

Accuracy of 11 intraocular lens power calculation formulas in short eyes

Tingting Pan

Central South University

Xue Ding

Beijing Aier-Intech Eye Hospital

Weikang Bi

Beijing Aier-Intech Eye Hospital

Daguang Bi

Beijing Aier-Intech Eye Hospital

Chenxi Hu

Beijing Aier-Intech Eye Hospital

Qian Zhao

Qingdao Aier Eye Hospital

Yan Gao

Taiyuan Aier Eye Hospital

Ping Zhao

Shenyang Aier Eye Hospital

Yan Wen

Chongqing Aier Eye Hospital

Shaowei Li

lishaowei@aierchina.com

Beijing Aier-Intech Eye Hospital

Research Article

Keywords: Intraocular lens power, Calculation, Formula, short axial length, Cataract surgery

Posted Date: July 1st, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9964242/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Graefe's Archive for Clinical and Experimental Ophthalmology on September 10th, 2026. See the published version at <https://doi.org/10.1007/s00417-026-07505-9>.

Abstract

Purpose

To compare the refractive prediction accuracy of 11 intraocular lens (IOL) power calculation formulas in cataract patients with short axial length (AL), and to further evaluate the predictive performance of these formulas across different AL and keratometry (Km) subgroups.

Methods

This was a multicenter retrospective study. The predictive performance of 11 IOL calculation formulas, including Barrett Universal II (BUII), Kane, EVO, Pearl-DGS, K6, Haigis, Hoffer Q, Holladay 1, SRK/T, T2, and SRK-II, was compared. Subgroup analyses were performed according to AL and Km.

Results

Overall analysis demonstrated statistically significant differences in absolute prediction error among the formulas ($P < 0.001$). The EVO formula showed the most favourable overall performance, with the lowest mean absolute error (MAE, 0.47 D) and median absolute error (MedAE, 0.38 D). Across AL subgroups, K6 showed favorable performance in eyes with $AL \leq 21.0$ mm, whereas Hoffer Q and EVO performed well in the $21.0 < AL \leq 21.5$ mm and $21.5 < AL \leq 22.0$ mm subgroups, respectively. Across Km subgroups, EVO, K6, and Pearl-DGS showed relatively smaller changes in prediction error than several other formulas.

Conclusions

New-generation formulas, particularly EVO and K6, demonstrated relatively favorable overall performance in Chinese cataract patients with short axial length. In extremely short eyes, traditional formulas such as Haigis and Hoffer Q remained highly competitive.

Key Messages

What is known

- Short axial length eyes remain challenging for intraocular lens power calculation and are associated with higher postoperative refractive prediction errors than normal eyes.

What is new

- This multicenter Chinese study compared 11 intraocular lens power calculation formulas in eyes with axial length ≤ 22.0 mm, including both T2 and K6 formulas.
- The predictive performance of different formulas varied across axial length and keratometry subgroups, suggesting that formula selection in short eyes should consider both axial length and corneal curvature.

- Short axial length eyes remain challenging for intraocular lens power calculation and are associated with higher postoperative refractive prediction errors than normal eyes.

Introduction

With increasing patient expectations for postoperative uncorrected visual acuity and visual quality, cataract surgery has increasingly evolved from a conventional vision-restoring procedure into a refractive procedure. Accurate intraocular lens (IOL) power calculation has therefore become a critical prerequisite for achieving optimal postoperative refractive outcomes. Over recent decades, IOL calculation formulas have continuously evolved from traditional regression-based formulas to new-generation formulas integrating multiple biometric parameters, theoretical optics, and artificial intelligence optimization, many of which have demonstrated excellent predictive accuracy in eyes with normal AL. However, refractive prediction in short eyes remains substantially more challenging [1, 2].

Short eyes are generally defined as eyes with an AL ≤ 22.0 mm and are consistently associated with inferior refractive outcomes compared with normal eyes. Previous studies have reported that short eyes exhibit higher mean absolute error (MAE) values (0.31–0.76 diopters [D] versus 0.24–0.46 D) and lower percentages of postoperative refractions within ± 0.50 D of target refraction (36.0%–75.2% versus 64.4%–90.7%) than normal eyes [3]. Importantly, refractive prediction errors in short eyes may lead to clinically significant “refractive surprise,” particularly because these eyes frequently require implantation of high-power IOLs, in which even small inaccuracies in effective lens position (ELP) prediction can result in amplified postoperative refractive deviation.

Unlike normal eyes, short eyes are not simply scaled-down ocular structures but often exhibit disproportionate anterior and posterior segment anatomy, including shallow anterior chamber depth (ACD), increased lens thickness (LT), crowded anterior segment configuration, and steeper corneal curvature [4–7]. Previous studies have suggested that measurement errors in AL, ACD, and keratometry (K) contribute approximately 36%, 42%, and 22% of postoperative refractive error, respectively [8, 9]. Furthermore, because ELP prediction remains the principal source of inaccuracy in modern IOL formulas, abnormal biometric relationships in short eyes may further compromise ELP estimation accuracy. Consequently, short eyes have long been regarded as one of the most challenging conditions in IOL power calculation.

Despite substantial advances in contemporary IOL calculation formulas, the optimal formula for short eyes remains controversial. Some studies have suggested that new-generation or artificial intelligence-assisted formulas, such as Kane, EVO, and Pearl-DGS, provide superior predictive performance in short eyes [10–12], whereas other investigations have demonstrated comparable or even superior outcomes using the traditional Hoffer Q formula [13, 14]. These inconsistent findings may not solely reflect differences in sample size, biometric devices, or constant optimization strategies, but may also indicate substantial biometric heterogeneity among short eyes themselves.

Importantly, short eyes do not represent a homogeneous biometric entity. Eyes with similar AL may exhibit markedly different corneal curvature, anterior chamber configuration, and lens geometry [15, 16]. Therefore, axial length alone may be insufficient to characterize the complex biometric variability in short eyes. Nevertheless, most previous studies have primarily stratified patients according to AL, whereas the potential interaction between AL and corneal curvature has received relatively limited attention. Such simplified stratification may partly explain the inconsistent performance of different formulas across studies.

Accordingly, the present study aimed not only to compare the predictive accuracy of 11 widely used IOL calculation formulas in Chinese cataract patients with $AL \leq 22.0$ mm, but also to investigate whether formula performance is influenced by AL and mean keratometry (Km). We hypothesized that refined biometric stratification may improve individualized IOL formula selection and provide more clinically meaningful guidance for refractive optimization in short eyes.

Patients and Methods

This multicenter retrospective study included 297 patients with axial length (AL) ≤ 22.0 mm who underwent cataract surgery at four Aier Eye Hospitals in Beijing Intech, Shengyang, Chongqing, and Taiyuan from June 2023 to March 2026. The exclusion criteria included a history of ocular trauma or surgery, opaque keratopathy, uveitis, glaucoma, retinal diseases (retinal detachment, diabetic macular degeneration, macular hole), vitreous hemorrhage, intraoperative and postoperative complications (e.g., posterior capsule opacification, IOL dislocation), corrected distance visual acuity (CDVA) below 0.5 after cataract surgery, and incomplete follow-up.

All patients underwent preoperative fundus examination, and macular function was assessed by optical coherence tomography. Preoperative ocular parameters, including AL, K1, K2, ACD, measured from the corneal epithelium to the anterior lens surface, and LT were measured by IOLMaster 700 or IOLMaster 500 (Carl Zeiss Meditec AG). All cataract surgeries were performed successfully by experienced surgeons under topical anesthesia. Manifest refraction and visual acuity examinations were performed at least 4 weeks after surgery by experienced optometrists, and the spherical equivalent was recorded as actual refraction.

The implanted IOL models included CT ASPHINA 509M and AT LISA tri 839MP (Carl Zeiss Meditec AG, Jena, Germany); ADAPT-AO and AKREOS-ADAPT (Bausch & Lomb, Inc., New York, USA); MCX11ASP (Human Optics, Inc., Erlangen, Germany); SOFTEC HD, SOFTEC I, and SOFTEC HDO (Lenstec (Barbados) Inc., Barbados, USA); SN60WF, SN6AD1, SN6AT2–SN6AT9, and SND1T3 (Alcon Laboratories, Inc., Texas, USA); and AR40E, AR40M, PCB00, ZMB00, ZCB00, and ZCT225 (Johnson & Johnson Vision Care, Inc., California, USA).

For all formulas, the optimized SRK/T A-constant was obtained from the User Group for Laser Interference Biometry (ULIB; <http://ocusoft.de/ulib/>). When updated information was available on the

IOLCon platform (<https://iolcon.org/>), the latest specifications and data from that platform were used for the relevant analyses. Patients' sex and age were recorded.

Formula calculation and analysis

The following 11 IOL power calculation formulas were evaluated: BUII [17], Kane [18], EVO, Pearl-DGS [19], T2 [20], SRK/T [21], Holladay 1 [22], Haigis [23], SRK-II, K6, Hoffer Q [24].

BUII (http://calc.apacrs.org/barrett_universal2105/), Kane (<https://www.iolformula.com/>), EVO (<https://www.evoiolcalculator.com/calculator.aspx>), Pearl-DGS (<https://iolsolver.com/regular>), and T2 (<https://t2.iolpower.net/>) online IOL power calculation formulas were obtained by entering ocular parameters online. The SRK/T, Holladay 1, Haigis, and SRK-II formulas were calculated using validated Excel software (obtained from IOLMaster 700 or IOLMaster 500).

Prediction error (PE) was defined as the postoperative actual spherical equivalent minus the formula-predicted spherical equivalent. A negative PE indicated a myopic shift, whereas a positive PE indicated a hyperopic shift. Original mean error (ME) was used to assess the systematic refractive bias of each formula before optimization. To allow a fair comparison of formula precision, PE was zero-centered for each formula by subtracting the overall mean PE of that formula from each individual PE, thereby setting the overall optimized ME to 0.00 D. Because optimization was performed using the overall cohort rather than within each subgroup, subgroup-specific ME was used to evaluate residual myopic or hyperopic bias across AL and mean Km subgroups. Optimized PE was used to calculate absolute error (AE), mean absolute error (MAE), median absolute error (MedAE), and the percentages of eyes within ± 0.25 D, ± 0.50 D, ± 0.75 D, and ± 1.00 D.

For AL-based subgroup analysis, eyes were divided into three groups: $AL \leq 21.0$ mm, $21.0 < AL \leq 21.5$ mm, and $21.5 < AL \leq 22.0$ mm. For Km-based subgroup analysis, eyes were divided into six groups: $Km \leq 44$ D, $44 < Km \leq 45$ D, $45 < Km \leq 46$ D, $46 < Km \leq 47$ D, $47 < Km \leq 48$ D, and $Km > 48$ D.

Statistical analysis

Statistical analyses were performed using Microsoft Excel (Microsoft Corp., Redmond, WA, USA), SPSS version 26.0 (IBM Corp., Armonk, NY, USA), Origin 2022 (OriginLab Corporation, Northampton, MA, USA), and GraphPad Prism version 8.0 (GraphPad Software Inc., San Diego, CA, USA). The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Normally distributed variables are presented as mean $\pm$ standard deviation, whereas non-normally distributed variables are presented as median and interquartile range.

For assessment of systematic prediction bias, ME was compared with zero using a one-sample t-test for normally distributed PE data or the Wilcoxon signed-rank test for non-normally distributed PE data. Differences in optimized AE among the 11 formulas were compared using the Friedman test, followed by Bonferroni-adjusted Wilcoxon signed-rank post hoc tests when appropriate. The proportions of eyes within predefined PE ranges were compared using Cochran's Q test, followed by Bonferroni-adjusted

McNemar tests for pairwise comparisons. A two-sided P value < 0.05 was considered statistically significant.

Results

The demographic and ocular characteristics of the included patients are summarized in Table 1. A total of 297 cataract patients were analyzed, with a median age of 70 years and a predominance of female patients. The median AL was 21.59 mm, confirming the short axial length characteristics of the study population. The median ACD was 2.57 mm, while the mean K1 and K2 values were 45.64 ± 1.49 D and 46.60 ± 1.48 D, respectively.

Table 1
Demographics
of cataract
patients (n =
297)

Table 2 presents the refractive outcomes of the 11 IOL power calculation formulas in eyes with $AL \leq 22.0$ mm. Overall, based on the original PE before zero-centered optimization, Hoffer Q showed a mild myopic shift (mean PE = -0.08 D, $P < 0.05$), whereas BUII, Kane, EVO, Pearl-DGS, K6, Haigis, and SRK-II showed hyperopic tendencies, although most shifts were clinically small. Significant differences were observed among formulas in absolute prediction error ($P < 0.001$). Figure 1 illustrates the distributions of absolute prediction error and prediction error for the 11 IOL formulas in eyes with $AL \leq 22.0$ mm. Most formulas showed median prediction errors close to zero, whereas the dispersion of both prediction error and absolute prediction error varied among formulas. SRK-II showed a relatively wider distribution of absolute prediction error than the other formulas.

Table 2

Refractive prediction accuracy of 11 intraocular lens calculation formulas in eyes with axial length ≤ 22.0 mm

Refractive prediction accuracy of 11 intraocular lens calculation formulas in eyes with axial length ≤ 22.0 mm								
Original PE			Optimized PE					
Formula	ME ^a (D)	SD (D)	MAE (D)	MedAE (D)	± 0.25 D (%)	± 0.50 D (%)	± 0.75 D (%)	± 1.00 D (%)
New-generation formulas								
BUII	0.07 ^b	0.59	0.48	0.42	34.68	59.26	78.79	90.57
Kane	0.15 ^b	0.63	0.48	0.38	37.04	61.28	78.11	88.89
EVO	0.14 ^b	0.61	0.47	0.38	39.39	63.97	77.44	88.22
T2	0	0.62	0.49	0.39	34.01	60.27	78.79	88.22
Pearl-DGS	0.24 ^b	0.63	0.49	0.39	33.00	61.95	77.44	88.22
K6	0.35 ^b	0.65	0.49	0.39	37.37	63.97	77.10	87.54
Traditional formulas								
Holladay 1	0.04	0.59	0.47	0.39	37.37	61.95	80.13	88.89
SRK/T	0.01	0.63	0.51	0.41	31.31	57.58	78.79	86.53
Hoffer Q	-0.08 ^b	0.61	0.48	0.38	34.68	60.61	79.46	87.88
Haigis	0.23 ^b	0.62	0.49	0.40	34.01	60.61	77.78	87.54
SRK-II	0.43 ^b	0.63	0.55	0.45	27.95	56.23	72.39	83.16
Original ME and SD of PE were calculated before optimization and used to assess systematic bias. Optimized MAE, MedAE, and the percentages of eyes within ± 0.25 D, ± 0.50 D, ± 0.75 D, and ± 1.00 D were calculated using the optimized PE. Superscript letters indicate comparison with zero.								
AL = axial length; BUII = Barrett Universal II; EVO = Emmetropia Verifying Optical formula version 2.0; PE = prediction error; ME = mean error; SD = standard deviation; MAE = mean absolute error; MedAE = median absolute error; D = diopters.								
a Comparison between prediction error and zero.								
b Statistically significant (P < 0.05).								

Among all formulas, EVO yielded the lowest MAE (0.47 D) and MedAE (0.38 D). Pairwise comparisons with Bonferroni correction demonstrated no statistically significant differences among Kane, Holladay 1, Hoffer Q, EVO, BUII, Haigis, K6, and Pearl-DGS. In contrast, SRK-II showed significantly larger absolute

errors than EVO, Kane, Holladay 1, and K6 (all $P < 0.05$), while SRK/T also performed worse than EVO and Kane.

Figure 2 shows the distribution of eyes within predefined prediction error ranges for each IOL formula. The percentage of eyes with PE within ± 0.50 D varied from 55.22% with SRK-II to 63.97% with EVO. After excluding SRK-II, no statistically significant difference was detected among the remaining 10 formulas for this outcome ($P = 0.45$). When a stricter threshold of ± 0.25 D was applied, only Kane, EVO, K6, and Holladay 1 showed proportions greater than 40%.

The AL-based subgroup results are summarized in Table S1 and Figure S1 in Online Resource 1. Overall, the formulas with the best numerical performance within each subgroup were generally consistent with those observed in the full dataset. In eyes with $AL \leq 21.0$ mm, K6 showed the lowest median absolute error (MedAE, 0.38 D) and the highest proportion of eyes within ± 0.50 D (60.71%). Haigis also showed a low MAE and MedAE, although K6 achieved the highest proportion within ± 0.50 D. In the $21.0 \text{ mm} < AL \leq 21.5$ mm subgroup, Hoffer Q showed the lowest MAE and MedAE, as well as the highest proportion of eyes within ± 0.50 D. In the $21.5 \text{ mm} < AL \leq 22.0$ mm subgroup, EVO achieved the highest proportion of eyes within ± 0.50 D (66.99%). Overall predictive accuracy in this subgroup was numerically higher than that in the $AL \leq 21.0$ mm subgroup across most formulas.

When stratified by Km, prediction errors varied across Km subgroups among the different IOL formulas (Fig. 3). In eyes with $Km \leq 46$ D, the hyperopic prediction error generally decreased as Km increased, and most formulas showed prediction errors close to zero in the $45 \text{ D} < Km \leq 46$ D subgroup. In eyes with $Km > 46$ D, several formulas showed a shift toward myopic prediction error as Km increased. This downward trend was most evident for SRK-II and SRK/T, particularly in the $Km > 48$ D subgroup. EVO, K6, and Pearl-DGS showed smaller changes in prediction error across the Km subgroups. The Km-based subgroup results are detailed in Table S2 in Online Resource 1.

Statistical comparisons of absolute prediction error showed significant differences among formulas only in selected AL and Km subgroups. Figure S2 in Online Resource 1 shows the distribution of absolute prediction error across AL subgroups for the 11 IOL formulas. Friedman testing showed significant differences among formulas in all three AL subgroups: $AL \leq 21.0$ mm ($\chi^2 = 19.014$, $P = 0.040$), $21.0 \text{ mm} < AL \leq 21.5$ mm ($\chi^2 = 21.357$, $P = 0.019$), and $21.5 \text{ mm} < AL \leq 22.0$ mm ($\chi^2 = 33.570$, $P < 0.001$). After Bonferroni-adjusted Wilcoxon signed-rank post hoc testing, significant pairwise differences remained only in the $21.5 \text{ mm} < AL \leq 22.0$ mm subgroup. In this subgroup, SRK-II showed significantly greater absolute prediction error than T2 (adjusted $P = 0.005$), Holladay 1 (adjusted $P = 0.025$), and SRK/T (adjusted $P = 0.030$).

Figure S3 in Online Resource 1 shows the distribution of absolute prediction error across Km subgroups for the 11 IOL formulas. Friedman testing showed significant differences among formulas in the $45 \text{ D} < Km \leq 46$ D subgroup ($\chi^2 = 19.564$, $P = 0.034$), the $47 \text{ D} < Km \leq 48$ D subgroup ($\chi^2 = 22.023$, $P = 0.015$), and the $Km > 48$ D subgroup ($\chi^2 = 38.067$, $P < 0.001$). No significant differences were observed in the $Km \leq 44$ D, $44 \text{ D} < Km \leq 45$ D, or $46 \text{ D} < Km \leq 47$ D subgroups. After Bonferroni-adjusted Wilcoxon signed-rank post

hoc testing, significant pairwise differences remained only in the $K_m > 48$ D subgroup. In this subgroup, SRK-II showed significantly greater absolute prediction error than BUII (adjusted $P = 0.028$), Kane (adjusted $P = 0.044$), Holladay 1 (adjusted $P = 0.004$), and Hoffer Q (adjusted $P = 0.016$).

The proportions of eyes within ± 0.50 D were further compared using Cochran's Q test. A significant overall difference was observed only in the $K_m > 48$ D subgroup ($Q = 23.314$, $df = 10$, $P = 0.010$). However, Bonferroni-adjusted McNemar post hoc comparisons did not identify any statistically significant pairwise differences. No significant differences in the proportion of eyes within ± 0.50 D were observed in the remaining K_m subgroups or in any AL subgroup.

Discussion

To the best of our knowledge, the present study represents one of the largest multicenter investigations in a Chinese population with short axial length ($AL \leq 22.0$ mm) evaluating the predictive accuracy of multiple intraocular lens (IOL) power calculation formulas. Moreover, this is the first study based on a Chinese cohort to simultaneously include both the T2 and K6 formulas for comparative analysis.

More importantly, unlike most previous studies that stratified analyses solely according to AL, the present study further investigated the influence of K_m on prediction error, thereby providing a more comprehensive evaluation of how different biometric parameters affect formula performance. Our findings demonstrated that among the new-generation formulas, EVO and K6 showed relatively superior overall numerical performance. However, in the extremely short eye subgroup ($AL \leq 21.0$ mm), several traditional formulas, particularly Haigis and Hoffer Q, remained highly competitive. These findings suggest that, in short eyes, there is no single optimal formula applicable to all biometric profiles, and that individualized formula selection based on specific biometric profiles may be of greater clinical relevance.

Notably, although several contemporary formulas, including the Kane formula, EVO, and Pearl-DGS, have demonstrated excellent predictive accuracy in previous studies [13, 25–27, 2, 28–30], some investigations in Western populations have reported that more than 80%–90% of eyes achieved postoperative refractive outcomes within ± 0.50 D of the target refraction [2, 29, 31–33, 19, 11]. In contrast, the predictive performance observed in the present study was markedly lower than those previously reported values. Interestingly, studies conducted in Chinese populations have yielded findings more consistent with our results. This discrepancy may be related to differences in the biometric characteristics of the study population.

At present, the development datasets of most contemporary new-generation formulas are predominantly derived from Western populations. Previous studies comparing ocular biometric characteristics across different ethnic groups have demonstrated that, relative to Caucasian populations, Chinese individuals generally exhibit smaller corneal diameters, steeper keratometry (K_m), and shallower anterior chamber depth (ACD) [34–38]. Therefore, Chinese patients with short axial lengths may possess more unique ocular anatomical characteristics, and their combination of biometric parameters may not fully represent the mainstream samples used in the development or validation of new-generation formulas. This factor

may partially explain why the predictive performance of these new-generation formulas in the present study was lower than that reported in some Western studies.

Another notable finding of the current study was that several traditional formulas retained clinically meaningful performance. In particular, Holladay 1 demonstrated relatively stable performance. Similar observations have been reported by Pereira et al., Doshi et al., and Gökce et al., who found that traditional vergence formulas remained clinically relevant in short eyes despite the emergence of newer-generation formulas [13, 25, 38].

The relatively favorable performance of Haigis in eyes with $AL \leq 21.0$ mm is also noteworthy. Unlike many vergence formulas that estimate ELP predominantly through AL-dependent regression assumptions, Haigis directly incorporates preoperative measured ACD into ELP prediction. This may partly explain why the Haigis formula continues to demonstrate relatively robust performance in eyes with extremely short axial lengths. Previous studies have similarly suggested that formulas incorporating measured anterior segment parameters may perform better in eyes with unusual anatomy [23]. These findings indicate that, in eyes with highly atypical ocular anatomy, traditional formulas have not been entirely supplanted by new-generation formulas; their design grounded in optical modeling or specific biometric parameters may still confer meaningful clinical utility.

Another important strength of the present study is the incorporation of keratometry-based analysis. Previous studies on short eyes have primarily focused on axial length (AL) stratification, with relatively limited attention paid to the influence of Km on PE. In the present study, we found that in short eyes, flat corneas ($Km < 44$ D) tended to induce hyperopic shifts in most formulas, whereas steep corneas ($Km > 46$ D) were more likely to result in myopic shifts. Moreover, individual formulas showed different patterns of PE change across Km subgroups. Highly sensitive formulas, such as SRK-II and T2, demonstrated pronounced amplification of prediction errors in eyes with extreme corneal curvature, whereas formulas showing smaller PE changes, including EVO and K6, exhibited more stable predictive performance across different Km subgroups. Therefore, in short eyes with extreme corneal curvature, formulas that are less sensitive to Km variations should be preferentially considered in order to reduce the risk of postoperative refractive error.

The current study also demonstrated that formula superiority should be interpreted cautiously. Although EVO and K6 showed numerically favorable performance trends, many pairwise comparisons did not remain statistically significant after Bonferroni correction. This finding suggests that differences among contemporary leading formulas in short eyes may be relatively small and potentially clinically overlapping. Therefore, emphasizing individualized formula selection according to specific biometric characteristics may be more clinically meaningful than attempting to identify a universally superior formula.

The present study has several limitations. First, this was a retrospective multicenter study, and therefore potential selection bias may exist. Second, although the sample size of this study exceeded that of most previous studies on short eyes, the number of extremely short eyes with $AL < 21.0$ mm remained

relatively limited. Third, the high proportion of female patients in this cohort may limit the generalizability of the findings to male patients with short axial lengths. Fourth, although the mean prediction error of each formula was adjusted to zero to reduce formula-related systematic bias and to simulate the predictive performance after constant optimization, individualized constant optimization was not performed according to surgeon, IOL model, or study center. Finally, the Olsen formula, which has shown promising performance in short eyes in previous studies, [39] was not included because the participating institutions lacked the required software platform.

In conclusion, contemporary formulas including Barrett Universal II, Kane, EVO, K6, T2, and Pearl-DGS demonstrated generally favorable refractive predictability in Chinese short eyes. However, traditional formulas such as Haigis and Hoffer Q retained favorable performance in extremely short eyes, suggesting that modern AI-assisted formulas do not universally outperform conventional vergence formulas under all biometric conditions. Moreover, subgroup analysis indicated that ocular biometric interactions beyond axial length alone may substantially influence formula performance. These findings support a more individualized strategy for formula selection in short eyes and highlight the need for future formula development using ethnically diverse and highly atypical biometric datasets.

Declarations

Acknowledgements

Not applicable.

Author Contributions

Study concept and design (SWL); data collection (PT, DX, BWK, HC, BDG, QZ, ZP, GY, WY); analysis and interpretation of data (PT); writing the manuscript (PT); critical revision of the manuscript (SWL, DX, BWK); statistical expertise (PT); administrative, technical, or material support (PT); supervision (SWL).

Funding: This work was supported by Clinic Research Foundation of Aier Eye Hospital Group (Grant No. AGK2302D10).

Competing interests: The authors declare that they have no relevant financial or non-financial interests to disclose.

Ethics approval:

This study was approved by the Ethics Committee of Beijing Aier-Intech Eye Hospital Co., Ltd. (approval No. BJAIER2024IRB29) and was conducted in accordance with the Declaration of Helsinki.

Consent to participate: The requirement for informed consent was waived by the Ethics Committee because of the retrospective nature of the study and the use of anonymized clinical data.

Consent for publication: Not applicable

Data availability: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Materials availability: Not applicable

Code availability: Not applicable

References

1. Stopyra W, Langenbucher A, Grzybowski A (2023) Intraocular lens power calculation formulas—a systematic review *Ophthalmology and Therapy* 12(6): 2881–2902
2. Shrivastava AK, Nayak S, Mahobia A et al (2022) Accuracy of intraocular lens power calculation formulae in short eyes: A systematic review and meta-analysis. *Indian J Ophthalmol* 70(3):740–748
3. Gao R, Zhang J, Han X et al (2025) Intraocular lens calculation formula selection for short eyes: Based on axial length and anterior chamber depth. *BMC Ophthalmol* 25(1):21
4. Susanna BN, Ferguson TJ, Randleman JB (2025) Cataract surgery following refractive surgery: principles for success. *Asia-pacific J Ophthalmol (philadelphia Pa)* 14(4):100227
5. Yan C, Yao K (2022) Effect of lens vault on the accuracy of intraocular lens calculation formulas in shallow anterior chamber eyes. *Am J Ophthalmol* 233:57–67
6. Yuan H, Zhang J, Han X et al (2024) Accuracy of 11 intraocular lens calculation formulas in shallow anterior chamber eyes. *Acta Ophthalmol* 102(5)
7. Elhusseiny AM, Sallam AB (2023) Cataract surgery in adult eyes with short axial length. *Curr Opin Ophthalmol* 34(1):84–93
8. Kane JX, Chang DF (2021) Intraocular Lens Power Formulas, Biometry, and Intraoperative Aberrometry: A Review. *Ophthalmology* 128(11):e94–e114
9. Stopyra W (2022) Effectiveness, sensitivity, and specificity of intraocular lens power calculation formulas for short eyes (. *Turkish J Ophthalmol* 52(3):201–207
10. Nemeth G, Kemeny-Beke A, Módos LJ (2021) Comparison of accuracy of different intraocular lens power calculation methods using artificial intelligence. *Eur J Ophthalmol* 32:235–241
11. Hipólito-Fernandes D, Elisa Luís M, Gil P et al (2020) VRF-G, a New Intraocular Lens Power Calculation Formula: A 13-Formulas Comparison Study. 14:4395–4402 *Clinical Ophthalmology* (Auckland, N.Z.)
12. Rocha-de-Lossada C, Colmenero-Reina E, Flikier D et al (2021) Intraocular lens power calculation formula accuracy: comparison of 12 formulas for a trifocal hydrophilic intraocular lens (. *Eur J Ophthalmol* 31(6):2981–2988
13. Pereira A, Popovic MM, Ahmed Y et al (2021) A comparative analysis of 12 intraocular lens power formulas. *Int Ophthalmol* 41(12):4137–4150
14. Moschos MM, Chatziralli IP, Koutsandrea C (2014) Intraocular lens power calculation in eyes with short axial length. *Indian J Ophthalmol* 62(6):692–694

15. High-hyperopia database, part I: Clinical characterisation including morphometric (biometric) differentiation of posterior microphthalmos from nanophthalmos | eye. [2026-05-21].
<https://www.nature.com/articles/eye2015206>
16. High prevalence of refractive errors in an elderly population; a public health issue | BMC ophthalmology | springer nature link. [2026-05-21].
<https://link.springer.com/article/10.1186/s12886-023-02791-x>
17. Barrett GD An improved universal theoretical formula for intraocular lens power prediction (1993). J Cataract Refractive Surg 19(6): 713
18. Comparison of the kane formula with existing formulas for intraocular lens power selection | BMJ open ophthalmology. [2026-02-05]. <https://bmjophth.bmj.com/content/4/1/e000251>
19. Debellemannièrè G, Dubois M, Gauvin M et al (2021) The PEARL-DGS formula: the development of an open-source machine learning-based thick IOL calculation formula. Am J Ophthalmol 232:58–69
20. Sheard RM, Smith GT, Cooke DL (2010) Improving the prediction accuracy of the SRK/T formula: The T2 formula. J Cataract Refract Surg 36(11):1829–1834
21. Retzlaff JA, Sanders DR, Kraff MC (1990) Development of the SRK/T intraocular lens implant power calculation formula. J Cataract Refract Surg 16(3):333–340
22. Holladay JT, Prager TC, Chandler TY et al (1988) A three-part system for refining intraocular lens power calculations. J Cataract Refract Surg 14(1):17–24
23. Haigis W, Lege B, Miller N et al (2000) Comparison of immersion ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to haigis. Graefè's Archive Clin Experimental Ophthalmol 238(9):765–773
24. Hoffer KJ (2024) Hoffer formulas/. In: Aramberri J, Hoffer KJ, Olsen T et al (eds) Intraocular Lens Calculations. Springer International Publishing, Cham, pp 649–660
25. Doshi D (2017) A comparative study to assess the predictability of different IOL power calculation formulas in eyes of short and long axial length. J Clin Diagn Res
26. Kane JX, Van Heerden A, Atik A et al (2017) Accuracy of 3 new methods for intraocular lens power selection. J Cataract Refract Surg 43(3):333–339
27. Vilaltella M, Cid-Bertomeu P, Huerva V (2023) Accuracy of 10 IOL power calculation formulas in 100 short eyes (≤ 22 mm). Int Ophthalmol 43(8):2613–2622
28. Ma Y, Lin Y, Li Y et al (2023) Accuracy of new intraocular lens calculation formulas in Chinese eyes with short axial lengths. Front Med 10:1257873
29. Shammas HJ, Taroni L, Pellegrini M et al (2022) Accuracy of newer intraocular lens power formulas in short and long eyes using sum-of-segments biometry. J Cataract Refract Surg 48(10):1113–1120
30. Darcy K, Gunn D, Tavassoli S et al (2020) Assessment of the accuracy of new and updated intraocular lens power calculation formulas in 10 930 eyes from the UK national health service 46(1)
31. Voytsekhivskyy OV, Hoffer KJ, Savini G et al (2021) Clinical accuracy of 18 IOL power formulas in 241 short eyes. Curr Eye Res 46(12):1832–1843

32. Skrzypecki J, Koch DD, Wang L (2024) Performance of formulas included in the ESCRS intraocular lens power calculator. *J Cataract Refractive Surg* 50(12):1224–1229

33. Wendelstein J, Hoffmann P, Hirnschall N et al (2022) Project hyperopic power prediction: accuracy of 13 different concepts for intraocular lens calculation in short eyes. *Br J Ophthalmol* 106(6):795–801

34. Hoffer KJ, Savini G (2017) Effect of gender and race on ocular biometry. *Int Ophthalmol Clin* 57(3):137–142

35. Comparison of anterior ocular segment biometry features and related factors among american caucasians, american chinese and mainland chinese - PubMed. [2025-11-07]. <https://pubmed.ncbi.nlm.nih.gov/22172206/>

36. Hickson-Curran S, Brennan NA, Igarashi Y et al (2014) Comparative evaluation of asian and white ocular topography. *Optometry Vis Science: Official Publication Am Acad Optometry* 91(12):1396–1405

37. Accuracy of 11 intraocular lens calculation formulas in shallow anterior chamber eyes - yuan – 2024 - acta ophthalmologica - wiley online library. [2026-05-21]. <https://onlinelibrary.wiley.com/doi/10.1111/aos.16654>

38. Gökce SE, Zeiter JH, Weikert MP et al (2017) Intraocular lens power calculations in short eyes using 7 formulas *Journal of Cataract and Refractive Surgery* 43(7): 892–897

39. Olsen T (2007) Calculation of intraocular lens power: A review. *Acta Ophthalmol Scand* 85(5):472–485

Table 1

Table 1 is available in the Supplementary Files section.

Figures

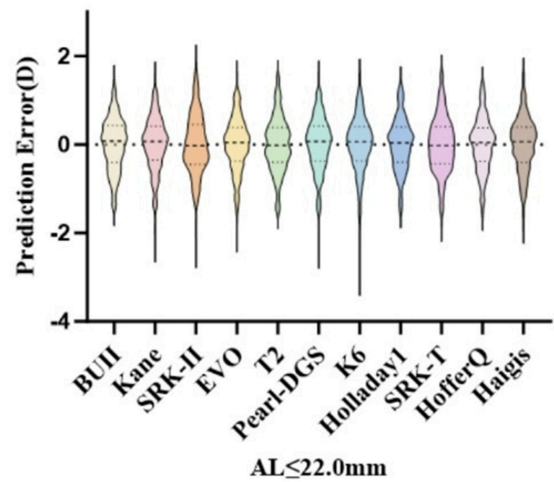
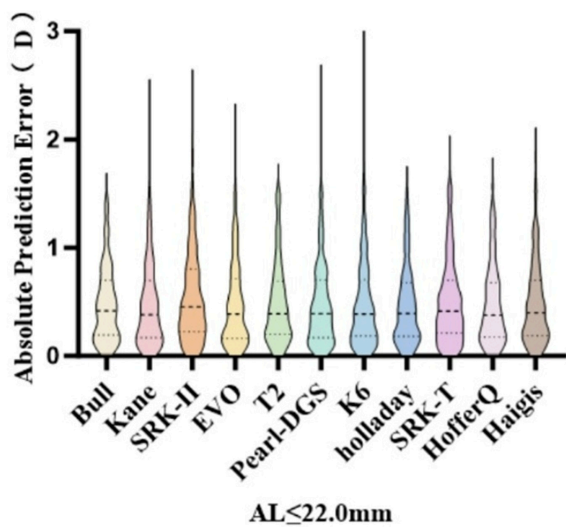


Figure 1

Violin plot of the prediction error and absolute prediction error for all formulas. D = diopters

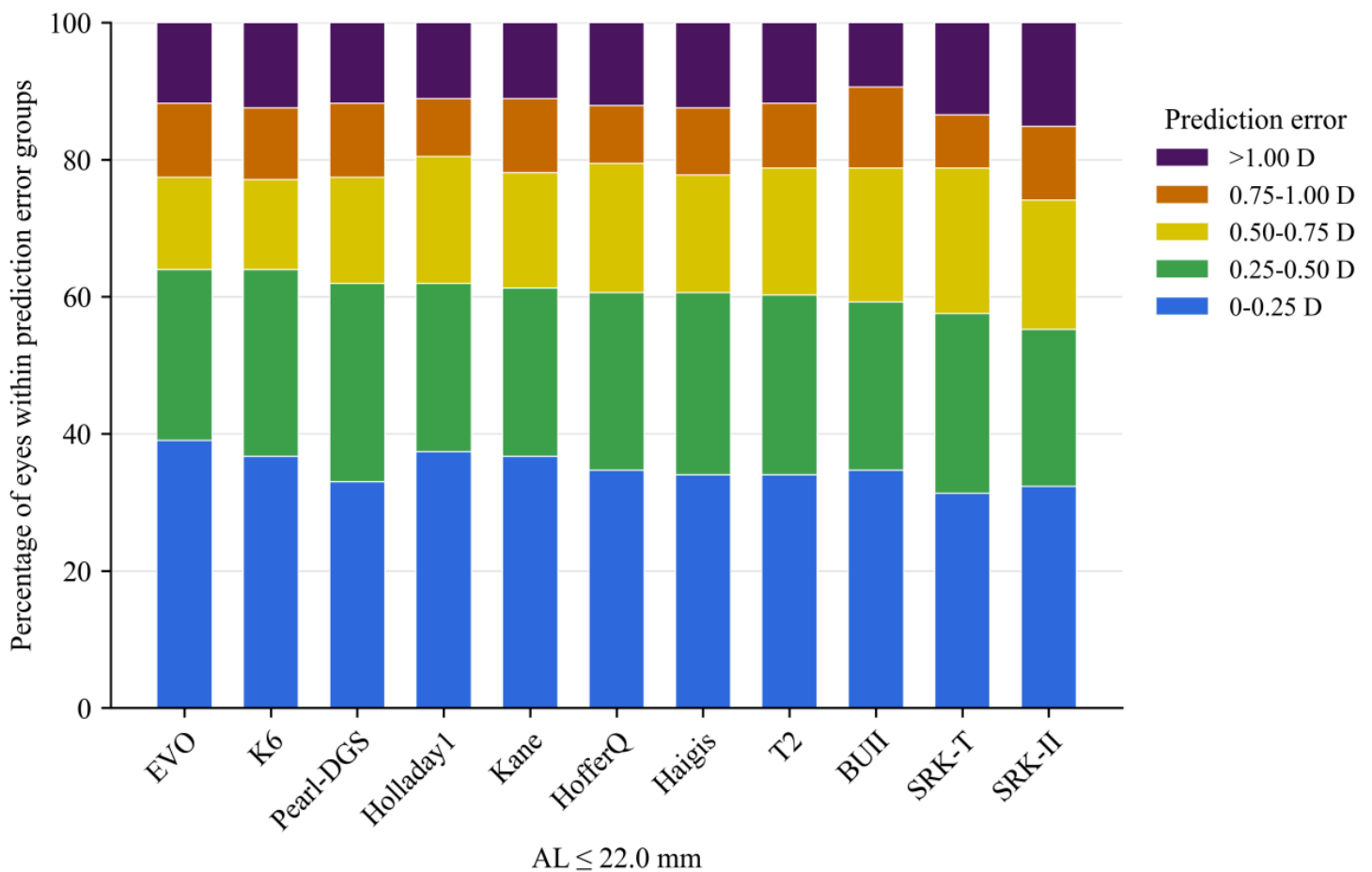


Figure 2

Absolute prediction error distribution of the 11 formulas. D = diopters

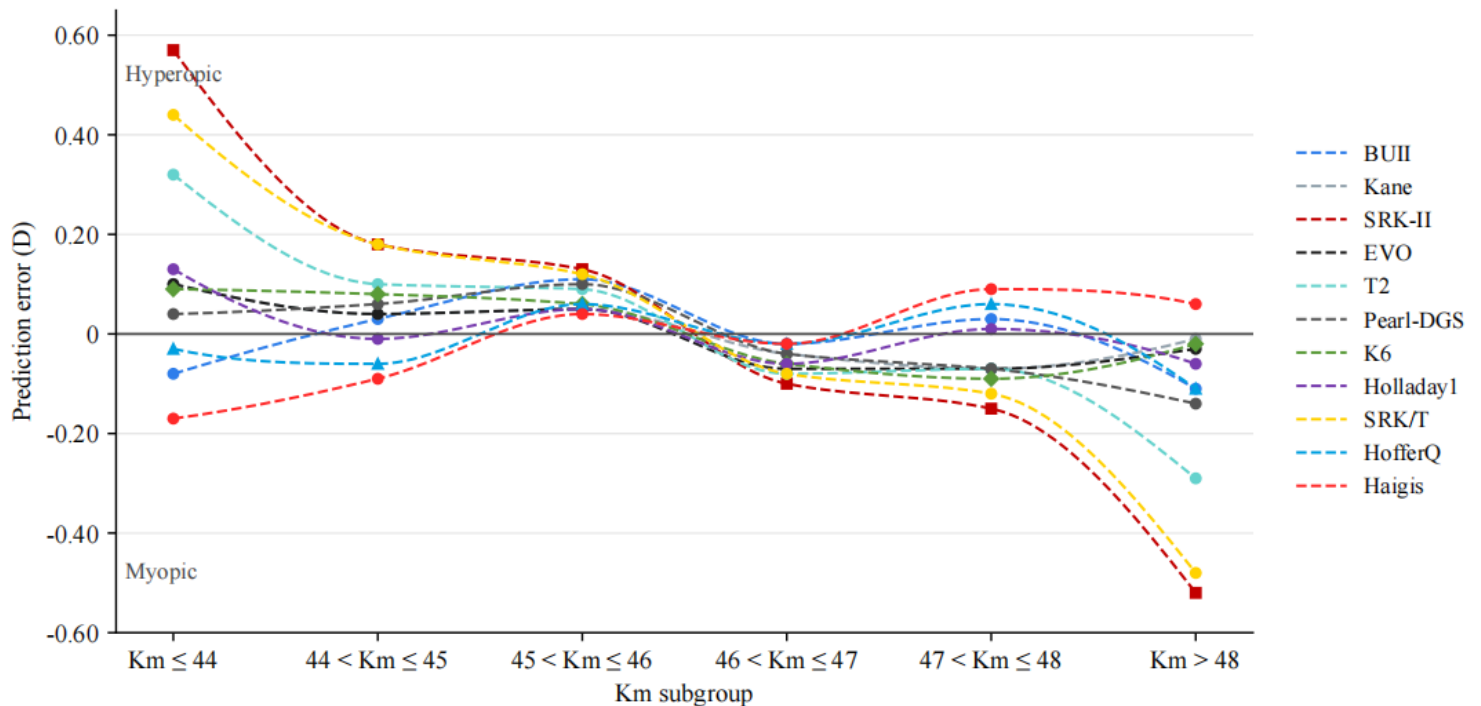


Figure 3

Comparison of IOL power prediction errors across different mean corneal curvature subgroups. The x-axis represents the mean corneal curvature (D), and the y-axis represents the prediction error (D). Positive values indicate hyperopic shifts, and negative values indicate myopic shifts. Each dashed line represents the trend of a specific intraocular lens (IOL) calculation formula

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [GraefesTable1.docx](#)
- [Supplementaryinformationinfo.docx](#)
- [Graefessupplementaryinformation.docx](#)