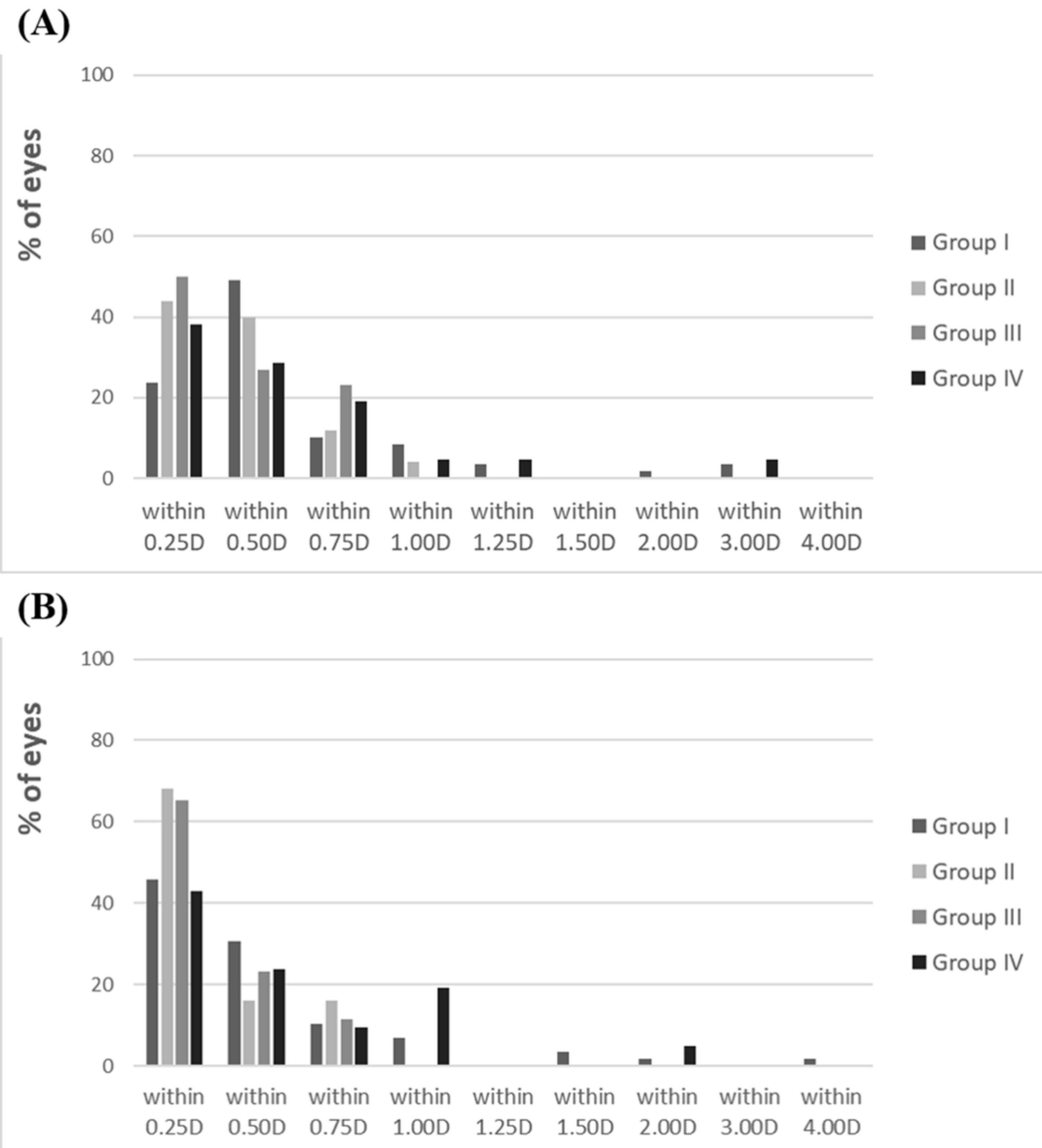

Figure 3

Mean absolute errors of (A) Shammas-PL and (B) Barrett True-K formulas.

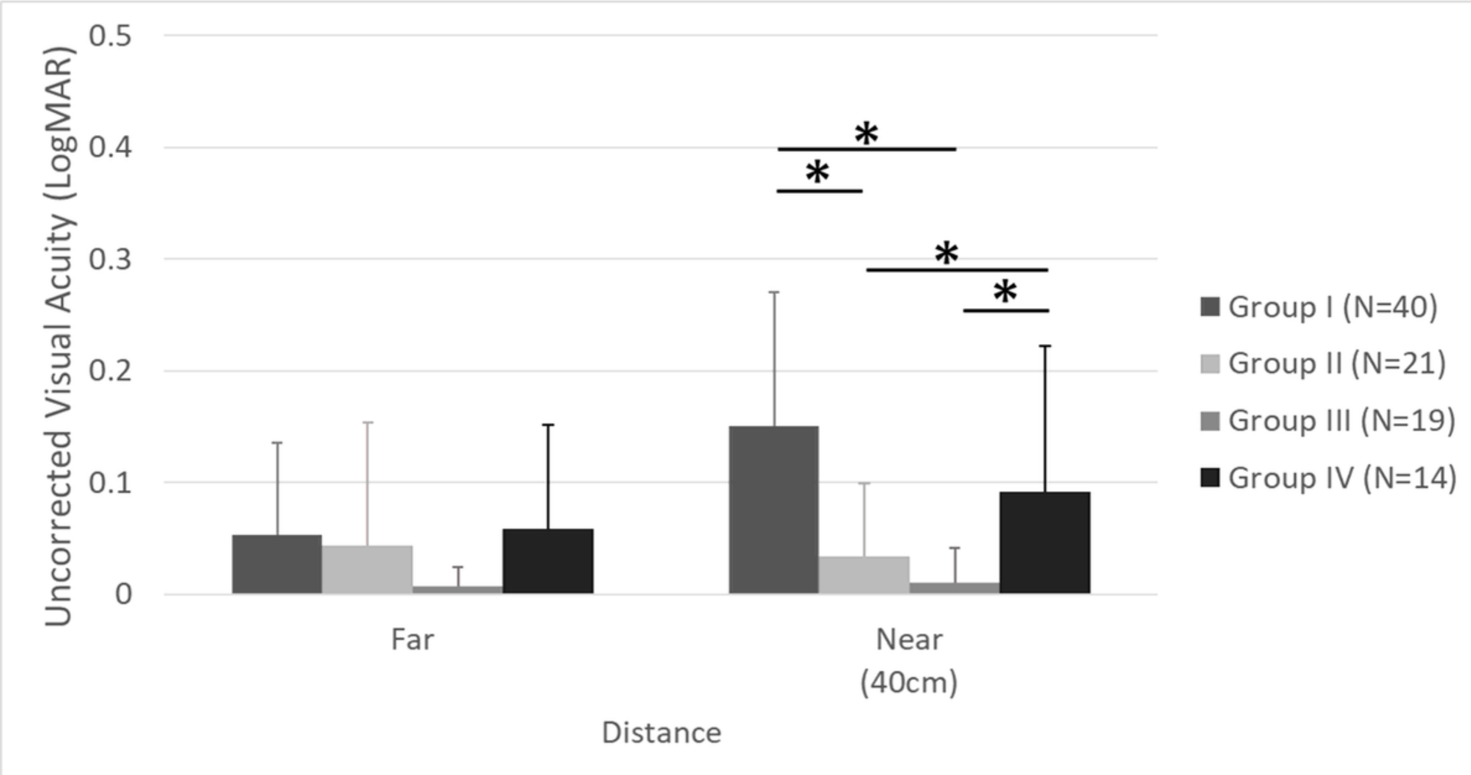

Figure 4

Postoperative LogMAR visual acuity of eyes having between 0.25 and −0.25 D of postoperative manifest refraction. Asterisks indicate statistically significant differences (P < 0.05, Kruskal−Wallis H test).