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SYSTEMATIC REVIEW

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Network meta-analysis of intraocular lens power calculation formulas based on artificial intelligence in short eyes

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Abstract

Purpose To systematically assess and compare the accuracy of artificial intelligence (AI) -based intraocular lens (IOL) power calculation formulas with traditional IOL formulas in patients with short eye length.

Design A systematic review and network meta-analysis.

Methods We performed an exhaustive search of the PubMed, Embase, Web of Science, and Cochrane Library databases to identify relevant studies published until February 2024. The extracted data comprised the mean absolute error (MAE) and the percentage of eyes with refractive prediction errors (PE) within ±0.50 and ±1.00 diopters (D). Network meta-analysis was performed using Review Manager 5.3 and StataSE 16.0.

Results A network meta-analysis of 21 formulas was carried out in 10 studies, including 756 eyes with axial length (AL) < 22 mm. The results showed that the top AI-based formula was Pearl-DGS. For the percentage of eyes with PE within ±0.50 D, the Pearl-DGS formula demonstrated the highest accuracy. In terms of the percentage of eyes with PE within ±1.00 D, the FullMonte IOL formula performed poorly, and no significant differences were observed among the other formulas.

Conclusions The Pearl-DGS formula emerged as the leading AI-based method for determining IOL power in patients with short eye lengths, demonstrating superior accuracy compared to conventional vergence formulas.

Keywords Intraocular lens, Artificial intelligence, Short eyes, Meta-analysis

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Introduction

Short eye means that the anterior and posterior diameter of the eyeball is short, which usually leads to hyperopia. A cataract refers to the partial or complete clouding of the crystalline lens [1]. For cataract patients with short eye axis, hyperopia and cataracts may have a greater impact on the patient's vision and quality of life. With the increasing expectations for quality of life and the high mobility of elderly populations, achieving spectacle independence has emerged as a new postoperative indicator. The implementation of optical biometry in clinical routines has paved the way for better refractive precision. However, predicting postoperative refractive status remains challenging in special cases [2]. Current phacoemulsification outcomes show that 60-81% of patients achieve refractive outcomes within ± 0.50D of the target, while 87-97% fall within ± 1.00D[3]. The accuracy of preoperative biometric parameters (such as AL, Keratometry (K), and anterior chamber depth (ACD))– where measurement errors may account for 36%, 22%, and 42% of deviations respectively– primarily depends on effective lens position (ELP) estimation derived from appropriate formula selection [4–6]. Short AL cataract patients demonstrate lower refractive accuracy, with PE increasing proportionally with hyperopic severity. This stems from the disproportional relationship between anterior segment dimensions and AL in short eyes, complicating accurate calculation of true ELP [7]. The higher IOL power required for emmetropia in shorter AL amplifies any ELP inaccuracies. Limited reports on refractive outcomes in this population reveal heterogeneous PE, with smaller intraocular structures and higher IOL powers rendering short AL cataract patients more prone to elevated MAE [3, 8]. Choosing an IOL with an appropriate degree is an important factor in helping these patients regain clear vision.

Cataract surgery ranks among the most commonly performed medical procedures worldwide, primarily due to the aging population and the rising life expectancy [9, 10]. The success of cataract surgery depends on the selection of an appropriate IOL power formula and the precision of the instruments utilized to measure ocular dimensions [5]. Since the introduction of the initial formulas by Fyodorov in 1967 [11] various calculation methods have been developed to predict the IOL power needed for cataract surgery. Recently, AI technology has been utilized to improve the accuracy of IOL power formulas. The Kane formula (accessible at: www.iolformula.com) serves as a prominent example of an AI-based formula that incorporates regression equations and AI components to enhance its precision [12]. The Hill-RBF formula, version 3.0 (retrieved on August 4, 2021), is an AI-based IOL power calculation formula that employs a radial basis function for pattern recognition and advanced data interpolation methods. Like the Kane formula, it was developed and validated using comprehensive datasets and incorporates regression equations and AI elements to improve its precision [13]. Pearl-DGS (accessible at: https://iolsolver.com.) is an AI-based formula for calculating IOL power, which employs postoperative data to retrospectively determine the theoretical internal lens position. This technique remains uninfluenced by both the placement of the lens's principal planes and the corneal thickness. Additionally, other AI-powered formulas like the Ladas Super Formula have been established [14, 15].

Materials and methods

Literature search

Two researchers, Xin Zheng and Meng Li, carried out an extensive review of literature from studies published until February 2024, utilizing databases such as Pubmed, Embase, Web of Science, and Cochrane Library. Subsequently, the titles and abstracts of the gathered literature underwent a screening process. The search terms used for Embase were: (Cataract* or Cataracts or Lens Opacities or Lens Opacity or Opacities, Lens or Opacity, Lens or Cataract, Membranous or Cataracts, Membranous) and (Lenses, Intraocular* or Intraocular Lenses or Lens, Intraocular or Intraocular Lens or Implantable Contact Lens or Contact Lens, Implantable or Lens, Implantable Contact) and (Hyperopia or short eye or short axial length or short axial lengths or short eyes or short al or short als) and (Calculate or formula).

#1 (Hyperopia or short eye or short axial length or short axial lengths or short eyes or short al or short als).af.

#2 (Lenses, Intraocular or Intraocular Lenses or Lens, Intraocular or Intraocular Lens or Implantable Contact Lens or Contact Lens, Implantable or Lens, Implantable Contact).af.

#3 (Calculate or formula).af.

#4 (Cataract* or Cataracts or Lens Opacities or Lens Opacity or Opacities, Lens or Opacity, Lens or Cataract, Membranous or Cataracts, Membranous).af.

#5 #1 and #2 and #3 and #4.

Inclusion and exclusion criteria

Studies were included if they met the following inclusion criteria: (1) individuals aged 18 and above; (2) Patients with short AL (< 22 mm); (3) Patients undergoing successful phacoemulsification surgery; (4) At least two or more IOL diopter calculation formulas used; (5) Biological measurement by optical method. The criteria for exclusion were as follows: (1) no AI -based formula was used; (2) Patients with a history of corneal refractive surgery; (3) The percentages of affected eyes of PE in the range of ± 0.50 D and ± 1.00 D were not available;

(4) Presence of other eye diseases; (5) Studies that were review articles, conference abstracts, or conducted on animals.

Extraction and processing of data

The researchers, Xin Zheng and Meng Li, independently gathered data regarding study design, participant details, and interventions from all the included studies and compared their findings. Any discrepancies found during this process were discussed and resolved with the third author. The methods for determining the IOL power comprised various formulas such as SRK/T, Hoffer Q, Haigis, Barrett Universal II, Holladay 1 and 2, Olsen, Hill-RBF versions 1.0, 2.0, and 3.0, Kane, T2, VRF, Emmetropia Verifying Optical (EVO), Castrop, Okulix, Pearl-DGS, Superladas, IA, FullMonte IOL, and Hoffer QST. The primary author, publication year, participant count, formulas used, and the proportion of PE within ± 0.50 D and ± 1.00 D were extracted from eligible studies. All studies employed manufacturer-provided IOL constants or ULIB standardized constants without individualized optimization to ensure inter-formula comparability. Additionally, the citations for each included study were thoroughly examined.

Quality assessment

The study quality was assessed using a modified checklist from the QUADAS-2 tool, which evaluated four domains: patient selection, indicator testing, reference criteria, and process and timing [16]. Each area was evaluated for a high risk, low risk, or indeterminable risk of bias.

Surface under the cumulative ranking curve (SUCRA)

The likelihood of intervention for each rank can be evaluated using SUCRA [17]. The SUCRA value for each formula was determined based on the proportion of eyes with a refractive PE within ± 0.50 D and ± 1.00 D range. SUCRA values range from 0 to 100%, with higher percentages indicating a greater likelihood of the formula being highly ranked. SUCRA ranking figures are included to present the SUCRA value for each respective result.

Statistical analysis

The percentage of eyes showing refractive PE within the specific range of ± 0.50 D and ± 1.00 D was analyzed, with a higher percentage indicating better formula accuracy. Statistical heterogeneity across studies was evaluated using the chi-square test and I^2 metric. A random effects model is used when the I^2 statistic exceeds 50% and the p-value is less than 0.1; in other instances, a fixed effects model is utilized. Network meta-analyses were conducted utilizing Review Manager 5.3 and StataSE 16.0 software.

Results

Literature selection

Identification and Selection of Reports for the Meta-analysis.

Figure 1 illustrates the comprehensive methodology for gathering and filtering literature. Initially, a total of 904 articles were sourced from various databases: 307 from Pubmed, 389 from Web of Science, 121 from Embase, and 81 from the Cochrane Library. Following the removal of 330 duplicate studies, 574 articles proceeded to the next phase. After evaluating titles and abstracts, the number was narrowed down to 45 articles. Applying predefined criteria for inclusion and exclusion led to the elimination of 35 studies, leaving 10 studies that were ultimately incorporated into this meta-analysis.

Study characteristics

Table 1 presents an overview of the 10 studies incorporated into this meta-analysis. Among them, nine are retrospective case analyses, and one is a prospective case study. The analysis involved a total of 756 eyes, all with an AL of under 22 mm. The range of sample sizes across the studies was from 16 to 150 eyes. The AI formulas evaluated included the Kane, Hill-RBF, FullMonte IOL, Pearl-DGS, and Ladas super formulas. Meanwhile, the conventional formulas assessed were based on either divergence or ray tracing methodologies and included SRK/T, Hoffer Q, Haigis, Barrett Universal II, Holladay 1, Holladay 2, Olsen, T2, VRF, EVO, Castrop, Okulix, IA, and Hoffer QST.

Quality assessment

The QUADAS-2 checklist, in its updated form, was employed to evaluate the bias risk associated with the 10 items included in the study. (Fig. 2). In terms of patient selection, one study did not clearly state when cases were included, which raised the risk of bias. Another study employed varying measurement methods for the reference criteria, making the bias risk unclear. Regarding the index test and its process and timing, the follow-up duration in two studies was undefined. Overall, eight studies were deemed to be of high quality.

Network meta-analysis results

The network plot

Figure 3 illustrates the initial comparison across 21 formulas. In this representation, each point signifies a distinct formula, with its size reflecting the number of eyes studied. The lines indicate direct comparisons between the formulas, with the thickness of each line representing the number of studies performed.

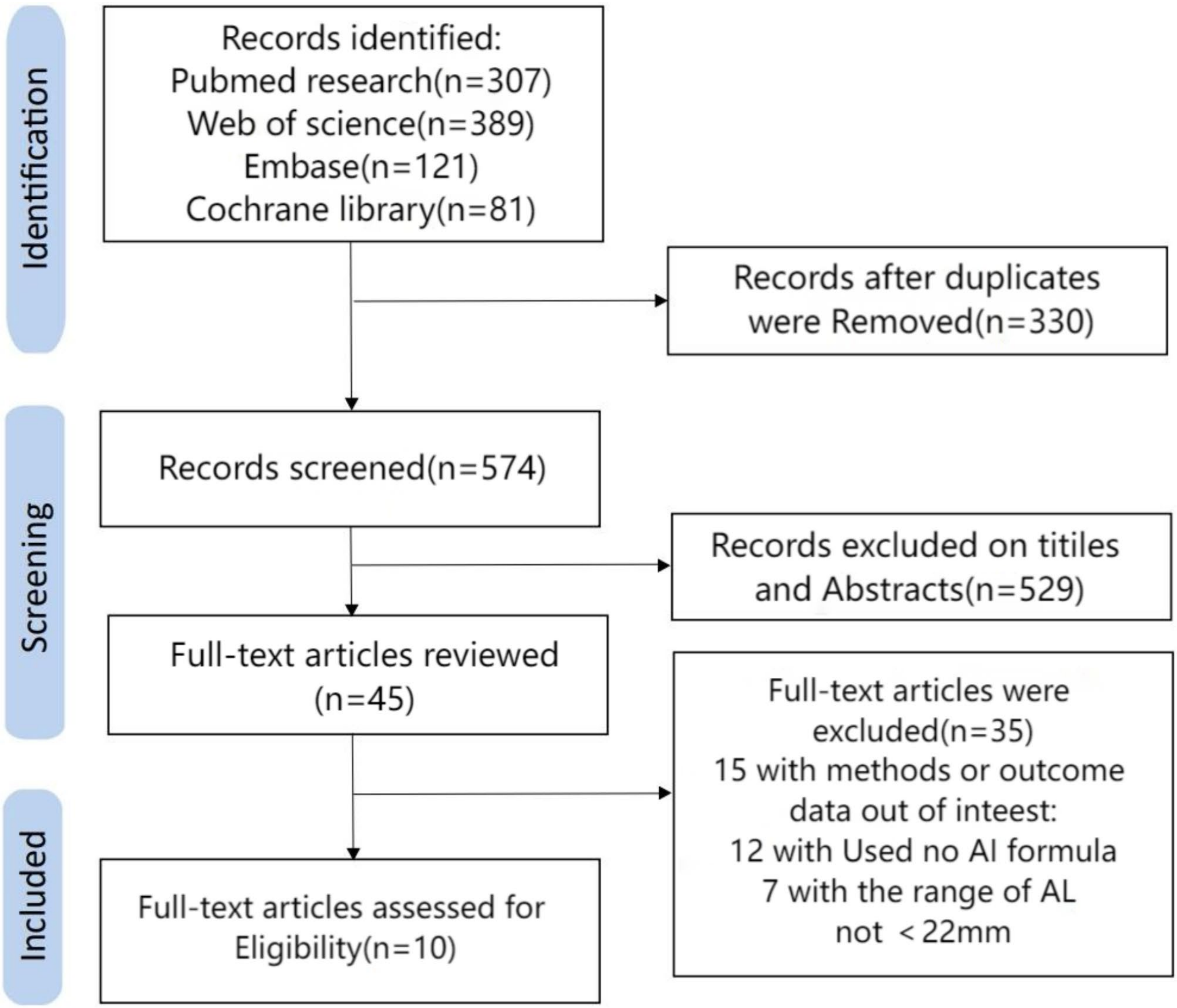

Fig. 1 The diagram illustrating the process of literature search and study selection

Statistical heterogeneity and inconsistency

The direct meta-analysis revealed minimal heterogeneity, with an I^2 value of 45.04% and a p-value exceeding 0.05, resulting in the choice of a random effects model for the analysis. The incorporation of ten studies exhibited robust global coherence ($p = 0.3864 > 0.05$). To evaluate local inconsistencies, the node splitting approach was used. The majority of studies showed consistency ($P < 0.05$), although a few exhibited low p-values ($p < 0.05$). After a comprehensive assessment, a network meta-analysis was conducted under the assumption of consistency.

Prediction discrepancy within ± 0.50 D

Bayesian network meta-analysis was applied to evaluate the percentage of eyes with a refractive PE within ± 0.50 D for both direct and indirect comparisons among 21 methods (Supplemental Table S1). The results of the Bayesian network meta-analysis are depicted in Supplemental Figure S1. Among AI-based formulas, Kane (pooled RR = 1.14; 95% Credible Interval [CrI]: 1.05–1.24) and Pearl-DGS (pooled RR = 1.21; 95% CrI: 1.09–1.34) outperformed the Barrett Universal II formula. Hill-RBF 1.0 (pooled RR = 1.09; 95% CrI: 0.98–1.21), Hill-RBF 2.0 (pooled RR = 1.04; 95% CrI: 0.91–1.18), Hill-RBF 3.0 (pooled RR = 1.09; 95% CrI: 0.98–1.20), and Ladas super formula (pooled RR = 1.05; 95% CrI: 0.95–1.16) demonstrated comparable or superior performance to the Barrett Universal II formula. Conversely, the FullMonte IOL formula (pooled RR = 0.89; 95% CrI: 0.75–1.06) showed inferior performance.

Figure 4 shows the SUCRA ranking probabilities for the percentage of eyes within ± 0.50 D. The outcomes of the network meta-analysis rankings were (from best

Table 1 Characteristics of included studies

Study	Year	Type of studies	Patients	Age	AL (mm)	IOL Model	IOL power	ACD (mm)	The final postoperative follow-up	Formula
Vilaltella M [18]	2023	retrospective case series	100 eyes (84 patients)	74.28 ± 8.42	21.55 ± 0.38	SN60WF, SN60AT, EyeCee®ONE	27.17 ± 2.03	2.64 ± 0.31	3 months	A B C D E F I K N R S T
Wendelstein [19]	2022	retrospective case series	150 eyes (150 patients)	NA	20.98 ± 0.54	SA60AT, ZCB00	30.23 ± 0.75	2.69 ± 0.34	4 weeks	A B C D E F G J K N O P Q
David [20]	2021	retrospective case series	57 eyes (57 patients)	NA	NA	NA	NA	NA	3 months	A B C D E F G I K N R
Tang [21]	2020	retrospective case series	16 eyes (16 patients)	74.5 ± 0.26	NA	SN60WF	20.6 ± 2.8	3.2 ± 0.43	3weeks to 4months	D F H
Oleksiy [22]	2018	retrospective case series	53 eyes (53 patients)	65.38 ± 13.85	23.79 ± 1.5	SN60WF	20.80 ± 4.29	3.22 ± 0.44	3 months	A B C E F L M
Sudhakar [23]	2019	retrospective case series	51 eyes (38 patients)	NA	21.46 ± 0.48	Akreos AO60 AF-1, FY-60AD, SA60AT, ZCT150, ZCT225, ZCT300, ZKB00, ZLB00	26.6 ± 2.5	3.42 ± 0.38	20days to 60days	B C D F H S
Kane [24]	2017	retrospective case series	137 eyes (137 patients)	NA	NA	SN60WF	NA	NA	14days	D E H R T
Wang [25]	2021	retrospective case series	17 eyes (17 patients)	70.11 ± 8.15	23.49 ± 1.41	posterior chamber IOL	20.90 ± 3.02	NA	8.45 ± 2.43 weeks	A C D E G
Bansal [26]	2022	prospective case series	65 eyes (57 patients)	59.7 ± 11.3	21.41 ± 0.42	Alcon AcrySof IQ	26.60 ± 2.45	2.73 ± 0.34	4 week	A B C D F H S
Taroni [27]	2023	retrospective case series	110 eyes (110 patients)	NA	23.70 (19.97–30.48)	AcrySof SN 60 WF, AcrySof SN60AT	NA	3.09 (1.94–4.45)	at least 1 month	B D I K N U

Formula：A = SRK/T B = HofferQ C = Haigis D = Barrett Universal II E = Holladay 1 F = Holladay 2 G = Olsen H = Hill-RBF 1.0 I = Hill-RBF 2.0 J = Hill-RBF 3.0 K = Kane L = T2 M = VRF N = EVO O = Castrop *P* = Okulix Q = Pearl-DGS R = Superladas S = IA (Intraoperative Aberrometry) T = FullMonte IOL U = Hoffer QST

to worst): Pearl-DGS (92.1%) > Okulix (89.9%) > Kane (77%) > IA (75%) > Castrop (71.6%) > Hoffer QST (61.3%) > EVO (60.9%) > Hill-RBF 1.0 (56.1%) > Hill-RBF 3.0 (55.4%) > VRF (52.7%) > SRK/T (51.4%) > Holladay 2 (48.6%) > T2 (43.9%) > Super Ladas (38.6%) > Hill-RBF 2.0 (35.1%) > Holladay 1 (31%) > Haigis (30.7%) > Olsen (30.2%) > Hoffer Q (27.9%) > Barrett Universal II (16.7%) > FullMonte IOL (3.9%).

Prediction discrepancy within ± 1.00 D

Bayesian network meta-analysis was employed to assess the percentage of eyes achieving a refractive PE within ± 1.00 D for both direct and indirect comparisons among 21 methods (Supplemental Table S2). Besides the subpar performance of the FullMonte IOL formula (combined relative risk = 0.89; 95% confidence interval: 0.83 to 0.95), no notable differences were found between the remaining AI-based formulas and conventional formulas.

Figure 5 shows the SUCRA ranking probabilities for the percentage of eyes within ± 1.00 D. The outcomes of the network meta-analysis rankings were (from best to worst): Castrop (95.4%) > Okulix (90.8%) > Hoffer QST (86.8%) > Pearl-DGS (73.5%) > EVO (70.2%) > Olsen (69%) > Kane (61.6%) > Hill-RBF 1.0 (61.1%) > Hill-RBF 2.0 (55.4%) > IA (53.2%) > Hill-RBF 3.0 (49.4%) > Holladay 1 (45.2%) > Holladay 2 (42.7%) > SRK/T (35.8%) > Super Ladas (35.4%) > Haigis (33.5%) > Barrett Universal II (24.1%) > Hoffer Q (23.8%) > T2 (23.7%) > VRF (14.1%) > FullMonte IOL (5.2%).

Risk of bias

Funnel plots adjusted for comparison-correction, showing the percentage of eyes within ± 0.50 D and ± 1.00 D were generated using Stata v. 16.0 software. Most data points cluster in the center of the funnel plot, indicating symmetry and implying a decreased probability of small sample effects or publication bias among the studies included (Fig. 6).

Discussion

Cataracts are among the primary causes of blindness worldwide. Compared to the normal AL population, IOL calculation formulas for short AL eyes continue to face significant challenges in predicting postoperative

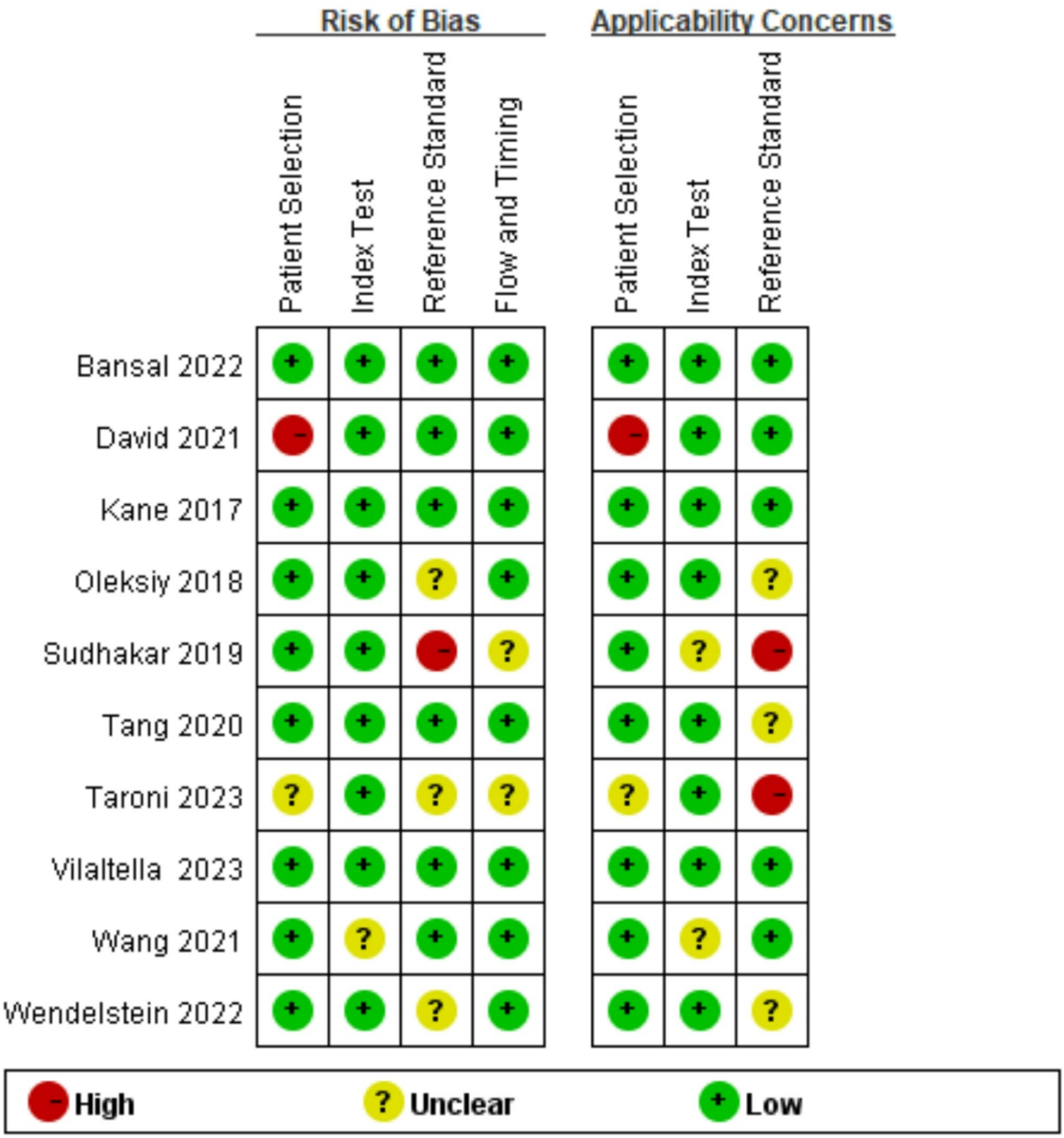

Fig. 2 Potential bias in the included studies studies

refractive errors, with the proportion of postoperative PE within ± 0.50D ranging merely from 31–75% [28, 29] - substantially lower than that in normal AL patients [30]. As ophthalmic AI technology develops, researchers and clinicians are increasingly focusing on less explored areas of the anterior segment [31]. The IOL intelligence and the creation of new formulas aim to achieve even better prediction accuracy [32]. The percentage of eyes with target diopter in the range of ± 0.50 D and ± 1.00 D is most closely related to postoperative satisfaction. Taking this into account, we conducted a meta-analysis to compare the proportion of eyes with PE within ± 0.50 D and ± 1.00 D, with the goal of identifying which AI-based formula performs best in short eyes.

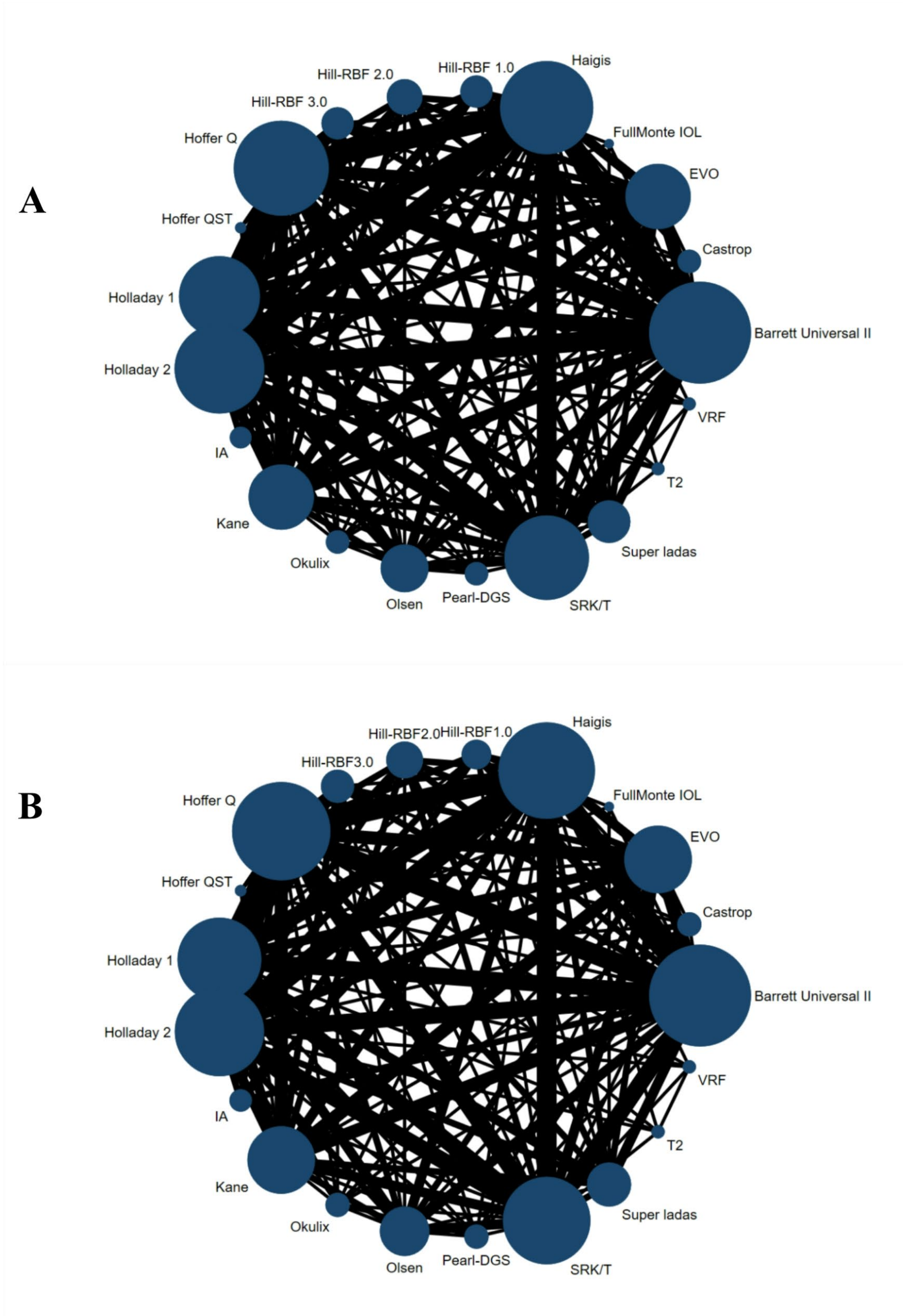

Fig. 3 Network diagrams. **A:** network diagram of predictions that fall within ± 0.50 D of the target diopter value. **B:** network diagram of predictions that fall within ± 1.00 D of the target diopter value

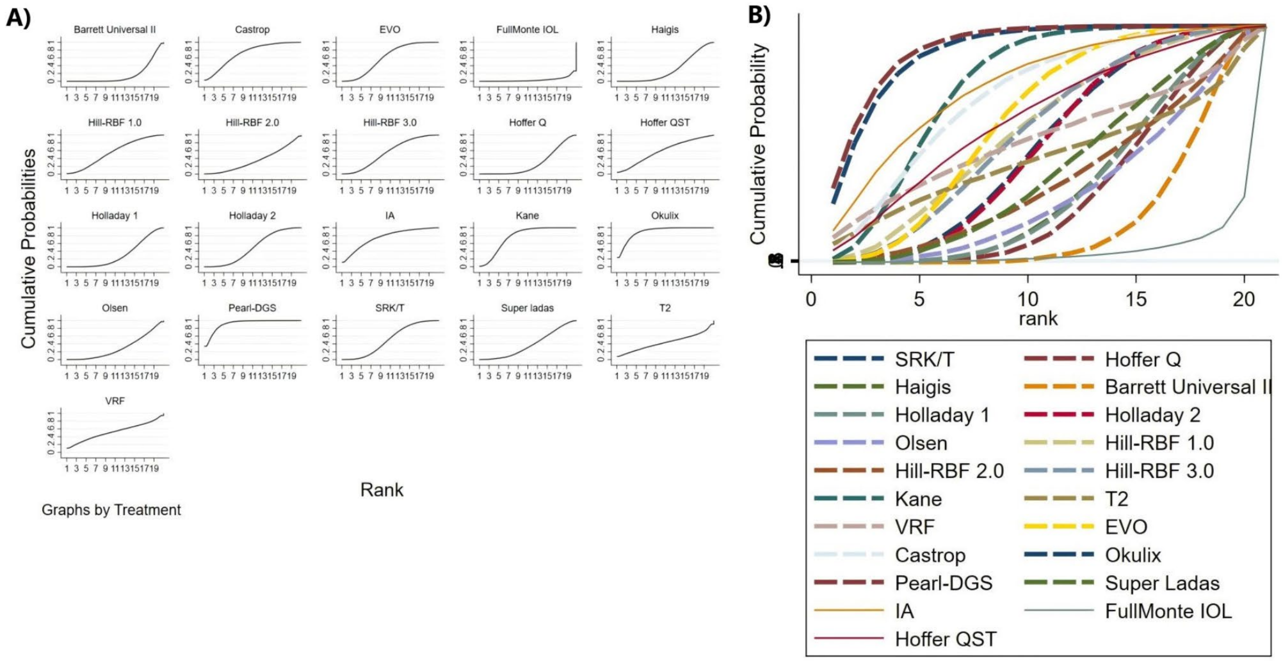

Fig. 4 (**A**) SUCRA ranking charts displaying the proportion of prediction errors within ± 0.50 D across various formulas. (**B**) A graphical representation of the formula rankings to enhance intuitive understanding of the results

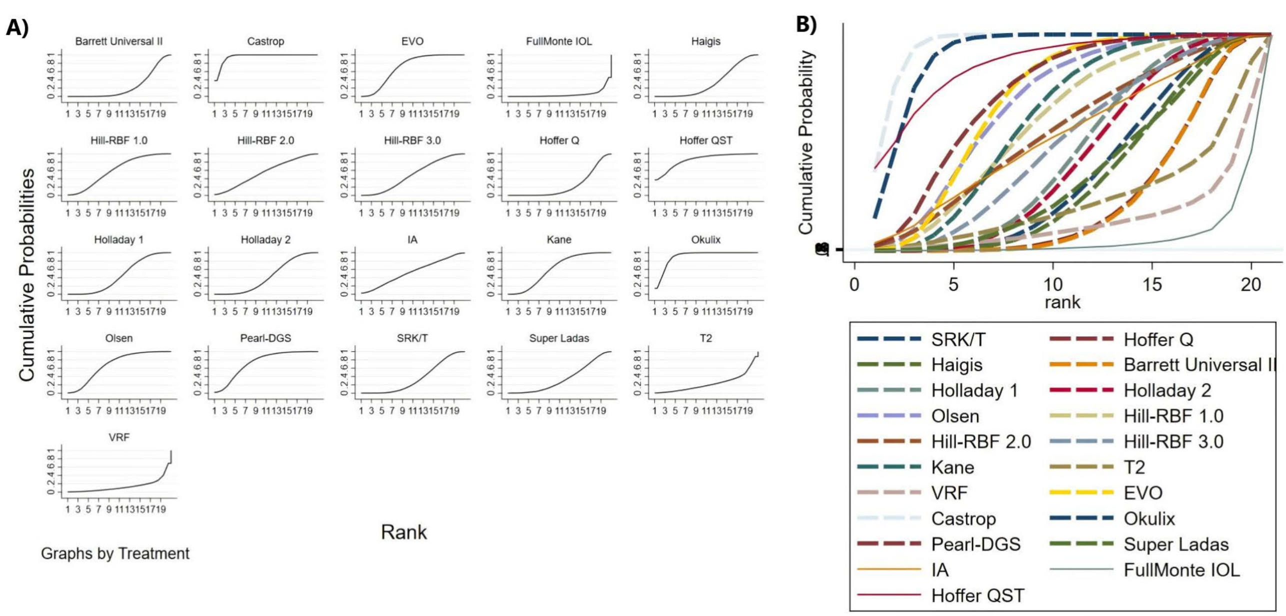

Fig. 5 (**A**) SUCRA ranking charts displaying the proportion of prediction errors within ± 1.00 D across various formulas. (**B**) The ranking of various formulas plotted to make results more intuitive

This research represents the initial network meta-analysis aimed at assessing the precision of AI-powered formulas for determining IOL power in eyes with AL shorter than 22.0 mm. Within this meta-analysis, Haigis, Barrett Universal II, Hoffer Q, Holladay 1 and Holladay 2 emerged as the five most frequently employed formulas in pairwise comparisons, reflecting a concentration of research focus on these methods. By evaluating the PE within ± 0.50 D and ± 1.00 D, our analysis identified Pearl-DGS as the most precise among AI-based formulas. Additionally, the Kane formula exhibited significantly

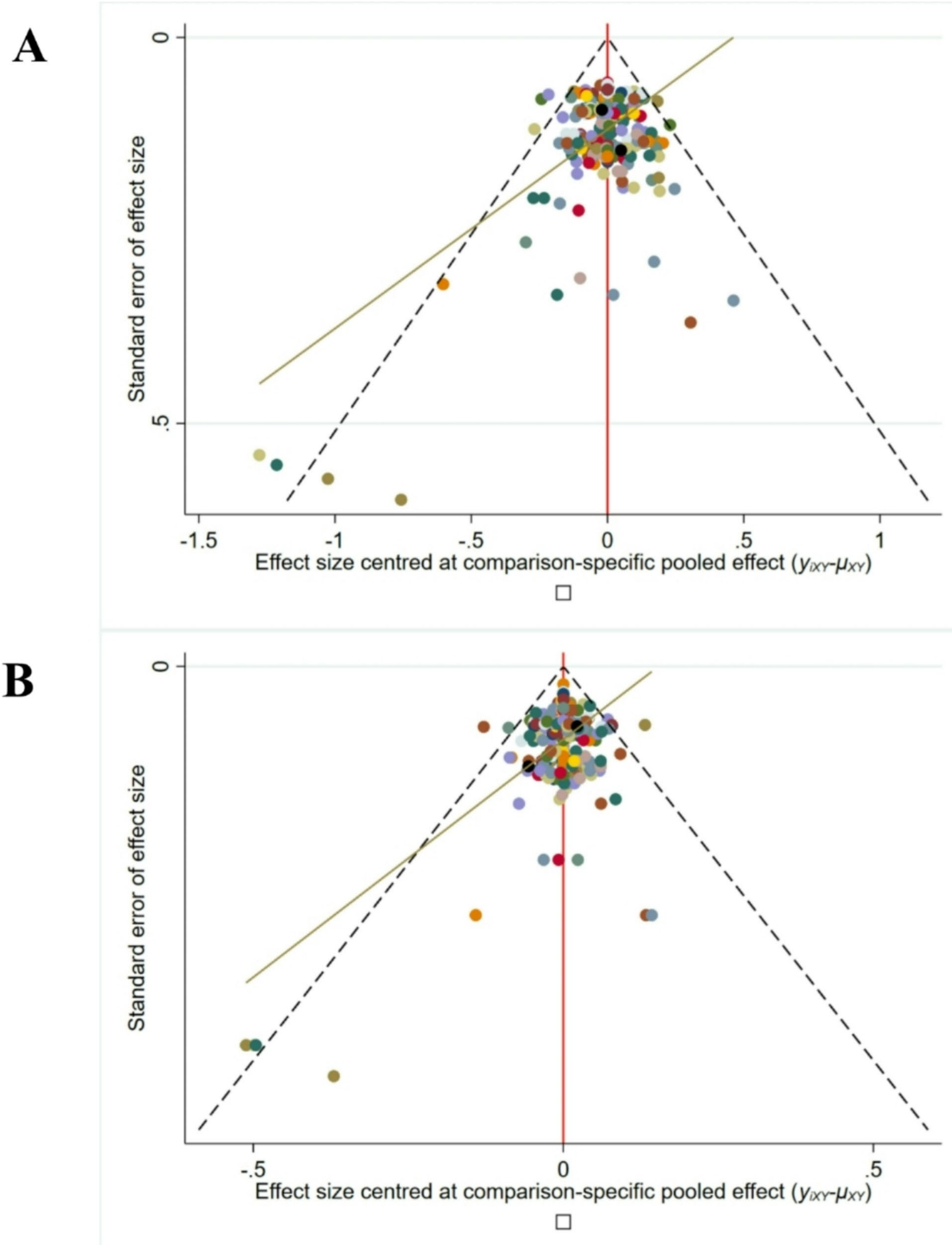

Fig. 6 Comparison-correction funnel plots. (**A**) The funnel plot displays the proportion of eyes whose prediction error falls within ± 0.50 diopters (**D**) of the target refraction. (**B**) Similarly, the funnel plot depicts the percentage of eyes with a prediction error within ± 1.00 D of the target refraction

superior performance compared to other conventional formulas, with the exception of Okulix.

In network meta-analysis, SUCRA serves as a critical methodological instrument for quantifying and comparing the relative efficacy of different therapeutic interventions, thereby supporting evidence-based clinical decision-making. The SUCRA value evaluates the hierarchical superiority of each treatment modality by calculating its cumulative probability distribution across all potential ranking positions. With a numerical range spanning 0 to 1 (equivalent to 0–100%), a SUCRA value approaching 1 indicates superior therapeutic performance and higher comparative ranking. In this study, the SUCRA methodology was employed to systematically rank the performance of various IOL power calculation formulas. Crucially, SUCRA values represent the integrated probabilistic distribution of all potential rankings for each formula, rather than simple percentage aggregation. The SUCRA values at ± 0.50D and ± 1.00D are statistically independent metrics. The SUCRA values and the percentages of eyes with PE within ± 0.50D and ± 1.00D calculated by various formulas are two distinct concepts. The SUCRA values we measured may be smaller within the ± 1.00D range because different formulas are included, and the differences among these formulas are not very pronounced within this range. Since the participating formulas vary, their relative advantages also differ. Within the wider range of ± 1.00D, the PE of most formulas (including traditional methods) are "diluted," which may lead to a reduction in ranking differences.

In this analysis, Pearl-DGS and Okulix emerged as the two most accurate formulas for calculating IOL power in eyes with short ALs. Pearl-DGS demonstrated superior accuracy within the ± 0.50 D range, while Okulix ranked second within both the ± 0.50 D and ± 1.00 D ranges, highlighting its notable advantages over other formulas.

In 2017, a novel formula named Pearl-DGS was proposed by Debellemanie`, Gatinel, and Saad. This formula employs a combination of machine learning techniques such as gradient boosted trees, regular multiple regression, and support vector regression to estimate the target intraocular lens power (TILP). The input parameters for the Pearl-DGS formula encompass AL, K, ACD, lens thickness (LT), white-to-white distance (WTW), and central corneal thickness (CCT). The IOL constants used in this formula are consistent with those utilized in third-generation formulas. During the development of the Pearl-DGS formula, an empirical value was assigned to the corneal index, whereas other refractive indices were retained as per the standard Atchison model eye. Notable characteristics of the Pearl-DGS formula include its ability to produce linear outputs and the elimination of the need for re-training when incorporating new IOL models [33, 34]. A systematic review by Topyra et al. [35]. of articles published between January 2015 and December 2022 on IOL calculation formula accuracy demonstrated that the Pearl-DGS formula achieved the highest precision in short AL cataract patients. Wendelstein et al.'s study [19] further revealed that both the Pearl-DGS and Kane formulas outperformed the Barrett Universal II and EVO formulas. In this study, the Pearl-DGS formula emerged as the most accurate AI-based formula, providing more precise IOL calculations for short AL patients, reducing postoperative refractive surprises, and enhancing patient satisfaction.

The Kane formula, an AI-based approach, shows promising performance according to SUCRA rankings, with 77% of eyes having a PE within ± 0.50 D and 61.6% within ± 1.00 D. This unpublished formula, with its largely unknown structure, is rooted in theoretical optics and integrates AI elements. Kane incorporates various parameters, including AL, K, ACD, LT, and CCT, along with patient gender, to make its predictions [2, 36]. In 2019, the National Health Service conducted a comparative analysis of several IOL power calculation formulas, including Kane, Hill-RBF 2.0, and adjusted AL formulas from Holladay 2, Barrett Universal II, Olsen, Haigis, Holladay 1, Hoffer Q, and SRK/T. The evaluation was based on data from 10,930 eyes. The findings indicated that the Kane formula exhibited the highest accuracy among those assessed [37]. Oleksiy et al. [38], compared 18 calculation formulas for eyes with AL < 22.0 mm, and found that the Kane formula was more accurate than Haigis, Hoffer Q, Barrett Universal II, Holladay 1, Holladay 1, and the Super Ladas Formula.

The latest generation of formulas demonstrated superior performance compared to traditional vergence formulas. In this research, the Castrop and Okulix formulas notably outperformed other formulas in achieving PE values within ± 0.50 D and ± 1.00 D for a higher percentage of eyes. No significant statistical difference was observed between the Hill-RBF and Super Ladas formulas, both based on AI, and other conventional formulas. The findings reported by Langenbucher et al. [39],in exploratory data analysis show that compared with the classical SRK/T, Hoffer Q, Holladay 1, or Haigis formulas, the Castrop formula has slightly better performance in terms of PE and AE.

Our study has several limitations. (1) Nine of the studies included were retrospective case series, and only one was a prospective case study; some had a limited sample size, potentially leading to bias. (2) We could not achieve uniformity in the types of IOLs included in the literature, inevitably increasing clinical heterogeneity across studies. (3) Three studies used the Lenstar optical measuring instrument, necessitating further research to analyze its effect. (4) Although we evaluated and ranked the postoperative refractive accuracy of different IOL calculation formulas, the area under the SUCRA curve is merely an additional measure for reference and does not signify a statistically significant difference.

In essence, we assessed the efficacy of 21 formulas used for calculating IOL power. The data suggested that for individuals with cataracts and Als shorter than 22.0 mm, AI-based formulas, notably the Pearl-DGS, demonstrated potential in achieving a higher proportion of eyes with PE within ±0.50 D compared to conventional vergence formulas. This study provides clinicians with clear guidance: For patients with AL < 22 mm, prioritizing AI-based formulas such as Pearl-DGS can significantly improve postoperative refractive prediction accuracy and reduce secondary surgery risks. AI-based formulas generally outperformed newer generation formulas like Barrett Universal II and Olsen, though the difference was not significant. Further research with large, geographically diverse samples is needed to confirm the effectiveness of AI-based formulas.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12886-025-04066-z.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Not applicable.

Author contributions
X.Z.and M.L.contributed to the study concept and design, interpretation of the data and editing the manuscript. JS.Z. and YY.M. contributed to data analysis. JS.Z. and YY.M. contributed to data analysis. All authors commented on drafts of the paper and have approved the final draft of the manuscript for submission.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This research does not require an ethics statement as it solely relies on previously published works.

Consent for publication
not applicable.

Competing interests
The authors declare no competing interests.

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