Accuracy of New Generation Intraocular Lens Calculation Formulas in Vitrectomized Eyes

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• PURPOSE: To compare the prediction accuracy of new intraocular lens (IOL) calculation formulas (Barrett Universal II [BUII], Emmetropia Verifying Optical [EVO], Kane and Ladas Super formula) and traditional formulas (Haigis, Hoffer Q, Holladay 1, and SRK/T) with Wang-Koch (WK) axial length (AL) adjustment in vitrectomized eyes.

• DESIGN: Retrospective consecutive case-series study.

• METHODS: One hundred eleven eyes of 111 patients underwent uneventful phacoemulsification and enVista MX60 implantation after vitrectomy were enrolled and divided into 4 groups according to whether the vitreous cavity was filled with silicone oil. The performance of each formula was evaluated with or without lens constant optimization.

• RESULTS: Before lens constants optimization, the mean prediction errors (MEs) of all formulas were statistically different from zero (0.14-0.46 diopters [D]) in vitrectomized eyes, except for the Kane formula. The BUII, EVO, Kane, and Haigis had relatively lower mean absolute error (MAE) and median absolute error (MedAE) with optimized constants. No significant systemic bias was found in new formulas for vitrectomized eyes with AL $>$26 mm ($P > .05$). The Hoffer Q and Holladay 1 displayed significantly hyperopic shift (0.39 and 0.51 D) for long eyes, which was corrected by the WK adjustment. There were no significant differences in the prediction accuracy of all formulas among 4 subgroups ($P > .05$).

• CONCLUSIONS: The BUII, EVO, Kane, and Haigis displayed comparable performance in vitrectomized eyes with optimized constants. In vitrectomized highly myopic eyes, the new formulas and traditional formulas with WK adjustment exhibited satisfactory prediction accuracy. Silicone oil tamponade did not affect the prediction accuracy of formulas using IOLMaster 700. (Am J Ophthalmol 2020;217:81–90. © 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).)

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Due to the continuous advances in instrumentation and surgical technique, the indications of pars plana vitrectomy (PPV) have expanded and have become a common surgical procedure for various vitreoretinal disorders, such as retinal detachment, macular hole, macular pucker, proliferative diabetic retinopathy, and vitreous hemorrhage.[1,2] One of the well-known sequela of vitrectomy is the cataract formation or acceleration,[3–5] with up to 80% within 2 years.[2,6–8] Studies have suggested that light toxicity, oxidation of lens proteins, use of intraocular gas or silicone oil, length of surgery, mechanical trauma, and increased postoperative oxygen tension within the eye may be causative factors of cataract after PPV.[4,6,7,9] Postvitrectomy cataract, such as nuclear sclerotic cataract, is clinically challenging because of the lack of vitreous support in the posterior segment and the relatively harder nucleus than in age-related cataract,[2] which increases the risk of surgical complications.[10,11]

Another challenge of postvitrectomy cataract surgery is the highly variable postoperative refractive outcomes.[12] Accurate prediction of refractive outcomes in vitrectomized eyes is difficult for multiple reasons. First, the absence of vitreous in the posterior segment can result in an unusually deep and fluctuating anterior chamber, which increases the mobility of the posterior capsule and intraocular lens (IOL) movement after surgery.[1] Furthermore, the high risk of zonular weakness and injury in vitrectomized eyes may lead to the instability of the lens capsular bag and the misalignment of IOL.[10] In addition, the replacement of the vitreous with aqueous humor or silicone oil tamponade changes the refractive index of the posterior segment, which could influence the accuracy of axial length (AL) measurement.[13,14] Finally, a relatively higher percentage of high myopia or staphylomatous eyes in this population aggravates the inaccuracy of IOL power calculation.[11] These factors make it difficult to predict the accurate effective lens position (ELP) and refractive outcomes for patients with previous PPV.

A variety of new IOL power calculations were developed to improve the prediction accuracy of refractive outcomes in the past decades. New generation formulas, such as the Barrett Universal II (BUII),[15] Emmetropia Verifying Optical (EVO)[16] (available at https://www.evoiolcalculator.

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com/calculator.aspx), Kane[16,17] (available at https://www.iolformula.com), and Ladas Super formula (LSF)[18,19] showed higher accuracy. Furthermore, the linear and nonlinear versions of Wang-Koch (WK) adjustment improved the accuracy of traditional formulas (Haigis, Hoffer Q, Holladay 1, and SRK/T) in highly myopic eyes.[20–22] However, there are limited data regarding refractive outcomes of phacoemulsification after PPV,[12,23] especially using new generation formulas and AL adjustment methods. The aim of this study is to compare the prediction accuracy of new generation IOL power calculation formulas (BUII, EVO, Kane, and LSF) and traditional formulas (Haigis, Hoffer Q, Holladay 1, and SRK/T) with WK AL adjustment in patients with previous PPV.

METHODS

THIS WAS A RETROSPECTIVE CONSECUTIVE CASE SERIES study that adhered to the previous protocol.[24] We reviewed the medical charts of patients who had phacoemulsification and IOL implantation from July 1, 2018, to June 30, 2019, at Zhongshan Ophthalmic Center, Sun Yat-sen University, Guangzhou, China. Patients previously underwent PPV were enrolled. The inclusion criteria were as follows: patients who underwent uneventful phacoemulsification after PPV and in the bag implantation of a single-piece hydrophobic acrylic IOL (enVista MX60; Bausch & Lomb Inc., Rochester, New York, USA). The exclusion criteria were as follows: 1) keratopathy, glaucoma, uveitis, ocular trauma, or lens dislocation; 2) a history of corneal refractive surgery; and 3) incomplete follow-up information. The right eye was selected if patients had bilateral cataract surgery. All procedures were performed in accordance with the Declaration of Helsinki. This study was approved by the Institutional Review Board/Ethics Committee of Zhongshan Ophthalmic Center, Sun Yat-sen University (2019KYPJ033), and informed consents were waived because only the medical records were involved.

Patients were divided into 4 groups according to whether the vitreous cavity was filled with silicone oil. The silicone oil used in our study was 5000 centistokes. Group 1 included patients without silicone oil tamponade in vitrectomy; group 2 underwent cataract surgery after silicone oil removal; group 3 underwent combined silicone oil removal and cataract surgery; and group 4 included patients with silicone oil retained after cataract surgery.

The following data were collected: age, gender, indication for PPV, use of gas or silicone oil tamponade and scleral buckle at the time of vitrectomy, time between PPV and phacoemulsification, preoperative ocular biometric parameters (axial length [AL], lens thickness [LT], corneal power, anterior chamber depth [ACD, measured from epithelium to lens], and corneal diameter [CD]) measured by IOLMaster 700 (1.80, Carl Zeiss, Oberkochen, Germany), power of IOL implanted, preoperative and postoperative best-corrected visual acuity (BCVA), and stable postoperative refraction results ≥3 months after surgery.

The accuracy of the formula was evaluated by the following steps.[25] First, each prediction error (PE) was calculated as the difference between the postoperative and formula-predicted spherical equivalent (SE) using the IOL power implanted. The BUII, EVO, Haigis, Hoffer Q, Holladay 1, Kane, LSF, and SRK/T formulas were calculated for all patients, while the Haigis, Hoffer Q, Holladay 1, and SRK/T with the first linear (WK1), second linear (WK2), and nonlinear (WKn) versions of WK AL adjustment were evaluated in patients with AL >26 mm. The mean error (ME) was the mean of all the PEs for each formula studied. The ME reflected the systemic bias of the formula. A negative and positive value indicated a trend toward myopic and hyperopic shift, respectively. In addition, the standard deviation (SD) of PE was reported. The User Group for Laser Interference Biometry constants were used to assess the ME of these formulas in real clinic practice (available at www.ocusoft.de/ulib/c1.html). Second, the absolute PE was the absolute value of each PE. The mean absolute PE (MAE) and the median absolute error (MedAE) were the mean and the median of all these values, respectively. Third, the percentage of eyes within ±0.25 diopters (D), ±0.50 D, and ±1.0 D of PE were also evaluated. The MAE, MedAE, and percentage of eyes within certain range were also evaluated after the lens constants were optimized by zeroing out the MEs of each formula.

Statistical analyses of demographic and clinical characteristics of participants in different groups were performed using 1-way analysis of variance for continuous variables and the χ^2 test for categorical variables. The BCVA was recorded in decimal units and converted to logarithm of the minimum angle resolution units for the statistical analyses. Statistical analyses of IOL power calculation formulas were performed according to the published protocol.[26] The normality of data was examined by the Kolmogorov-Smirnov test. The 1-sample t test was used to test whether the ME was significantly different from 0 because the data were normally distributed in this study. The Friedman test was performed to compare the absolute PE of different formulas. The Cochran Q test was performed to compare the percentages of cases within ±0.25 D, ±0.50 D, and ±1.0 D of PE. Multiple comparisons were corrected by the Bonferroni method and $P < .05$ was considered statistically significant. The analysis of data was performed using SPSS software (version 20.0; IBM Corp., Armonk, New York, USA).

RESULTS

IN TOTAL, 111 EYES OF 111 PATIENTS (61 MALES) WHO UNDERwent uneventful phacoemulsification and IOL implantation after PPV were enrolled. The mean age of the

TABLE 1. Demographic and Clinical Characteristics of Participants

Parameter	Overall	Group 1	Group 2	Group 3	Group 4	*P* Value
Eye, n	111	28	40	27	16	
Female, n (%)	50 (45.05)	15 (53.57)	22 (55.00)	10 (37.04)	3 (18.75)	.055
Age, year ± SD	57.59 ± 12.03	64.64 ± 8.19	55.98 ± 11.53	51.48 ± 12.93	60.25 ± 11.32	<.001[a]
Preoperative BCVA, logMAR ± SD	1.26 ± 0.55	1.04 ± 0.36	1.56 ± 0.58	1.11 ± 0.47	1.10 ± 0.59	<.001[a]
Postoperative BCVA, logMAR ± SD	0.66 ± 0.51	0.40 ± 0.38	0.72 ± 0.57	0.81 ± 0.50	0.72 ± 0.49	.017[a]
Time between PPV and PE, months ± SD	15.36 ± 17.75	21.54 ± 17.88	17.82 ± 23.04	8.70 ± 5.36	7.67 ± 2.90	.015[a]
AL, mm ± SD	25.38 ± 2.44	24.37 ± 1.84	26.13 ± 2.71	25.63 ± 2.61	24.63 ± 1.22	.017[a]
Corneal power, D ± SD	43.60 ± 1.77	43.86 ± 2.04	43.61 ± 1.78	43.62 ± 1.70	42.92 ± 1.08	.505
ACD, mm ± SD	3.10 ± 0.38	3.18 ± 0.36	3.03 ± 0.42	3.12 ± 0.37	3.09 ± 0.27	.452
LT, mm ± SD	4.57 ± 0.46	4.56 ± 0.43	4.66 ± 0.48	4.42 ± 0.47	4.67 ± 0.36	.165
CD, mm ± SD	11.95 ± 0.45	11.85 ± 0.52	12.00 ± 0.45	11.93 ± 0.43	12.08 ± 0.32	.384
IOL power, D ± SD	17.49 ± 5.63	19.79 ± 4.55	15.98 ± 6.70	16.65 ± 5.21	19.08 ± 2.30	.026[a]

ACD = anterior chamber depth (corneal epithelium to lens); AL = axial length; BCVA = best-corrected visual acuity; CD = corneal diameter; D = diopter; IOL = intraocular lens; logMAR = logarithm of the minimum angle resolution; LT = lens thickness; PE = phacoemulsification; PPV = pars plana vitrectomy; SD = standard deviation.

[a]Statistically significant ($P < .05$).

patients was 57.59 ± 12.03 years (range 15-79 years) and the mean AL was 25.38 ± 2.44 mm (range 22.15-33.43 mm). There were 28 eyes in group 1 (AL 24.37 ± 1.84 mm), 40 eyes in group 2 (AL 26.13 ± 2.71 mm), 27 eyes in group 3 (AL 25.63 ± 2.61 mm), and 16 eyes in group 4 (AL 24.63 ± 1.22 mm), respectively. Demographic and clinical characteristics of included patients are listed in Table 1. The age of groups 1 (64.64 ± 8.19 years) and 4 (60.25 ± 11.32 years) was older than that of groups 2 (55.98 ± 11.53 years) and 3 (51.48 ± 12.93 years, $P < .05$). The preoperative BCVA was lowest in group 2 (1.56 ± 0.58, $P < .05$), and the postoperative BCVA was best in group 1 (0.40 ± 0.38, $P < .05$). The time between PPV and phacoemulsification of groups 1 (21.54 ± 17.88 months) and 2 (17.82 ± 23.04 months) were longer than that of groups 3 (8.70 ± 5.36 months) and 4 (7.67 ± 2.90 months, $P < .05$). Groups 2 and 3 had the relatively longer AL and the lower power of IOL implanted than groups 2 and 3 ($P < .05$). The corneal power, ACD, LT, and CD were comparable among the 4 groups ($P > .05$). Indications for vitrectomy included retinal detachment in 68 eyes (61.26%), macular hole in 19 eyes (17.12%), macular pucker in 10 eyes (9.01%), proliferative diabetic retinopathy in 9 eyes (8.11%), and vitreous hemorrhage in 5 eyes (4.50%). The indications for PPV are listed in Supplemental Table 1. Six eyes received vitrectomy with 16% perfluoropropane (C3F8) tamponade and scleral buckles were used in 5 eyes.

The prediction outcomes of 8 IOL calculation formulas with optimized lens constants in overall are shown in Table 2 and Figure 1, A. The prediction accuracy of 15 formulas in eyes with AL >26 mm is shown in Table 3 and Figure 1, B. The percentage of cases within the ±0.25 D, ±0.50 D, ±0.75 D, ±1.0 D, and >1.0 D of PE in overall and long AL subgroup is shown in Figure 2. The MAE and MedAE of 4 subgroups are displayed in Figure 3. The prediction outcomes of IOL calculation formulas with User Group for Laser Interference Biometry constants in overall and high myopia subgroup are displayed in Supplemental Tables 2 and 3.

Before the lens constants were optimized, the MEs of all IOL calculation formulas, except for Kane, were statistically different from zero (0.14-0.46 D) in patients who underwent phacoemulsification after PPV ($P < .05$). Of the 8 formulas, the Kane was the only formula that had no significant systemic bias ($P = .184$), while the Haigis formula displayed the largest hyperopic PE (0.46 D, Supplemental Table 2). With the optimized lens constants, there were no statistically significant difference in prediction accuracy among 4 new generation formulas, Haigis and Hoffer Q ($P > .05$). However, the BUII, EVO, Kane, and Haigis displayed relatively lower MAE (0.53-0.55 D) and MedAE (0.38-0.41 D), and a higher percentage of PE within ±0.25D (29.91-36.45%), ±0.50 D (57.94-60.75%), and ±1.0D (84.11-85.98%). Among them, the EVO showed the lowest MAE (0.53 D) and the highest percentage of cases within the ±0.50 D (60.75%) and ±1.0 D (85.98%) of PE, and the prediction accuracy was significantly higher than that of Holladay 1 ($P = .007$) and SRK/T ($P = .021$). The Kane displayed the highest percentage of cases within ±0.25 D (36.45%), while the BUII showed the lowest MedAE (0.38 D). The LSF showed a higher but not statistically different MAE (0.56 D) and MedAE (0.51 D) compared with the other 3 new

TABLE 2. Predictive Outcomes of Various Intraocular Lens Formulas in Total

Formula	Group[a]	ME	SD	MAE	MedAE	Max Error	±0.25 D (%)	±0.50 D (%)	±1.0 D (%)
BUII	Total	0	0.71	0.54	0.38	2.26	30.84	57.94	85.05
	1	0.01	0.70	0.53	0.36	1.89	28.57	60.71	89.29
	2	0.02	0.75	0.58	0.42	1.59	32.50	55.00	80.00
	3	−0.05	0.77	0.55	0.36	2.26	33.33	59.26	85.19
	4	0.03	0.55	0.44	0.37	1.24	25.00	58.33	91.67
EVO	Total	0	0.70	0.53	0.40	2.28	31.78	60.75	85.98
	1	−0.02	0.68	0.52	0.40	1.75	28.57	60.71	89.29
	2	0.00	0.72	0.57	0.42	1.61	27.50	57.50	82.50
	3	−0.01	0.77	0.52	0.32	2.28	40.74	59.26	85.19
	4	0.09	0.54	0.41	0.34	1.31	33.33	75.00	91.67
Kane	Total	0	0.72	0.55	0.40	2.30	36.45	59.81	84.11
	1	0.02	0.72	0.57	0.42	1.90	32.14	53.57	85.71
	2	−0.03	0.73	0.56	0.41	1.67	40.00	52.50	82.50
	3	−0.02	0.81	0.56	0.42	2.30	40.74	66.67	81.48
	4	0.11	0.52	0.41	0.32	1.29	25.00	83.33	91.67
LSF	Total	0	0.73	0.56	0.51	2.08	34.58	49.53	85.05
	1	0.00	0.70	0.54	0.34	1.67	35.71	53.57	89.29
	2	0.01	0.79	0.64	0.59	1.64	30.00	35.00	80.00
	3	−0.04	0.76	0.54	0.34	2.08	37.04	59.26	85.19
	4	0.05	0.54	0.38	0.31	1.35	41.67	66.67	91.67
Haigis	Total	0	0.72	0.55	0.41	2.34	29.91	58.88	85.05
	1	−0.07	0.72	0.58	0.47	1.44	25.00	53.57	85.71
	2	0.07	0.74	0.57	0.44	1.95	35.00	55.00	85.00
	3	−0.03	0.81	0.56	0.35	2.34	29.63	62.96	81.48
	4	−0.01	0.50	0.40	0.35	1.10	25.00	75.00	91.67
Hoffer Q	Total	0	0.77	0.59	0.46	2.24	25.23	55.14	79.44
	1	−0.05	0.64	0.51	0.46	1.50	21.43	57.14	89.29
	2	0.08	0.87	0.69	0.54	1.61	25.00	47.50	67.50
	3	−0.04	0.82	0.60	0.40	2.24	25.93	62.96	81.48
	4	−0.05	0.57	0.44	0.43	1.23	33.33	58.33	91.67
Holladay 1	Total	0	0.83	0.63	0.49	2.69	22.43	51.40	77.57
	1	−0.07	0.81	0.58	0.38	2.69	21.43	57.14	82.14
	2	0.08	0.87	0.70	0.56	1.74	20.00	47.50	70.00
	3	−0.03	0.92	0.67	0.50	2.48	22.22	48.15	77.78
	4	−0.03	0.58	0.46	0.41	1.21	33.33	58.33	91.67
SRK/T	Total	0	0.81	0.61	0.47	2.85	27.10	52.34	84.11
	1	−0.02	0.82	0.56	0.43	2.85	28.57	64.29	89.29
	2	0.05	0.86	0.69	0.65	1.93	20.00	37.50	77.50
	3	−0.08	0.86	0.63	0.47	2.28	33.33	51.85	85.19
	4	0.08	0.55	0.42	0.35	1.29	33.33	75.00	91.67

±0.25 D (%), ±0.50 D (%), ±1.0 D (%) = percentage of refractions within ±0.25 D, ±0.50 D, or ±1.0 D of prediction error; BUII = Barrett Universal II formula; D = diopter; EVO = Emmetropia Verifying Optical formula; LSF = Ladas Super formula; MAE = mean absolute refractive prediction error; Max Error = maximum refractive prediction error; ME = mean refractive prediction error; MedAE = median absolute error; SD = standard deviation of the refractive prediction error.

[a]Group 1, without silicone oil tamponade. Group 2, underwent cataract surgery after silicone oil removal. Group 3, combined silicone oil removal and cataract surgery. Group 4, with silicone oil retained after cataract surgery.

generation formulas. The Holladay 1 formula displayed the largest MAE (0.63 D), a relatively higher MedAE (0.49 D), and the lowest percentage of cases within the ±0.25 D (22.43%) and ±1.0 D (77.57%) range of PE. After the lens constants were optimized, there were no systemic bias in all 4 subgroups of each formula ($P > .05$). In addition, whether the MEs were zeroed out or not, the MAE and MedAE of all formulas among 4 subgroups showed no significant differences ($P > .05$).

Of the 111 vitrectomized eyes, there were 33 eyes (29.73%) with an AL >26 mm. Whether the lens constants were optimized or not, the MEs of new generation formulas (BUII, EVO, Kane, and LSF) and the traditional formulas (Haigis, Hoffer Q, Holladay 1, and SRK/T) with

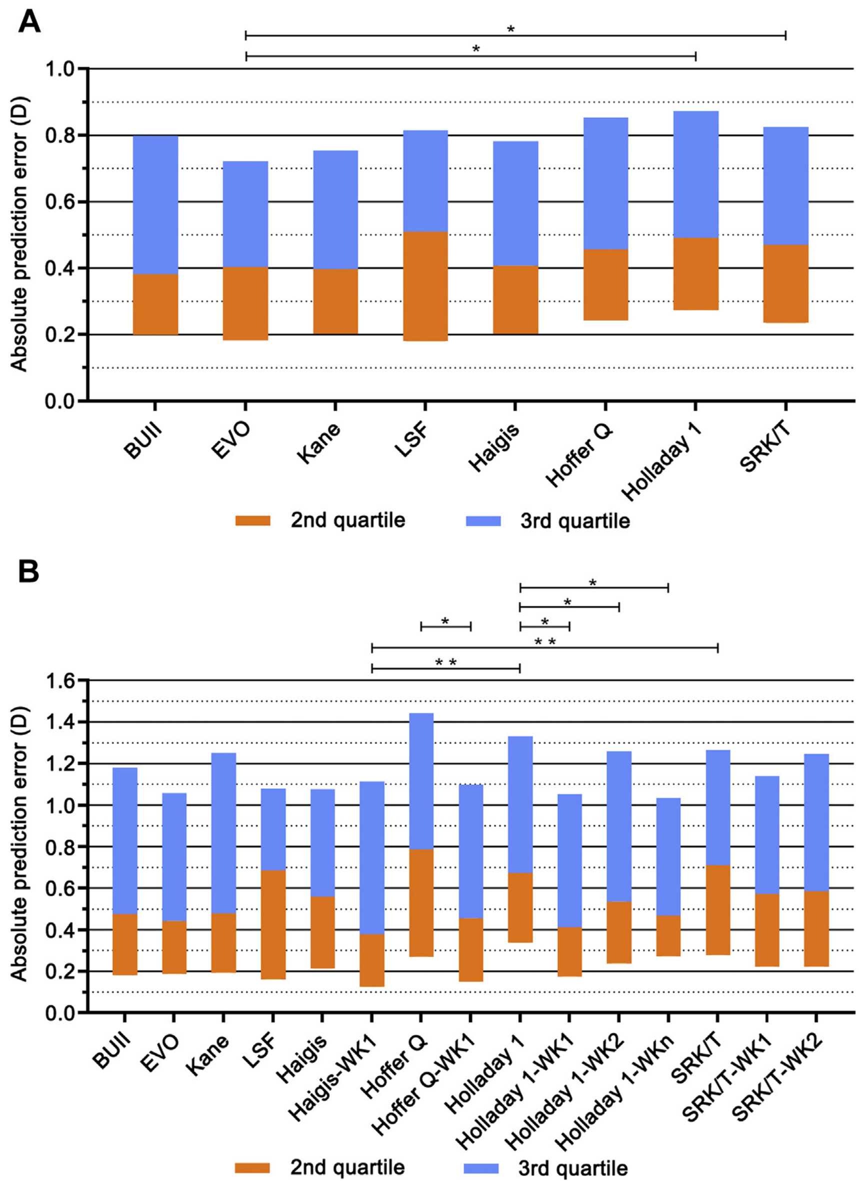

FIGURE 1. Box plots showing the absolute prediction error of intraocular lens calculation formulas in overall (A) and highly myopic subgroups with an axial length > 26 mm (B). Orange boxes represent the second quartile, and blue boxes represent the third quartile. BUII = Barrett Universal II formula; EVO = Emmetropia Verifying Optical formula; LSF = Ladas Super formula; Haigis-WK1 = Haigis with the first linear version of Wang-Koch AL adjustment; Hoffer Q-WK1 = Hoffer Q with the first linear version of Wang-Koch AL adjustment; Holladay 1-WK1 = Holladay 1 with the first linear version of Wang-Koch AL adjustment; Holladay 1-WK2 = Holladay 1 with the second linear version of Wang-Koch AL adjustment; Holladay 1-WKn = Holladay 1 with the nonlinear version of Wang-Koch AL adjustment; SRK/T-WK1 = SRK/T with the first linear version of Wang-Koch AL adjustment; SRK/T-WK2 = SRK/T with the second linear version of Wang-Koch AL adjustment. *$P < .05$, **$P < .01$.

WK adjustment showed no statistically significant difference with 0 ($P > .05$). However, the traditional formulas (Haigis, Hoffer Q, Holladay 1, and SRK/T) displayed significantly hyperopic MEs (0.47-0.84 D) without lens constants optimization (Supplemental Table 3). After the lens constants were optimized, the traditional formulas also displayed hyperopic MEs (0.25-0.51 D), whereas the MEs of Haigis (0.25 D) and SRK/T (0.29 D) were not significantly different from 0 ($P = .101$ and $P = .138$). The Hoffer Q showed the largest MedAE (0.79 D), and the Holladay 1 displayed the largest MAE (0.92 D) and the lowest percentage of cases within ±0.25 D (12.12%), ±0.50 D (36.36%), and ±1.0 D (57.58%) of PE. The WK adjustment significantly improved the accuracy of the traditional formulas (Hoffer Q and Holladay 1) in vitrectomized high myopic eyes ($P = .018$ and $P = .047$),

TABLE 3. Predictive Outcomes of Various Intraocular Lens Formulas in Patients with Axial Length >26 mm

Formula	ME	SD	*P* Value[a]	MAE	MedAE	Max Error	±0.25 D (%)	±0.50 D (%)	±1.0 D (%)
BUII	0.08	0.94	.644	0.70	0.48	2.26	30.30	54.55	69.70
EVO	0.04	0.91	.824	0.67	0.44	2.28	30.30	51.52	72.73
Kane	−0.04	0.98	.796	0.72	0.48	2.30	42.42	51.52	66.67
LSF	0.15	0.95	.379	0.74	0.69	2.08	33.33	39.39	66.67
Haigis	0.25	0.85	.101	0.68	0.56	2.34	27.27	45.45	75.76
Haigis-WK1	0.00	0.82	1.000	0.60	0.38	2.13	39.39	54.55	72.73
Hoffer Q	0.39	0.95	.027[b]	0.83	0.79	2.24	21.21	42.42	60.61
Hoffer Q-WK1	0.00	0.86	1.000	0.64	0.46	2.03	36.36	54.55	69.70
Holladay 1	0.51	1.05	.009[b]	0.92	0.67	2.69	12.12	36.36	57.58
Holladay 1-WK1	0.00	0.95	1.000	0.69	0.41	2.15	30.30	54.55	75.76
Holladay 1-WK2	0.00	0.96	1.000	0.71	0.53	2.27	24.24	45.45	72.73
Holladay1-WKn	0.16	0.95	.325	0.72	0.47	2.38	21.21	54.55	69.70
SRK/T	0.29	1.11	.138	0.87	0.71	2.85	24.24	39.39	69.70
SRK/T-WK1	0.00	1.04	1.000	0.76	0.57	2.55	30.30	48.48	75.76
SRK/T-WK2	0.00	1.06	1.000	0.79	0.58	2.56	24.24	48.48	72.73

±0.25 D (%), ±0.50 D (%), ±1.0 D (%) = percentage of refractions within ±0.25 D, ±0.50 D, or ±1.0 D of prediction error; BUII = Barrett Universal II formula; D = diopter; EVO = Emmetropia Verifying Optical formula; LSF = Ladas Super formula; MAE = mean absolute refractive prediction error; Max Error = maximum refractive prediction error; ME = mean refractive prediction error; MedAE = median absolute error; SD = standard deviation of the refractive prediction error; WK1 = first linear version of Wang-Koch axial length adjustment; WK2 = second linear Wang-Koch axial length adjustments; WKn = nonlinear version of Wang-Koch axial length adjustment.

[a]Comparison between PE and 0.

[b]Statistically significant ($P < .05$).

while it did not increase the accuracy of Haigis and SRK/T ($P = .078$ and $P = .616$). The Haigis formula with WK1 adjustment showed the lowest MAE (0.60 D), MedAE (0.38 D), and the highest percentage of cases within the ±0.50 D (54.55%) range of PE, and had significant differences with the traditional formulas Holladay 1 ($P = .006$) and SRK/T ($P = .005$).

DISCUSSION

ONE CHALLENGE OF THE POSTVITRECTOMY CATARACT surgery is highly variable refractive errors, leading to unsatisfactory surgical outcomes.[12,23] Therefore, it is critical to investigate the refractive outcomes of phacoemulsification after PPV and the accuracy of the IOL calculation formulas in this population. We for the first time compared the prediction accuracy of the new online calculators (BUII, EVO, Kane, and LSF) and the WK calculations in vitrectomized eyes using IOLMaster 700, swept-source optical coherence tomography (SS-OCT)–based biometry. Our study demonstrated that more hyperopic bias was noticed in vitrectomized eyes without lens constant optimization, except for the Kane formula. The BUII, EVO, Kane, and Haigis displayed comparable and good performance with optimized lens constants. In vitrectomized eyes with AL >26 mm, the new generation formulas and traditional formulas with WK adjustment exhibited satisfactory prediction accuracy. Furthermore, with the use of IOLMaster 700, silicone oil tamponade did not affect the prediction accuracy of formulas.

Studies regarding the refractive outcomes of phacoemulsification after vitrectomy are limited. Lee and associates[23] reported the more hyperopic shift in vitrectomized eyes (0.40 D) than the nonvitrectomized eyes (0.19 D), though there was no significant difference. The hyperopic refractive outcomes may related to the significantly deep ACD in vitrectomized eyes, thus causing a relatively more posterior ELP. In this study, traditional second- and third-generation formulas (SRK II and SRK/T) were used and AL was measured by ultrasonographic A-scan. Recently, Lamson and associates[12] reported the variable and hyperopic refractive outcomes in patients with previous vitrectomy and Holladay 2 formula[27] displayed the lowest MAE and MedAE using partial coherence interferometry. Lamson and associates[12] included a variety of IOLs in their study. In our study, only 1 type of IOL was included to avoid the profound influence of different IOL design and material, and SS-OCT (IOLMaster 700) was used. Furthermore, we evaluated the latest formulas (BUII, EVO, Kane, and LSF), which are available online and easy to use in clinical practice. Before the lens constants were optimized, more hyperopic refractive outcomes were also noted in our study for all formulas, except for the Kane formula, which displayed no statistically significant systemic bias. The

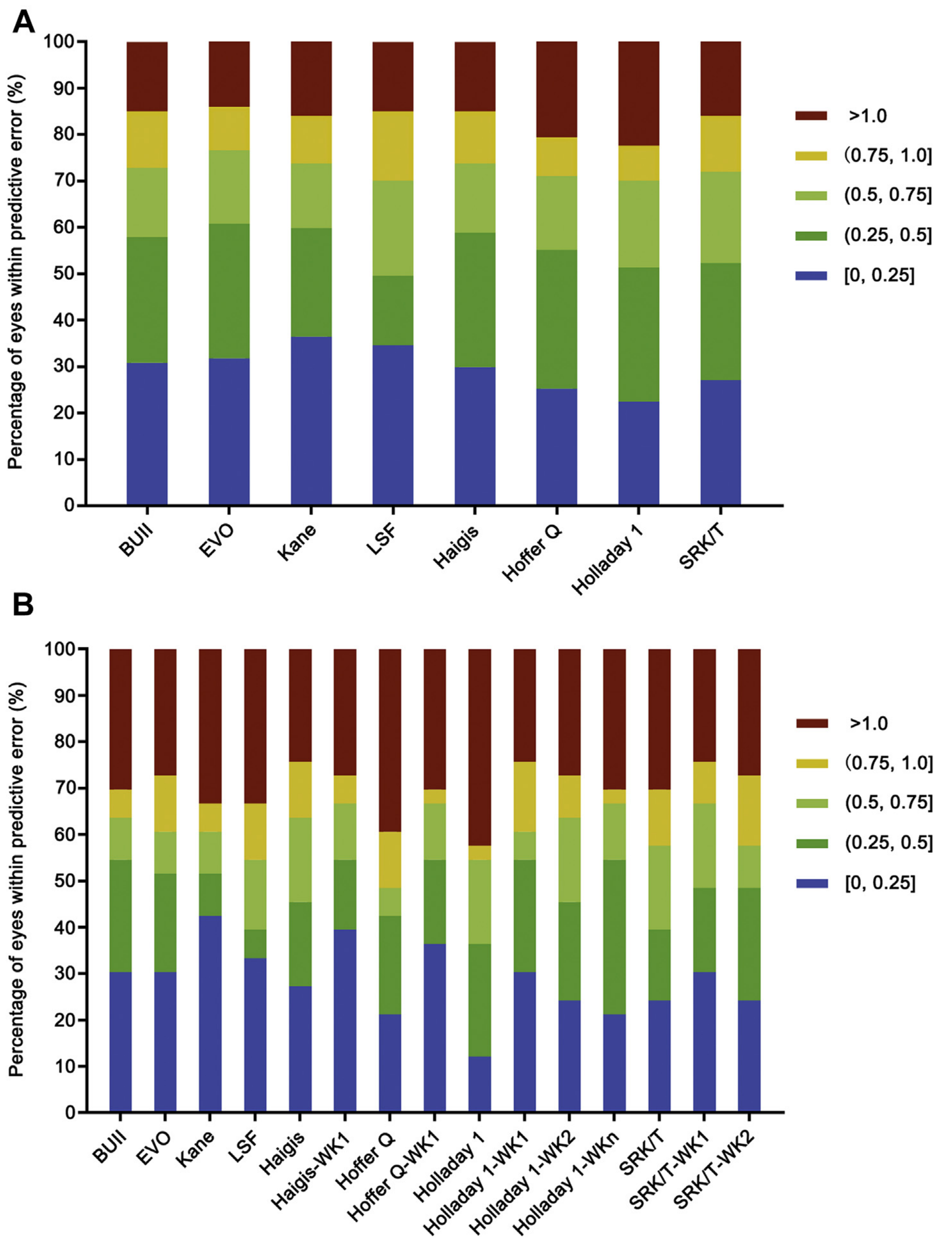

FIGURE 2. **Stacked histogram showing percentage of eyes within ±0.25 diopters (D), ±0.50 D, ±0.75 D, ±1.0 D, and > 1.0 D range of prediction error in overall (A) and highly myopic subgroups with an axial length > 26 mm (B). BUII = Barrett Universal II formula; EVO = Emmetropia Verifying Optical formula; LSF = Ladas Super formula; Haigis-WK1 = Haigis with the first linear version of Wang-Koch AL adjustment; Hoffer Q-WK1 = Hoffer Q with the first linear version of Wang-Koch AL adjustment; Holladay 1-WK1 = Holladay 1 with the first linear version of Wang-Koch AL adjustment; Holladay 1-WK2 = Holladay 1 with the second linear version of Wang-Koch AL adjustment; Holladay 1-WKn = Holladay 1 with the nonlinear version of Wang-Koch AL adjustment; SRK/T-WK1 = SRK/T with the first linear version of Wang-Koch AL adjustment; SRK/T-WK2 = SRK/T with the second linear version of Wang-Koch AL adjustment.**

BUII, EVO, Kane, and Haigis displayed relatively lower MAE and MedAE with the optimized lens constant. These findings indicate that the Kane might be the most accurate IOL calculation formula for the patient with previous vitrectomy without lens constant optimization, while the theoretical performances of BUII, EVO, Kane, and Haigis were comparable and good after lens constants are optimized. Considering that clinicians typically optimize the lens constant for all eyes in a real clinical setting, a minor myopic target refraction (−0.50 D) is suggested to compensate the hyperopic shift in traditional formulas (Haigis, Hoffer Q, and Holladay 1) if the lens constants are not

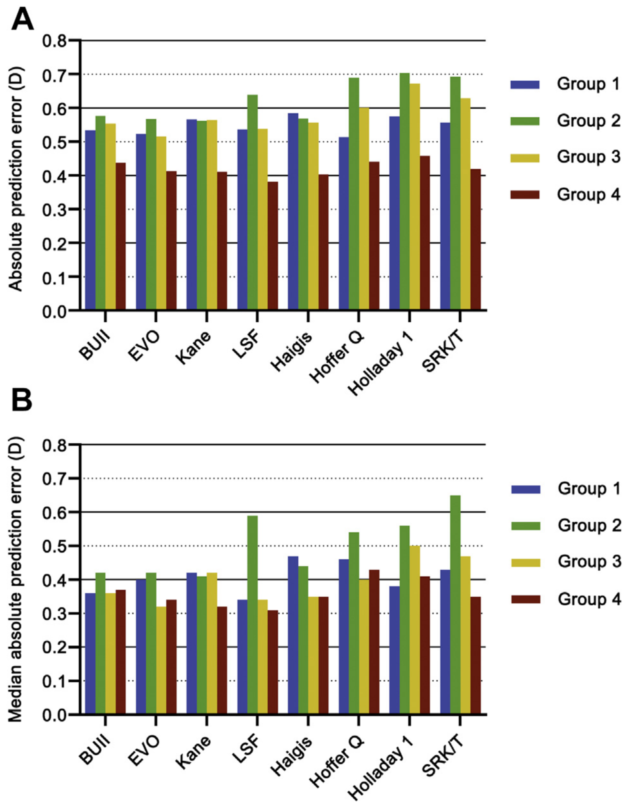

FIGURE 3. Comparison of absolute prediction errors (A) and median absolute prediction error (B) of intraocular lens calculation formulas in 4 subgroups. Group 1, Without silicone oil tamponade in vitrectomy. Group 2, Underwent cataract surgery after silicone oil removal. Group 3, Underwent combined silicone oil removal and cataract surgery. Group 4, With silicone oil retained after cataract surgery. BUII = Barrett Universal II formula; EVO = Emmetropia Verifying Optical formula; LSF = Ladas Super formula.

optimized. On some occasions, combined phacoemulsification and PPV are needed. Previous studies have reported the more myopic refractive shift[28–31] and greater MAE[30,31] in combined phacovitrectomy than in phacoemulsification alone after vitrectomy. The factors that contribute to the myopic bias in combined phacovitrectomy may include the underestimation of AL in retinal detachment,[29] intraocular gas tamponade,[28,29] preoperative foveal detachment,[32] and worse baseline BCVA.[31,32] Therefore, a slightly hyperopic target refraction is recommended in patients having combined surgery without lens constants optimization.

Patients with previous vitrectomy have a relatively high percentage of high myopia, approximately 30% in our study, which increased the challenge of IOL power calculation. Various methods of IOL power calculation for highly myopic eyes were developed in the past decades. New generation formulas, such as the BUII,[15] Kane, and Olsen,[16] as well as the traditional formulas with WK adjustment,[33] showed high accuracy for highly myopic eyes, but there is limited evidence for their accuracy in long eyes with previous vitrectomy. Lamson and associates[12] reported that the Holladay 1 and SRK/T formulas with WK1 adjustment displayed no systemic bias in vitrectomized eyes with AL >25.2 mm. However, the newly developed WK2 and WKn AL adjustments were not evaluated and the sample size of long eyes was relatively small in that study. Our study demonstrated that whether the lens constants were optimized or not, the new generation formulas and the traditional formulas with WK adjustment exhibited satisfactory prediction outcomes. However, the traditional formulas displayed hyperopic shifts, which were reduced by WK adjustment. Several studies also have reported that application of the WK AL modification resulted in a shift from hyperopic to myopic outcomes in nonvitrectomized highly myopic eyes.[15,21,22,34] Insignificant difference between hyperopic PE (0.25 and 0.29 D) and 0 in traditional formulas (Haigis and SRK/T) for long eyes may be related to the relatively small sample size and high deviation. Therefore, for vitrectomized highly myopic eyes, the new generational formulas and WK calculations are recommended for high accuracy.

In our study, silicone oil was used as tamponade during PPV in 3 groups except for group 1. Several studies have demonstrated that silicone oil was associated with worse postoperative BCVA, which may be caused by the reduction in inner retinal thickness and neuronal cell loss in the macular area.[35,36] In our study, the postoperative BCVA was best in group 1 and relatively worse in other 3 groups, which was consistent with previous studies. It has been reported that the extent of silicone oil emulsification was more severe in younger patients.[37] Therefore, silicone oil is recommended to be removed once the vitreoretinal disorders are stationary, especially in young patients. In our study, the silicone oil was removed in patients in groups 2 and 3, who were younger than those in groups 1 and 4. Combined phacoemulsification and silicone oil removal could avoid further surgery and was optimal for patients with visually significant cataract formation in a short time after vitrectomy with silicone oil tamponade. In addition, intravitreal silicone oil should be retained in some complicated cases to achieve a long-term tamponade effect. However, several studies have reported the biometry in silicone oil–filled eyes is challenging because of the optical and sound attenuation in silicone oil, thus causing a false longer eye and postoperative hyperopic refractive errors (0.60-2.89 D).[38,39] Liu and associates[39] reported that the refractive outcomes were more variable and had a significant hyperopic shift (2.89 D) in silicone oil–filled eyes compared with simply vitrectomized eyes (0.04 D) with the use of contact A-scan echography. Kunavisarut and associates[38] found that the partial coherence interferometry–based optical biometer (IOLMaster V5.0) was more accurate in predicting the postoperative refractive error than A-scan immersion in silicone oil–filled eyes (0.60 D vs 1.79D) because of the precise measurement of AL.[13,14] Piasecka and associates[40] reported optical low-coherence reflectometry (Lenstar, Haag-Streit USA, Mason, Ohio, USA) enabled comparable refractive outcome in silicone oil–filled eyes with nonvitrectomized eyes. Recently, the IOLMaster 700, the SS-OCT–based biometry, provides an image-based measurement and better lens penetration ability and AL measurements.[41,42] So far, there were no reports regarding the accuracy of AL measurement and refractive outcomes in silicone oil–filled eyes using the IOLMaster 700. Our study shows that there were no significant differences in PE, MAE, and MedAE of all formulas among 4 subgroups, which indicates that IOLMaster 700 enables the comparable refractive outcomes in silicone oil–filled eyes as in simply vitrectomized eyes and silicone oil removed eyes.

Some limitations of this study should be addressed. First, the sample size was relatively small, which may limit the ability to detect statistically significant differences among subgroups. Future prospective studies with large series of patients are necessary. Second, the preoperative BCVA was lowest in group 2 and comparable among other groups. As worse baseline BCVA may cause poor fixation and inaccurate measurement of AL, the significant differences in preoperative BCVA between groups may affect postoperative refraction. The accuracy of postoperative manifest refraction may also be affected by the retinal pathology and relatively worse visual acuity in vitrectomized eyes, which may influence the evaluation of the IOL calculation formulas. Third, another 3 latest formulas—the radial basis function (available at https://rbfcalculator.com), Olsen, and Holladay 2 formulas—were not evaluated in this study. A portion of the study population with an AL >26 mm fell outside the target refraction range within −2.5 D of the radial basis function method. Moreover, the Olsen and Holladay 2 formulas were not included because of patents. Fourth, as only 1 type of IOL were included in this study, the findings from this study should be treated cautiously when applying to other types of IOLs. Last, as ethnicity may affect the accuracy of IOL calculation formulas, the conclusion of our study, where only Chinese ethnicity was involved, is not necessarily applicable to other ethnicity.

In summary, without lens constant optimization, more hyperopic refractive outcomes were noticed in patients with previous vitrectomy, except for the Kane formula. The BUII, EVO, Kane, and Haigis formulas displayed comparable and good performance with the optimized lens constants. As for vitrectomized highly myopic eyes, the new generation formulas and traditional formulas with WK adjustment exhibited satisfactory prediction accuracy. Slicone oil tamponade did not affect the prediction accuracy of formulas using an IOLMaster 700.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

XUHUA TAN: CONCEPTUALIZATION, METHODOLOGY, Writing - original draft, Funding acquisition. **Jiaqing Zhang:** Resources, Formal analysis. **Yi Zhu:** Writing - review & editing. **Jingmin Xu:** Investigation, Data curation. **Xiaozhang Qiu:** Investigation, Data curation. **Guangyao Yang:** Investigation. **Zhenzhen Liu:** Investigation. **Lixia Luo:** Supervision, Project administration, Funding acquisition. **Yizhi Liu:** Supervision.

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