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CLINICAL INVESTIGATION

Accuracy of no-history formulae for intraocular lens power calculation in post-myopic laser vision correction eyes: a multicenter study in Japan

So Goto[1,2] · Yosai Mori[3] · Hidemasa Torii[4] · Yumi Hasegawa[5] · Takashi Kojima[6] · Kazutaka Kamiya[7] · Takuya Shiba[8] · Kazunori Miyata[3]

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Abstract

Purpose To compare the refractive prediction accuracy of seven no-history intraocular lens (IOL) power calculation formulas in post-myopic laser vision correction (M-LVC) eyes in Japanese patients.

Study design Multicenter retrospective case series.

Methods This study included patients with previous M-LVC who underwent cataract surgery between 2016 and 2023. IOL power calculation formulas were assessed using measurements from a swept-source optical coherence biometer. Refractive prediction errors were calculated for the Emmetropia Verifying Optical 2.0 (EVO 2.0), Post Myopic LASIK/PRK Hoffer QST (Hoffer QST), and Post-M-LVC PEARL-DGS (PEARL-DGS) formulas. These were compared with the Barrett True-K No History (BTKNH), Haigis-L, Shammas, and the ASCRS average formulas. Heteroscedastic testing for root mean square absolute error (RMSAE) was used to evaluate formula performance.

Results The study comprised 125 post-LASIK eyes from 89 patients. Only the BTKNH had mean numerical errors not significantly different from zero. The formulas were ranked by absolute prediction error (MAE): ASCRS average (0.42 D), BTKNH (0.43 D), Hoffer QST (0.46 D), Pearl-DGS and Shammas (0.46 D), EVO 2.0 (0.48 D), and Haigis-L (0.51 D). The BTKNH and ASCRS average demonstrated smaller RMSAE compared to Shammas ($P < .0001$). The Hoffer QST had a smaller RMSAE than Pearl-DGS ($P = 0.02$).

Conclusion The BTKNH, ASCRS average, and Hoffer QST formulas are precise and reliable for improving postoperative refractive outcomes in Japanese patients with a history of M-LVC.

Keywords Post-myopic laser vision correction · Cataract surgery · IOL power calculation · Japanese eye

Corresponding Author: Takayuki Baba

✉ So Goto
gotoso@ophthal.med.osaka-u.ac.jp

[1] Department of Ophthalmology, Osaka University Graduate School of Medicine, Room E7, Yamadaoka 2-2, Suita, Osaka 565-0871, Japan

[2] Department of Ophthalmology, National Hospital Organization, Tokyo Medical Center, 2-5-1 Higashigaoka, Meguro-ku, Tokyo 152-8902, Japan

[3] Miyata Eye Hospital, Kurahara 6-3, Miyakonojo, Miyazaki 885-0051, Japan

[4] Department of Ophthalmology, Keio University School of Medicine, 35 Shinanomachi , Shinjuku-ku, Tokyo 160-8582, Japan

[5] Department of Ophthalmology, Faculty of Medicine, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8575, Japan

[6] Nagoya Eye Clinic, 24-14 Namiyose, Atsuta-ku, Nagoya, Aichi 456-0003, Japan

[7] School of Allied Health Sciences, Visual Physiology, Kitasato University, 1-15-1 Kitasato, Minami, Sagamihara, Kanagawa 252-0373, Japan

[8] Roppongi Shiba Eye Clinic, Minato-ku, Tokyo, Japan

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Introduction

Advancements in measurement technology, surgical procedures, and innovation of the intraocular lens (IOL) have significantly improved the accuracy of cataract surgery [1, 2]. However, the precision of IOL power calculations for eyes with corneal abnormalities, such as post-myopic laser vision correction (M-LVC) eyes [3, 4] and eyes after phototherapeutic keratectomy [5, 6], remains limited. Over 30 methods have been developed to correct errors in IOL power calculations for patients who have undergone myopic refractive surgery. There are two main methods for calculating IOL power for post-M-LVC eyes: 1) historical methods that use pre-LVC keratometry or refractive data and 2) nonhistorical methods that use the current biometric (namely, post-LVC) data whenever pre-LVC data are unavailable. Several no-history formulas including the Barrett True-K No History, based on the Barrett Universal II formula [7], Haigis-L [8], and Shammas [9] formulas are available on the american society of cataract and refractive surgery (ASCRS) web calculator for IOL power calculations in post-M-LVC eyes [10]. Recent studies report that the predictive accuracy of the no-history method has improved the refractive outcome even if biometric data of previous LVC is unavailable [11, 12].

The introduction of swept-source optical coherence tomography (SS-OCT)-based biometers has enhanced the precision of refractive outcomes in calculating the IOL power for normal cases [13–15]. These advanced devices are anticipated to improve the accuracy of IOL power predictions for post-M-LVC eyes. However, due to the limited number of cases, further study is required. This study aimed to evaluate the accuracy of no-history methods, including the latest formulas such as EVO 2.0 [16], Hoffer QST [17], Pearl-DGS [18] formulas, utilizing data from SS-OCT-based biometers, in a multicenter study conducted in Japan.

Methods

Study design and participants

This study was approved by the ethics committee of Miyata Eye Hospital (Identifier no. CS-377-005) and followed the tenets of the Declaration of Helsinki. The study was a retrospective review of post-myopic LVC eyes that underwent cataract extraction and IOL implantation between January 2016 and June 2023 at six surgical centers in Japan, namely, Keio University Hospital, Miyata Eye Hospital, Nagoya Eye Clinic, Shiba Roppongi Eye Clinic, Tokyo Medical Center, and Tsukuba University Hospital. All patients provided written informed consent. Inclusion criteria were patients with postoperative corrected distance visual acuity (CDVA) of 20/30 or better at one month or later. Ocular biometry was measured using the swept-source OCT-based-biometer: the IOLMaster 700 (Carl Zeiss Meditec AG), OA-2000 (Tomey Corporation), or ARGOS (Alcon). The exclusion criteria for the study were: history of ocular surgery and/or ocular trauma, the presence of significant ocular comorbidity (e.g., ocular surface diseases, corneal opacity, keratoconus, pterygium, or pseudoexfoliation syndrome), unreliable or undetectable pre-operative biometry measurements, or a history of intra- or post-operative complications.

Surgical procedure

Standard phacoemulsification surgery was performed by experienced surgeons for all patients. The surgical technique included continuous curvilinear capsulorhexis, nucleus and cortex extraction, and IOL implantation in the capsular bag. The specific IOL used was selected based on the surgeon's preference at each institution. Postoperatively, all patients were treated with steroids, antibiotics, and bromfenac sodium for 1 month. Details about the implanted IOLs are provided in Table 1.

Intraocular power calculation

The predicted refraction for each formula was calculated using the A-constant optimized by each institution for every IOL. For eyes that had undergone M-LCV surgery, the Barrett True-K No History (BTKNH), Haigis-L, and Shammas formulas were calculated using the ASCRS website. The ASCRS average formula values were obtained by averaging the predictions from three formulas: the Shammas, Haigis-L, and BTKNH formulas. The results for the Emmetropia Verifying Optical 2.0 Post Myopic LASIK/PRK (EVO 2.0), Post Myopic LASIK/PRK Hoffer QST (Hoffer QST), and Post-M-LVC PEARL-DGS (Pearl-DGS) formulas were calculated using their respective formula-specific websites.

The prediction error (PE) for each formula was calculated as the actual postoperative refraction (calculated as spherical equivalent) minus the predicted refraction for each formula. The mean numerical prediction error (ME), mean absolute prediction error (MAE), standard deviation (SD) of the prediction error, and median absolute prediction error (MedAE) were calculated for each formula, as well as the percentages of eyes that had a prediction error of ±0.50 and ±1.00 diopters (D). All calculations were performed from April to June 2024.

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Table 1. Demographic and ocular characteristics (n = 125)

Characteristic	Mean + SD	Minimum	Maximum
Age (years)	58.2 ± 9.08	34	75
Female/male	43/46	–	–
IOL power (D)	19.36 ± 2.42	14.5	25.5
Axial length (mm)	27.05 ± 1.64	24.1	31.1
Mean keratometry (D)	39.01 ± 2.06	34.1	44.85
K1 (flat)	38.62 ± 2.04	33.55	44.64
K2 (steep)	39.41 ± 2.10	34.15	45.06
Anterior chamber depth (mm)	3.42 ± 0.36	2.1	4.27
Lens thickness (mm)	4.37 ± 0.44	3.08	5.48
IOL model	Number (%)		
Alcon SN60WF	47 (37.6)		
Alcon SN60AT	18 (14.4)		
Santen LS-313	13 (10.4)		
Alcon TFNT00	9 (7.2)		
NIDEK SZ-1	9 (7.2)		
HOYA XY-1	6 (4.8)		
Alcon SV25T0	5 (4.0)		
J&J DFR00V	4 (3.2)		
Bausch FINEVISION	3 (2.4)		
J&J ZCB00V	3 (2.4)		
J&J DIB00V	2 (1.6)		
J&J ZMB00	2 (1.6)		
HOYA NY60	1 (0.8)		
J&J ZLB00	1 (0.8)		
KOWA AN6KA	1 (0.8)		
SIFI Medtech Mini WELL	1 (0.8)		

D diopter, *IOL* intraocular lens, *SD* standard deviation

Statistical analysis

The Shapiro–Wilk test was used to check for normality, and non-parametric tests were used for non-normally distributed data. Mean numerical PE was compared with zero using the 1-sample *t*-test or 1-sample Wilcoxon signed-rank test depending on the data distribution. The percentages of eyes within ± 1.0 D were assessed with the McNemar test, and P values were adjusted using the Holm correction. We compared the root-mean-square absolute error (RMSAE) and mean absolute error (MAE) of numerical PE between formulas using nonparametric heteroscedastic analysis with Holm correction [19, 20]. Spearman's test was used to assess the relationship between PE and preoperative biometric data of keratometry (K) and axial length (AL). A P-value <0.05 was considered statistically significant. The sample size was calculated to detect a difference in the median absolute error of 0.25 D between two groups; with a significance level of 5%, a statistical power of 80%, and assuming SD to 0.45 D, 104 eyes were required. In this study, 125 eyes were included. Statistical analyses were performed with JMP Pro version 14.0.0 (SAS Institute Inc.).

Results

The study included 125 eyes of 89 patients, all of whom had undergone LASIK. Table 1 summarizes the demographic, biometric data, and IOL types. Table 2 displays descriptive statistics for refractive prediction errors, including MEs, SDs, MAEs, MedAEs, RMSAEs, Max AE, and the percentages of eyes within ±0.50 D and ±1.00 D, calculated for all 125 eyes.

Only the BTKNH had ME that was not significantly different from the target of 0 D ($P = .37$). The EVO 2.0, Hoffer QST, and Pearl-DGS formulas produced hyperopic errors ($P < .05$, Fig. 1), whereas the Shammas, Haigis-L, and ASCRS average had significant myopic MEs ($P < .05$, Fig. 1). On the basis of MAE, the formulas were ranked as follows: ASCRS average (0.42D), BTKNH (0.43 D), Hoffer QST, Pearl-SDG and Shammas (0.46 D), EVO 2.0 (0.48 D), and Haigis-L (0.51 D). The BTKNH and ASCRS average demonstrated smaller RMSAE compared with the Shammas ($P < .0001$). The Hoffer QST had a smaller

Table 2. Descriptive statistics for refractive prediction errors for 125 eyes among the 6 study centers

Formulas	Mean	SD	MAE	MedAE	RMSAE	Max AE	±0.50 D(%)	±1.00 D(%)
BTKNH	− 0.04	0.60	0.43	0.30	0.60	2.50	70.4%	91.2%
ASCRS average	− 0.21	0.62	0.42	0.29	0.65	2.70	69.6%	95.2%
Hoffer QST	0.21	0.63	0.46	0.35	0.66	2.83	70.4%	91.2%
EVO 2.0	0.25	0.65	0.48	0.37	0.69	2.65	68.8%	84.8%
Shammas	− 0.30	0.66	0.46	0.36	0.73	2.85	66.4%	91.2%
Pearl-DGS	0.42	0.65	0.46	0.36	0.77	3.22	67.2%	89.6%
Hagis-L	− 0.26	0.73	0.51	0.38	0.77	2.64	63.2%	89.6%

ASCRS American Society of Cataract and Refractive Surgery, *BTKNH* Barrett True-K No History, *D* diopters, *EVO* Emmetropia Verifying Optical, *MAE* mean absolute prediction error, *ME* mean prediction error, *MedAE* median absolute prediction error, *RMSE* root mean square error, *SD* standard deviation of the prediction error; ±0.50 and ±1.00 *D* = percentage of eyes with a prediction error within ±0.50 D and ±1.00 D. Formulas are ranked by root mean square absolute error (RMSAE).

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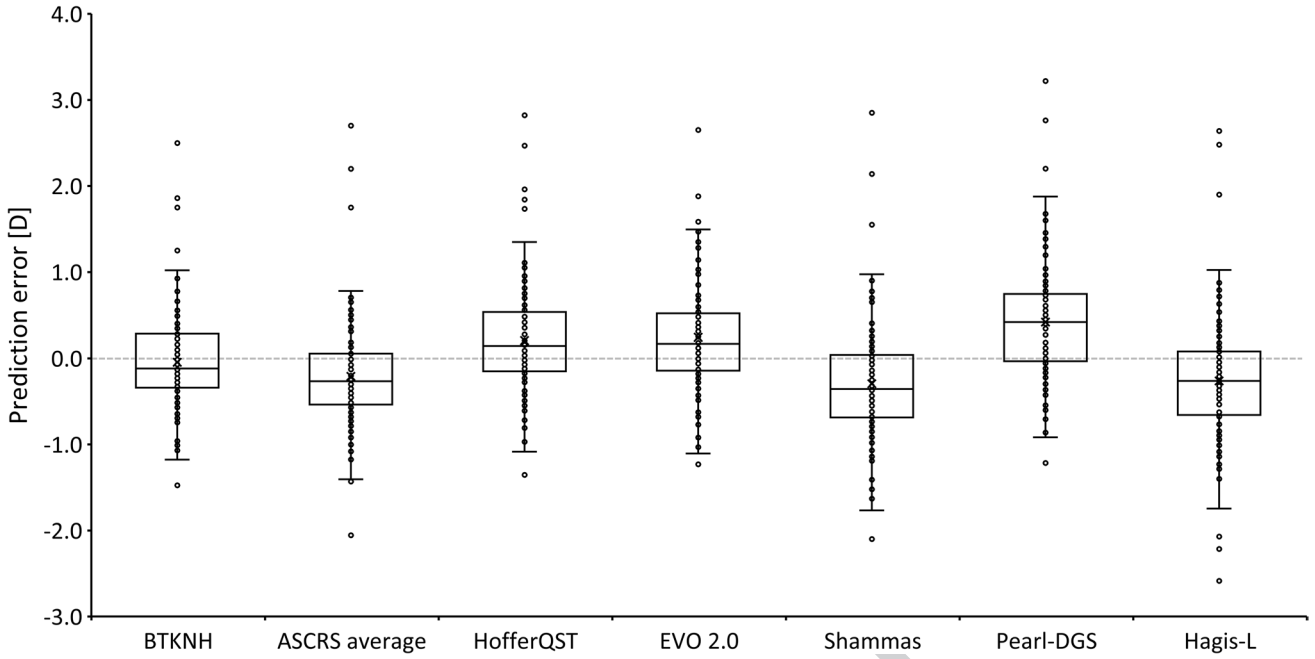


Fig. 1. Box plots illustrating the numerical prediction errors in refraction with intraocular lens calculation formulas. *ASCRS* American Society of Cataract and Refractive Surgery; *BTKNH* Barrett True-K No History; *EVO* 2.0 Emmetropia Verifying Optical 2.0

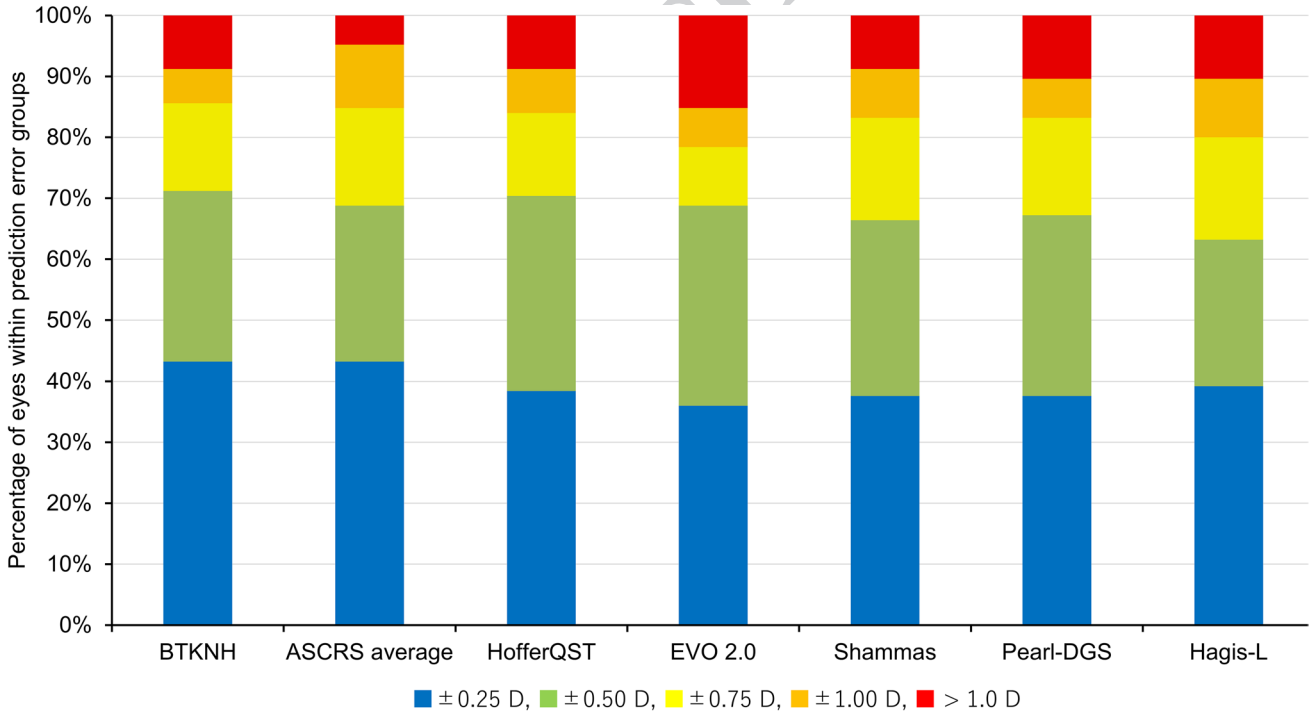


Fig. 2. Stacked histogram showing the percentage of eyes within ±0.25 diopter (D), ±0.50 D, ±0.75 D, ±1.0 D, and >1.0 D range of prediction error. *ASCRS* American Society of Cataract and Refractive Surgery; *BTKNH* Barrett True-K No History; *EVO* 2.0 Emmetropia Verifying Optical 2.0

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RMSAE than the Pearl-DGS ($P = 0.02$). The BTKNH and Hoffer QST had a statistically significant lower MAE compared with the Pearl-DGS ($P < .0001$ and 0.04, respectively). The formula prediction accuracy within ±1.0 is shown in Table 2 and Fig. 2. A statistically significant difference in the prediction accuracy within ±1.0 D was observed: BTKNH vs. Shammas and Pearl-DGS, ASCRS average vs. Hoffer QST and Pearl-DGS, Haigis-L vs Pearl-DGS, and Shammas vs. Hoffer QST and Pearl-DGS ($P < 0.001$, respectively).

Figure 3 presents the correlation between PE and preoperative biometric parameters including AL and mean K. Shammas, Hoffer QST, and Pearl-DGS had weak positive correlations between AL and PE (r range between 0.26 and

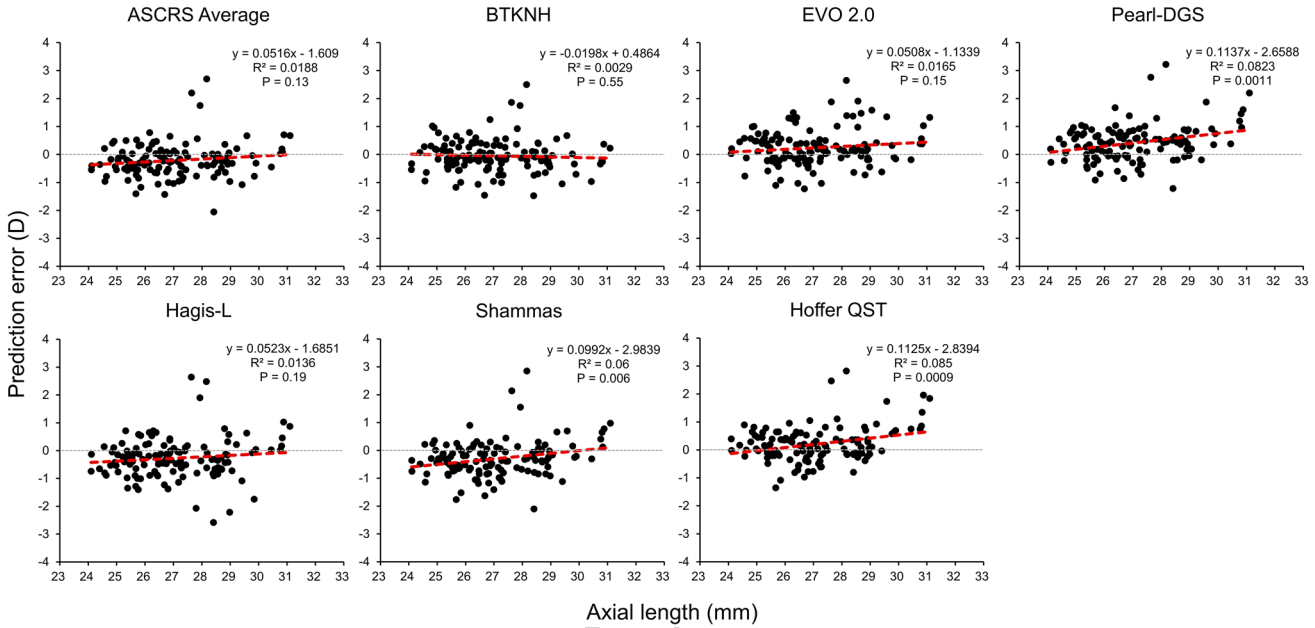


Fig. 3. Scatterplot of numerical prediction error versus axial length value for each formula. *ASCRS* American Society of Cataract and Refractive Surgery; *BTKNH* Barrett True-K No History, *EVO* 2.0 Emmetropia Verifying Optical 2.0., R^2 coefficient of determination

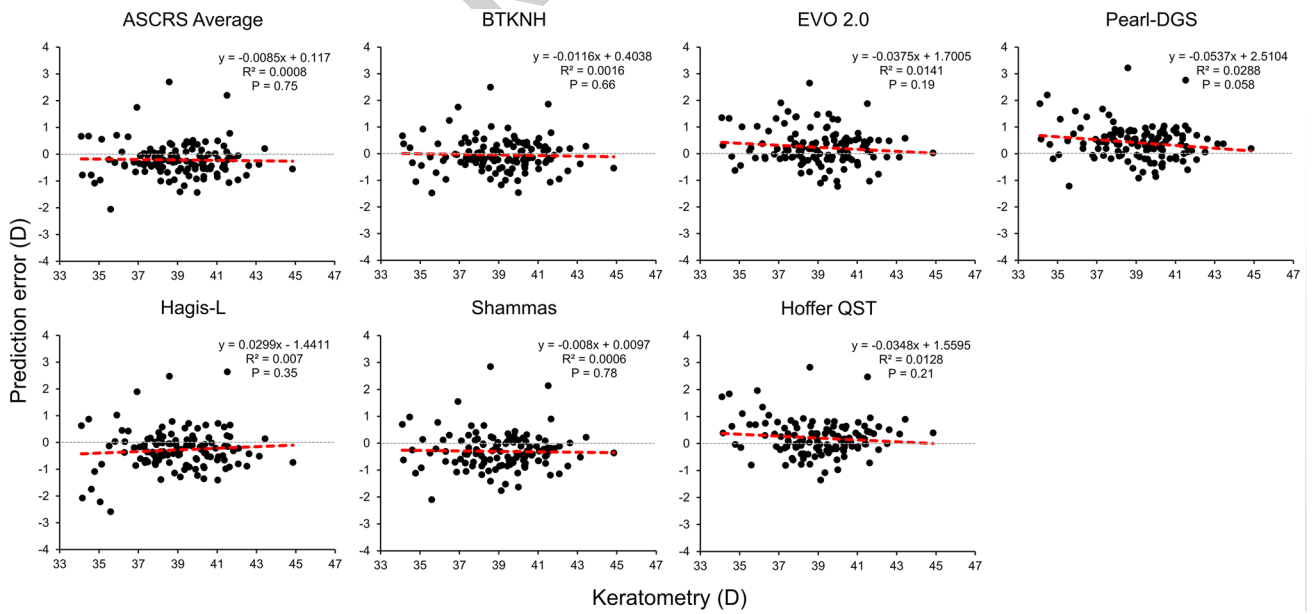


Fig. 4. Scatterplot of numerical prediction error versus keratometry value for each formula. *ASCR* American Society of Cataract and Refractive Surgery, *BTKNH* Barrett True-K No History, *EVO* 2.0 Emmetropia Verifying Optical 2.0., R^2 coefficient of determination

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0.29, $P < 0.05$). However, no correlation was found between mean K and PE (Fig. 4).

Discussion

This study analyzed the available no-history methods of IOL power calculation in Japanese eyes with a history of M-LVC, including recent no-history post-M-LVC formulas and formulas from the ASCRS calculator. We evaluated the refractive prediction accuracy of seven IOL power calculation formulas in 125 eyes from 89 patients. The well-established ASCRS methods, including BTKNH, Haigis-L, Shammas, and ASCRS average, were compared with three recently introduced formulas: EVO 2.0, Hoffer QST, and Pearl DGS. All biometric measurements were obtained using the SS-OCT-based biometer. The results indicate that the BTKNH and ASCRS average formulas yielded the best outcomes, followed by the Hoffer QST formula.

The BTKNH and ASCRS average formulas demonstrated superior performance in Japanese post-M-LVC eyes, achieving prediction errors within 1.0 D for 91.2 and 95.2% of cases, respectively, with the Hoffer QST formula performing similarly at 92.1%. These results surpass those reported in earlier studies [3, 4, 21], suggesting that differences in patient demographics and other variables might account for the discrepancy [22], warranting further investigation. One potential factor is the use of SS-OCT-based devices in this study, as opposed to partial coherence interferometry (PCI). A previous study involving post-M-LVC 302 eyes measured by PCI with the IOLMaster 500 (Carl Zeiss Meditec AG) showed prediction errors within 1.0 D for 76.8% of eyes using the BTKNH, and 81.5% using the Hoffer QST formula [11]. On the other hand, recent studies using SS-OCT-based biometer data in 576 and 56 post-M-LVC eyes reported prediction errors within 1.0 D for 91 and 93% of eyes using the BTKNH, and 89 and 79% using the Hoffer QST formula [23, 24], which aligns closely with the findings of this study.

Interestingly, while recent studies report high predictive accuracy for the EVO 2.0 and Pearl-DGS formulas in different populations [12, 25], our results did not replicate these findings. Both EVO 2.0 and Pearl-DGS formulas produced hyperopic errors and performed less favorably compared to the BTKNH and ASCRS average formulas. This discrepancy may be attributed to the lack of prior evaluations in Japanese populations, suggesting potential ethnic differences in biometric parameters [23].

As observed in the study by Lanza et al. [11], there is a significant relationship between AL and prediction errors in post-myopic LASIK eyes. They report that longer ALs tend to be associated with greater PEs, highlighting the importance of considering AL in IOL power calculations. In our study, similar trends were observed, particularly with the Shammas, Hoffer QST, and Pearl-DGS formulas, which exhibited weak positive correlations between AL and PE (r range between 0.26 and 0.29, $P < 0.05$). However, no significant correlation was found between mean K and PE, suggesting that AL might be more critical for certain formulas to address in enhancing refractive outcomes.

This study has several limitations. First, this was a retrospective study involving six surgical sites with multiple surgeons; thus, a non-standardized surgical technique with multiple IOL platforms was used, which may have introduced variability. Even with SS-OCT-based devices, each facility used different biometers, and manifest refractions were evaluated by multiple technicians. Because of the low number of eyes with previous M-LVC and subsequent cataract surgery, we included both eyes of some patients. We conducted similar analyses with 89 eyes from 89 cases (one eye per patient, selecting the first eye for surgery if both met criteria), yielding results consistent with those from the validation of 125 eyes (Supplemental Information 1). Additionally, the use of A-constants optimized at each facility could affect the generalizability of the results. However, the real-world nature of the data provides valuable insights into the practical applications of these formulas. All formulas used in this study were no-history methods, excluding those requiring pre-LVC data or corneal tomography-based measurements [26]. Furthermore, the predictive accuracy was evaluated using only the most commonly used monofocal IOL (Supplemental Information 2). Widely used monofocal IOLs may have significant potential for IOL power prediction in post-LASIK eyes. However, further prospective multicenter studies with larger sample sizes are warranted to validate these findings and explore the performance of different formulas in various populations.

In summary, this study evaluated seven no-history methods for IOL power calculations in Japanese eyes post-M-LVC using the data from SS-OCT-based biometer. The BTKNH and ASCRS average formulas exhibited the highest accuracy, with prediction errors within 1 D for over 84% of cases. Notably, while the Hoffer QST formula also performed well, recent innovations like EVO 2.0 and Pearl-DGS showed less favorable outcomes in our population.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10384-025-01217-z.

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