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Accuracy of intraocular lens calculation formulas based on swept-source OCT biometer in cataract patients with phakic intraocular lens

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Abstract

Purpose To research the accuracy of intraocular lens (IOL) calculation formulas and investigate the effect of anterior chamber depth (ACD) and lens thickness (LT) measured by swept-source optical coherence tomography biometer (IOLMaster 700) in patients with posterior chamber phakic IOL (PC-pIOL).

Methods Retrospective case series. The IOLMaster 700 biometer was used to measure axial length (AL) and anterior segment parameters. The traditional formulas (SRK/T, Holladay 1 and Haigis) with or without Wang-Koch (WK) AL adjustment, and new-generation formulas (Barret Universal II [BUII], Emmetropia Verifying Optical [EVO] v2.0, Kane, Pearl-DGS) were utilized in IOL power calculation.

Results This study enrolled 24 eyes of 24 patients undergoing combined PC-pIOL removal and cataract surgery at Xiamen Eye Center of Xiamen University, Xiamen, Fujian, China. The median absolute prediction error in ascending order was EVO 2.0 (0.33), Kane (0.35), SRK/T-$WK_{modified}$ (0.42), Holladay 1-$WK_{modified}$ (0.44), Haigis-WK_{C1} (0.46), Pearl-DGS (0.47), BUII (0.58), Haigis (0.75), SRK/T (0.79), and Holladay 1 (1.32). The root-mean-square absolute error in ascending order was Haigis-WK_{C1} (0.591), Holladay 1-$WK_{modified}$ (0.622), SRK/T-$WK_{modified}$ (0.623), EVO (0.673), Kane (0.678), Pearl-DGS (0.753), BUII (0.863), Haigis (1.061), SRK/T (1.188), and Holladay 1 (1.513). A detailed analysis of ACD and LT measurement error revealed negligible impact on refractive outcomes in BUII and EVO 2.0 when these parameters were incorporated or omitted in the formula calculation.

Conclusion The Kane, EVO 2.0, and traditional formulas with WK AL adjustment displayed high prediction accuracy. Furthermore, the ACD and LT measurement error does not exert a significant influence on the accuracy of IOL power calculation formulas in highly myopic eyes implanted with PC-pIOL.

Keywords Cataract, Phakic intraocular lens, IOL calculation formula, Anterior chamber depth measurement error, IOLMaster 700

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Introduction

Owing to the commendable efficacy, predictability, reversibility and preservation of the native corneal biostructure, posterior chamber phakic intraocular lens (PC-pIOL) have emerged as a preferred therapeutic modality for individuals presenting with moderate to high degrees of myopia [1–3]. Despite the significant achievements in PC-pIOL implantation for the correction of refractive errors in recent years, there are some complications that warrant attention, including but not limited to lens opacification, endothelial cell loss, and angle-closure glaucoma [4, 5]. Cataract development, a well-recognized complication after PC-pIOL implantation [6], has been reported with an incidence rate ranging from 1.8–9.8% [7, 8]. Notably, Guber et al. reported a noteworthy 18.3% of patients with intraocular collamer lens (ICL) implantation necessitating cataract surgery a decade post-surgery [9]. Given the increasing global utilization of PC-pIOLs, it is prudent to anticipate a growing cohort of individuals necessitating PC-pIOL removal concomitant with cataract extraction and pseudophakic IOL implantation in the foreseeable future [10].

Nowadays, the precision of IOL power calculation formulas has witnessed significant enhancement with advancements in technology and data science, making the cataract surgery much more precise. Beyond common parameters such as axial length (AL) and corneal keratometry (Km), numerous additional variables, including anterior chamber depth (ACD), lens thickness (LT), central corneal thickness (CCT), and white-to-white (WTW), particularly preoperative ACD, contributes to improve the accuracy of IOL power calculation formulas [11–14]. Existing evidence posits that the presence of PC-pIOL may influence the measurement accuracy of ACD and LT in swept-source optical coherence tomography (SS-OCT) [15, 16]. The inaccurate measurement of ACD and LT would potentially affect the calculation outcome by formulas incorporating ACD or LT into calculation. Furthermore, Ouchi discerned that ACD measurement inaccuracy exerted a discernible influence on the accuracy of Haigis and Barrett Universal II (BUII) TK formulas, resulting in an approximate decrease of 0.3 D in IOL power [16]. The ACD and LT measurement errors attributed to PC-pIOL and its impact on IOL power calculation need further exploration.

Notably, the current research lacks investigations into whether the precision of IOL calculation formulas is susceptible to alterations induced by ACD and LT measurement errors in cataract patients with PC-pIOL, particularly in formulas incorporating ACD or LT into IOL power calculation. Therefore, we examined the prediction accuracy of several traditional formulas (SRK/T, Holladay 1 and Haigis) with or without Wang-Koch (WK) AL adjustment, and new-generation formulas (BUII, Emmetropia Verifying Optical [EVO] v2.0, Kane, Pearl-DGS) in patients implanted with pIOL undergoing cataract surgery, and explore the potential influence of ACD and LT measurement errors on prediction outcomes.

Materials and methods

Study Design

This was a retrospective case series study and performed in accordance with tenets of the Declaration of Helsinki. Ethical clearance was obtained from the Ethics Committee of Xiamen Eye Center of Xiamen University. We retrospectively reviewed the medical records of the patients underwent pIOL removal and phacoemulsification with pseudophakic IOL implantation at the Xiamen Eye Center of Xiamen University, Xiamen, Fujian, China, from March 2018 to October 2023. The general exclusion criteria were as follows: corneal endothelial decompensation (ECD $\leq$ 1000 cells/mm^2), glaucoma, lens or IOL dislocation, posterior capsular rupture during the surgery, ocular fundus diseases, and postoperative best corrected distance VA less than 20/40. Figure 1 shows the flowchart of study enrollment.

According to the anterior surface of the crystalline lens was identified in IOLMaster 700, we set up two subgroups. The eyes with misidentified segmentation line on the anterior surface of pIOL as the anterior surface of crystalline lens were divided into misidentification group, and correctly identified the anterior surface of crystalline lens were divided into correct identification group (Fig. 2).

Data Collection and IOL calculation formula

The data collection included demographic data, biometric characteristics, endothelium cell density (ECD), as well as preoperative and postoperative corrected distance visual acuity (CDVA). Biometry was measured by IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany), included AL, Km, ACD, LT, CCT and WTW. Instances wherein the anterior surface of the PC-pIOL led to erroneous measurements of ACD and LT were documented. Refractive spherical equivalent (SE) was collected at 1 month after surgery or later.

In this study, several traditional formulas with or without WK-AL adjustment were assessed, Haigis formula used the 1-center regression version (Haigis-WK$_{C1}$) [18], SRK/T and Holladay 1 formula used the modified version published in 2018 (SRK/T-WK$_{modified}$ and Holladay 1-WK$_{modified}$) [19]. The new-generation formulas included Kane (available at https://www.iolformula.com; accessed on November 2023), Pearl-DGS (available at http://www.iolsolver.com; accessed on November 2023), BUII (available at http://calc.apacrs.org/barrett_universal2105/; accessed on November 2023), and EVO 2.0 (available at www.evoiolcalculator.com; accessed on

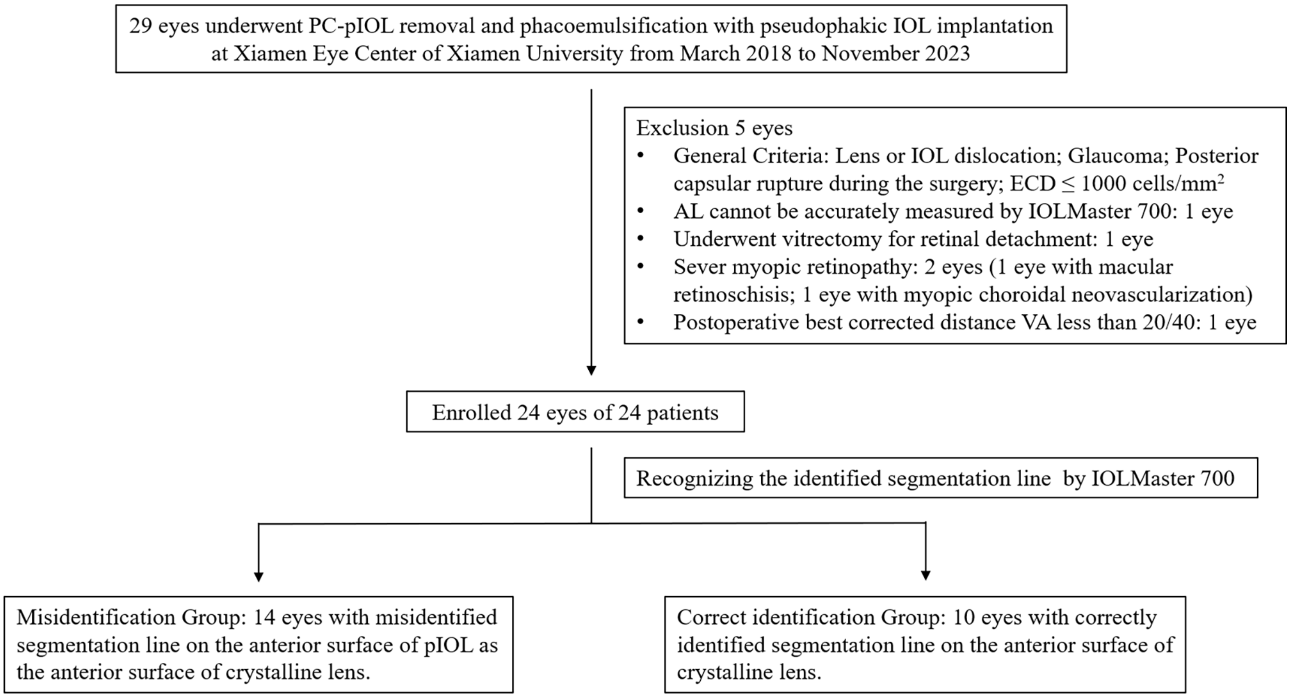

Fig. 1 Flowchart of patient enrollment

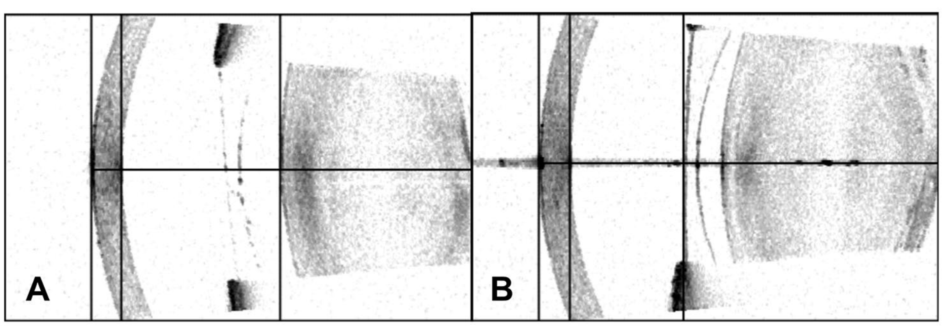

Fig. 2 The segmentation line correctly identified the anterior surface of crystalline lens (**A**) and misidentified the anterior surface of pIOL as the anterior surface of crystalline lens (**B**)

November 2023). We also assessed the outcomes of BUII and EVO 2.0 without ACD and LT into formula calculation ($BUII_{noACD+LT}$ and EVO $2.0_{noACD+LT}$). Furthermore, the Pearl-DGS formula provided an option to adjust AL after ICL implantation, and this calculation pattern was also assessed ($Pearl\text{-}DGS_{ICL}$). The constants used in this study were refer to https://iolcon.org. The Sensar AR40E (Johnson & Johnson Vision), MI60 Akreos (Bausch & Lomb), and CT ASPHINA 409MP (Carl Zeiss) were used in this study, the constants were shown in Supplementary Table 1.

Only AL and Km parameters were considered for BUII and EVO 2.0 formula calculation when ACD and LT was excluded. In contrast, when ACD was integrated into IOL power calculation, variables such as LT, CCT, WTW, or other relevant factors were entered into the formula as requested. The formulas incorporating ACD and/or LT into calculation included Haigis, $Haigis\text{-}WK_{C1}$, Kane, BUII, EVO 2.0, Pearl-DGS, and $Pearl\text{-}DGS_{ICL}$, the accuracy of formulas calculation outcomes in both the misidentification and correct identification groups was evaluated. Additionally, within the misidentification group, a comparative analysis was conducted, specifically focusing on the prediction outcomes of BUII and EVO 2.0, with and without ACD and LT incorporation into calculation ($BUII_{noACD+LT}$ and EVO $2.0_{noACD+LT}$).

Statistical analysis

To evaluate the accuracy of the formula, we calculated the refractive prediction error (PE) as the difference between the measured and predicted postoperative SE (actual refraction – predicted refraction). The mean prediction error (ME) is the average of all the PE for each formula. Statistical parameter, including ME, mean absolute prediction error (MAE), median absolute prediction error (MedAE), root-mean-square absolute prediction error (RMSAE), and percentage of eyes within ±0.25 D, ±0.5 D, ±0.75 D and ±1.0 D of the PE.

Statistical analysis was performed using SPSS software version 26.0 (IBM Corporation) and R project 4.3.0. The normal distribution of data was evaluated using the Shapiro-Wilk test. The one-sample *t* test was used to assess whether the ME was significantly different from zero. The Friedman test was used to compare the absolute prediction error of formulas. The bootstrap-t method was used to compare the RMSAE values between IOL calculation formulas and the Holm's adjusted p-value was used for multiple comparisons, according to the statistical analysis suggested by Holladay et al. [32]. and Stopyra et al. [33]. The Cochran's Q test was used to compare the proportion of eyes within ±0.25, ±0.50, ±0.75 and ±1.00 D of PE between formulas. The post-hoc Bonferroni correction was used for multiple comparisons. To compare the biometry between misidentification and correct identification groups, the normally distributed data used independent-sample *t* test and non-normally distributed data used Mann-Whitney *U* test. A *P* value of less than 0.05 was considered statistically significant.

Results

This study enrolled 24 eyes of 24 patients with PC-pIOL implantation undergoing cataract surgery, the mean age of the patients was 37.75±5.89 years, 15 females and 9 males. In total, the mean AL was 31.20±2.06 mm, Km was 44.08±1.78 D, ACD was 3.05±0.37 mm, LT was 4.38±0.35 mm, WTW was 11.80±0.45 mm, and CCT was 534.79±30.15 µm. The average IOL power was 3.98±3.88 D. The preoperative and postoperative CDVA was 0.64±0.43 and 0.14±0.23 logMAR, respectively (Table 1).

Accuracy of IOL Power Calculation Formulas

The prediction outcomes of formulas are shown in Table 2. Among the formulas, the ME of Kane, SRK/T-$WK_{modified}$, Holladay 1-$WK_{modified}$, and Haigis-WK_{C1} displayed no significant difference from zero (P=0.256, P=0.413, P=0.995, and P=0.530, respectively). The myopic shift was found in Kane and SRK/T-$WK_{modified}$, and the hyperopic shift was found in SRK/T, Holladay 1, Haigis, Haigis-WK_{C1}, BUII, $BUII_{noACD+LT}$, EVO 2.0, EVO $2.0_{noACD+LT}$, Pearl-DGS, and Pearl-DGS_{ICL}.

Comparing the MedAE, the best results were obtained by EVO 2.0 (0.33), Kane (0.35), SRK/T-$WK_{modified}$ (0.42), Holladay 1-$WK_{modified}$ (0.44), and Haigis-WK_{C1} (0.46), and the worst by Haigis (0.75), SRK/T (0.79), and Holladay 1 (1.32). The MedAE among formulas had significant difference (P<0.001). In terms of the RMSAE, the Haigis-WK_{C1} obtained the lowest RMSAE (0.591), followed by Holladay 1-$WK_{modified}$ (0.622), SRK/T-$WK_{modified}$ (0.623), EVO $2.0_{noACD+LT}$ (0.670), EVO 2.0 (0.673), Kane (0.678), and the Haigis (1.061), SRK/T (1.188), Holladay 1 (1.513) yielded the highest RMSAE. The detailed comparison outcomes of the RMSAE were shown in Supplementary Table 2.

Comparing the proportion of eyes within ±0.25, ±0.50, ±0.75 and ±1.00 D of PE between formulas (Fig. 3), no significant difference was found in PE within ±0.25 D between formulas (P=0.573), but PE within ±0.5 D, ±0.75 D and ±1.0 D were significantly different (P=0.005, P<0.001, and P<0.001, respectively). Most formulas achieved a percentage of >50% within the ±0.5 D category. Kane demonstrated the highest percentage (62.5%), followed by EVO 2.0, EVO $2.0_{noACD+LT}$, and Haigis-WK_{C1} (both 58.3%). SRK/T, Holladay 1, and Haigis had low percentage of PE within ±0.5 D, with a noticeable increase in percentage facilitated by WK-AL adjustment (54.2–58.3%).

Table 1 Characteristic biometric parameters

Characteristic	Overall (*n*=24, eyes)	Misidentification (*n*=14, eyes)	Correct Identification (*n*=10, eyes)
AL, mm	31.20 ± 2.06	30.78 ± 2.35	31.79 ± 1.48
Km, D	44.08 ± 1.78	44.32 ± 2.05	43.75 ± 1.35
ACD, mm	3.05 ± 0.37	2.81 ± 0.23	3.38 ± 0.25
LT, mm	4.38 ± 0.35	4.46 ± 0.25	4.26 ± 0.44
WTW, mm	11.80 ± 0.45	11.95 ± 0.49	11.60 ± 0.31
CCT, µm	534.79 ± 30.15	547.29 ± 29.30	517.30 ±22.36
ECD, cells/mm^2	2590.33 ± 371.99	2597.50 ± 366.59	2580.30 ± 399.14
IOL power, D	3.98 ± 3.88	5.04 ± 4.07	2.50 ± 3.21
Preoperative CDVA (logMAR)	0.64 ± 0.43	0.49 ± 0.24	0.85 ± 0.56
Postoperative CDVA (logMAR)	0.14 ± 0.23	0.13 ± 0.21	0.16 ± 0.26

ACD = anterior chamber depth; AL = axial length; CDVA = corrected distance visual acuity; CCT = central corneal thickness; D = diopter; ECD = endothelium cell density; IOL = intraocular lens; Km = corneal keratometry; logMAR = logarithm of the minimum angle resolution; LT = lens thickness; WTW = white-to-white

Table 2 Accuracy of IOL Power Calculation Formulas (N=24)

Formula	ME±SD[a]	MAE±SD	MedAE	RMSAE	% of Eyes with PE Range			
					±0.25D	±0.50D	±0.75D	±1.0D
SRK/T	0.85±0.85[b]	0.94±0.74	0.79	1.188	25.0%	37.5%	45.8%	62.5%
SRK/T-$WK_{modified}$	-0.11±0.63	0.52±0.35	0.42	0.623	33.3%	54.2%	70.8%	91.7%
Holladay 1	1.24±0.88[b]	1.32±0.75	1.32	1.513	12.5%	16.7%	20.8%	37.5%
Holladay 1-$WK_{modified}$	0.00±0.64	0.50±0.37	0.44	0.622	33.3%	54.2%	75.0%	91.7%
Haigis	0.87±0.62[b]	0.87±0.62	0.75	1.061	20.8%	29.2%	50.0%	62.5%
Haigis-WK_{C1}	0.08±0.60	0.47±0.36	0.46	0.591	33.3%	58.3%	83.3%	95.8%
Kane	-0.16±0.67	0.49±0.48	0.35	0.678	37.5%	62.5%	79.2%	87.5%
BUII	0.42±0.77[b]	0.69±0.53	0.58	0.863	25.0%	50.0%	54.2%	75.0%
$BUII_{noACD+LT}$	0.36±0.83[b]	0.73±0.52	0.73	0.889	20.8%	45.8%	50.0%	70.8%
EVO 2.0	0.30±0.62[b]	0.53±0.43	0.33	0.673	33.3%	58.3%	70.8%	83.3%
EVO $2.0_{noACD+LT}$	0.28±0.62[b]	0.52±0.43	0.36	0.670	41.7%	58.3%	66.7%	79.2%
Pearl-DGS	0.41±0.64[b]	0.60±0.46	0.47	0.753	29.2%	54.2%	62.5%	75.0%
Pearl-DGS_{ICL}	0.43±0.64[b]	0.61±0.46	0.49	0.761	29.2%	50.0%	62.5%	75.0%

MAE = mean absolute prediction error; ME = mean refractive prediction error; MedAE = median absolute prediction error; RMSAE = root-mean-square absolute error

[a]Comparison between PE and zero

[b]Statistically significant (P < 0.05)

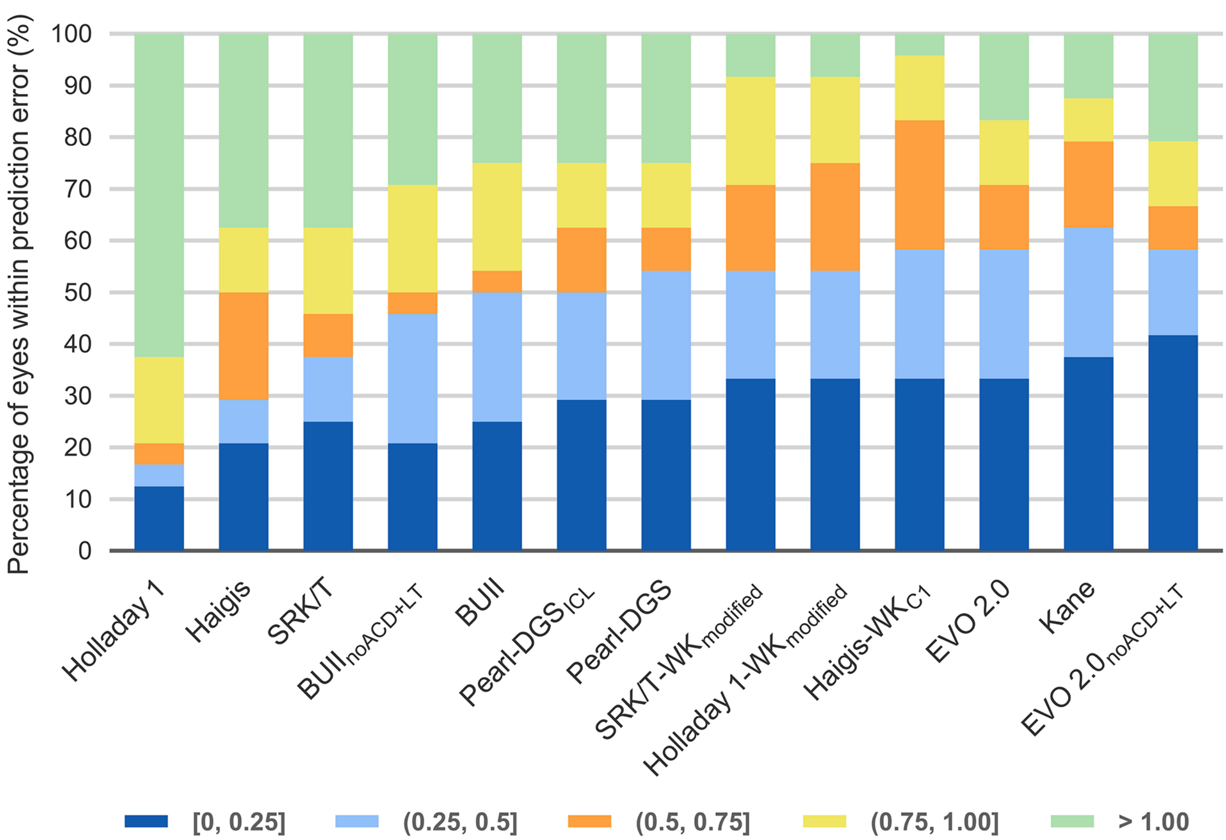

Fig. 3 Proportion of eyes with absolute PE within ±0.25, ±0.50, ±0.75 and ±1.00 D

Comparisons of misidentification and correct identification groups

In this study, a total of 14 eyes were misidentified by the IOLMaster 700, resulting in a misidentification rate of approximately 58.3%. Upon comparing the biometry between the misidentification and correct identification groups, no statistically significant differences were found in AL, Km, LT, WTW, ECD, and IOL power. For ACD, the misidentification and correct identification groups were 2.81±0.23 and 3.38±0.25, respectively (P<0.001).

No significant difference was found in preoperative and postoperative CDVA between the two groups (Table 1).

The calculation outcomes of formulas incorporating ACD into calculation in both the misidentification and correct identification groups were presented in Table 3. In the misidentification and correct identification groups, the MedAE in ascending order was Kane (0.31; 0.36), EVO 2.0 (0.33; 0.48), Haigis-WK_{C1} (0.35; 0.55), Pearl-DGS (0.43; 0.73), Pearl-DGS_{ICL} (0.43; 0.75), BUII (0.47, 0.79), Haigis (0.75, 1.06), respectively. In terms of the RMSAE, the misidentification group in ascending order was Haigis-WK_{C1} (0.458), EVO 2.0 (0.619), Pearl-DGS (0.642), Pearl-DGS_{ICL} (0.647), Kane (0.746), BUII (0.817), Haigis (0.883), and the correct identification group was Kane (0.569), Haigis-WK_{C1} (0.738), EVO 2.0 (0.743), Pearl-DGS (0.887), Pearl-DGS_{ICL} (0.898), BUII (0.925), Haigis (1.268).

Within the misidentification group, BUII and $BUII_{noACD+LT}$ exhibited ME values of 0.27±0.80 and 0.21±0.87 D, MAE was 0.63±0.54 and 0.69±0.53 D, MedAE was 0.47 and 0.53 D, and RMSAE was 0.817 and 0.862 D, respectively. For EVO 2.0 and EVO $2.0_{noACD+LT}$, ME was 0.16±0.62 and 0.15±0.60 D, MAE was 0.49±0.39 and 0.47±0.38 D, MedAE was 0.33 and 0.36 D, and RMSAE was 0.619 and 0.598 D, respectively.

Discussion

The importance of preoperative ACD as a prediction factor for IOL power calculation is only second to AL [12]. Previous study had reported that inaccurate estimations of postoperative ACD contribute substantially, accounting for 42% of the prediction error in IOL power calculation [20]. The IOLMaster 700, based on SS-OCT, stands as a widely utilized biometry measurement device in cataract surgery [21]. Nevertheless, previous studies found that the presence of PC-pIOL may lead to the misidentification of the anterior surface of PC-pIOL as the anterior surface of the lens by the IOLMaster 700 [15, 16, 22]. Zhang J et al. reported a misjudgment rate of approximately 62.5% for the IOLMaster 700 in measuring ACD and LT in cataract patients with PC-pIOL [22], similarly, it was 58.3% in our study. Therefore, it is of great significance to investigate the impact of anterior segment measurement error caused by PC-pIOL on prediction accuracy in this specific cohort.

We suppose that the IOLMaster 700 is based on the segmented measurement principle, and existence of PC-pIOL in the light pathway may alter anterior segment measurement, which contribute to the instrument mistakenly recognizing the anterior surface of the PC-pIOL as the anterior surface of the lens. Intriguingly, we observed that the measurement error of ACD and LT did not exert an influence on the prediction accuracy of formulas incorporating ACD and/or LT into calculation in this study. A prior investigation demonstrated that a 1 D discrepancy in IOL prediction error translates to approximately 0.7 D of refractive error at the spectacle plane [17]. Olsen reported that 1 mm change in ACD results in a 0.32 D refractive shift after the cataract surgery [20]. In our study, the difference in ACD between the misidentification group and correct identification group was 0.57 mm. Despite the influence of PC-pIOL on ACD and LT measurement, this minor difference would not cause significant refractive error. Meier PG et al. also reported that the presence of pIOL did not significantly affect IOL power calculation [23], aligning with our study.

Comparing with normal eyes, the highly myopic eyes have deeper ACD, Miao et al. reported that ACD of elongated eyes was approximately 2.96±0.50 mm [24]. The cases in this study were almost extremely elongated eyes, the average AL was 31.20±2.06 mm and ACD was 3.05±0.37 mm. Norrby S demonstrated that the change of ACD have less impact on the PE of formulas calculation in highly myopic eyes [25]. Similarly, Vega et al. suggested that the influence of ACD is minimal in the BUII formula calculation for eyes with AL longer than 22 mm [26]. Consequently, it is plausible to integrate error ACD and LT directly into formula calculations for highly myopic eyes without manual correction, while exercising caution in shorter eyes where the impact of error ACD and LT warrants consideration.

Table 3 Prediction outcomes of formulas incorporated ACD into calculation in misidentification and correct identification groups

Formula	Misidentification Group				Corret Identification Group			
	ME±SD	MAE±SD	MedAE	RMSAE	ME±SD	MAE±SD	MedAE	RMSAE
Haigis	0.79±0.41	0.79±0.41	0.75	0.883	0.99±0.84	0.99±0.84	1.06	1.268
Haigis-WK_{C1}	0.01±0.48	0.37±0.28	0.35	0.458	0.17±0.76	0.62±0.43	0.55	0.738
Kane	-0.33±0.69	0.52±0.56	0.31	0.746	0.08±0.59	0.46±0.36	0.36	0.569
BUII	0.27±0.80	0.63±0.54	0.47	0.817	0.63±0.71	0.76±0.55	0.79	0.925
EVO 2.0	0.16±0.62	0.49±0.39	0.33	0.619	0.50±0.58	0.58±0.49	0.48	0.743
Pearl-DGS	0.21±0.63	0.52±0.40	0.43	0.642	0.70±0.57	0.73±0.53	0.73	0.887
Pearl-DGS_{ICL}	0.22±0.63	0.52±0.40	0.43	0.647	0.72±0.57	0.74±0.54	0.75	0.898

MAE = mean absolute prediction error; ME = mean refractive prediction error;

MedAE = median absolute prediction error; RMSAE = root-mean-square absolute error

In the comparisons of IOL calculation formulas, Kane, EVO 2.0, Haigis-WK_{C1}, Holladay 1-$WK_{modified}$, and SRK/T-$WK_{modified}$ demonstrated the good calculation accuracy in both MedAE and RMSAE. The analysis of MAE, MedAE and PE within ±0.50 D among formulas revealed that Kane (0.49±0.48 D, 0.35 D, and 62.5%) and EVO 2.0 (0.53±0.43, 0.33 D, and 58.3%) performed optimally among the new-generation formulas. As previous studies have demonstrated, these two formulas showed high prediction accuracy in highly myopic eyes, Kane (0.318±0.227 D, 0.271 D, and 78.9%), and EVO 2.0 (0.314±0.216 D, 0.288 D, and 82.3%) [27]. The Kane formula uses a combination of theoretical optics, thin lens formulas, and "big data" techniques, it is based on optics and includes both regression and AI elements to improve the prediction outcomes, especially have high prediction accuracy in extreme eyeball AL [34, 35]. The EVO is a thick-lens formula based on the theory of emmetropization that generates an "emmetropia factor" for each eye, EVO version 2.0 has improved prediction for long and short AL, or steep and flat Km [35]. Within traditional formulas, the WK AL adjustment significantly improved refractive prediction accuracy. We hypothesize that the formulas which are suitable for elongated eyes may also be applicable to highly myopic patients implanted with PC-pIOL, yielding good prediction accuracy.

Notably, we compared the outcomes of EVO 2.0 and BUII with and without incorporating error ACD and LT into IOL power calculation in the misidentification group, and the results indicated that error ACD and LT did not significantly influence PE in these two formulas. However, we found the EVO $2.0_{noACD+LT}$ performed slightly better, aligning with the findings of Savini G et al. that EVO 2.0 operates more accurately without factoring in ACD [28]. This interesting observation leads us to recommend the utilization of EVO 2.0 and BUII formulas without ACD and LT incorporation in this particular group, thereby not only circumventing the potential impact of error ACD and LT but also potentially enhancing prediction accuracy.

In terms of Pearl-DGS formula, we found that the optimization calculation for patients implanted with ICL had no significant effect on prediction accuracy. Prior studies have reported that the presence of pIOL and their materials can influence ultrasound AL measurements [29, 30], but have minimal impact on optical measurements [16]. The optimization calculation in Pearl-DGS involves a slight correction of AL, guided by prior studies indicating that the presence of phakic IOLs can lead to AL measurement errors [15, 31]. We posit that the adjusted AL is approximately 0.01 to 0.02 mm, a negligible change that does not significantly affect IOL power calculation in highly myopic eyes. Our results indicate that the calculation outcomes of Pearl-DGS are almost identical to Pearl-DGS_{ICL}.

There are some limitations in this study. Firstly, the sample size was constrained, warranting a larger cohort in future investigations. Secondly, the eyes enrolled in this study were elongated AL, thus limiting the generalization of findings to normal and shorter AL eyes. Thirdly, the study exclusively employed the IOLMaster 700 due to equipment constraints, necessitating further exploration of other optical biometry measurement devices' performance. Fourthly, although optimizing the lens constants can improve the prediction accuracy of IOL power calculation formulas, it is difficult to optimize the constants in this small size, retrospective, and single-center study, thus we used the optimized constants recommended in https://iolcon.org.

In conclusion, the measurement error of ACD and LT in patients with PC-pIOL does not exert a significant influence on the prediction accuracy of IOL power calculation formulas. Among the new-generation formulas, the Kane and EVO 2.0 performed best, and the traditional formulas with WK-AL adjustment demonstrate high prediction accuracy in this specific cohort.

Abbreviations

ACD	Anterior chamber depth
AL	Axial length
CCT	Central corneal thickness
CDVA	Corrected distance visual acuity
D	Diopter
ECD	Endothelium cell density
ICL	Intraocular collamer lens
IOL	Intraocular lens
Km	Corneal keratometry
LT	Lens thickness
MAE	Mean absolute prediction error
ME	Mean prediction error
MedAE	Median absolute prediction error
PC-pIOL	Posterior chamber phakic intraocular lens
PE	Prediction error
RMSAE	Root-mean-square absolute error
SE	Spherical equivalent
SS-OCT	Swept-source optical coherence tomography
WTW	White-to-white
WK	Wang-Koch

Supplementary Information

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Supplementary Material 1

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None.

Author contributions
Zongsheng Zeng: Conceptualization, Methodology, Validation, Investigation, Data Curation, Writing-Review & Editing, and Visualization. Meiyi Zhu: Formal Analysis, Data Curation, Writing-Original Draft, Writing-Review & Editing, and Visualization. Guangbin Zhang: Conceptualization, Methodology, Resources,

Supervision, and Project administration. All authors read and approved the final manuscript.

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Data availability
The data presented in this study are included in the article. The data are not publicly available due to restrictions that apply to the availability of the data (e.g., privacy or ethical). Datasets from this study may be available upon request from the corresponding author and provided upon approval from the sponsor and in accordance with data privacy and ethical provisions.

Declarations

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Ethics approval and informed consent
The studies involving human participants were reviewed and approved by the Human Ethics Committee of Xiamen University affiliated with the Xiamen Eye Center. All participants provided written informed consent to take part in this study.

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