Accuracy of intraocular lens calculation formulas using a swept-source optical coherence tomography biometer in high myopia

Chi Zhang
1st Medical Center of the Chinese PLA General Hospital
Zi Ye
1st Medical Center of the Chinese PLA General Hospital
Wenqian Chen
1st Medical Center of the Chinese PLA General Hospital
Yi Gao
1st Medical Center of the Chinese PLA General Hospital
Tianju Ma
1st Medical Center of the Chinese PLA General Hospital
Zhaohui Li (zhaohuili650@hotmail.com)
1st Medical Center of the Chinese PLA General Hospital

Research Article

Keywords: intraocular lens formula, high myopia, cataract, IOLMaster700

Posted Date: March 23rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-310951/v1

Abstract

Background: To compare the accuracy of intraocular lens (IOL) calculation formulas in cataract patients with high myopia using the measurements of a swept-source optical coherence tomography (SS-OCT) biometer, the IOLMaster700.

Methods: Patients with axial length (AL) equal to or longer than 26.00mm undergoing uneventful cataract surgery were enrolled. Kane, Hill-RBF3.0, EVO, Barrett Universal II, Haigis, and SRK/T formulas were evaluated with the measurements taken by IOLMaster700. The manifest refraction was measured at one month postoperatively. After the mean refractive errors were zeroed out, the mean absolute error (MAE), the median absolute error (MedAE), the standard deviation of prediction error (SD), and the percentage of eyes with refractive errors within ±0.25, ±0.50, ±0.75, and ±1.00 diopter (D) were calculated. A subgroup analysis was based on the axial length.

Results: 65 eyes of 65 patients were included. There were significant differences between the absolute refractive errors predicted by these formulas ($P<0.05$), but no significant differences between the percentage of eyes within a certain range of refractive errors ($P>0.05$). The Kane formula achieved the lowest MAE (0.323D), SD (0.402D), followed by EVO, Hill-RBF3.0, Barrett Universal II, Haigis, and SRK/T formulas. The Kane formula also had the highest percentage of eyes with refractive errors within ±0.50D (80.0%) and ±1.00D (98.5%). The Hill-RBF3.0 formula achieved the lowest MedAE (0.240D). In eyes with an AL ≥ 30.00mm, the Kane formula had the lowest MAE (0.358D).

Conclusion: Newer formulas such as Kane, EVO, Hill-RBF3.0, and Barrett Universal II show the highest accuracy in refractive prediction in eyes with high myopia while using the measurements of IOLMaster700. In extremely myopic eyes with an AL ≥ 30.00mm, the Kane formula is the most accurate.

Background

Today, cataract surgery has been shifted from a rehabilitation procedure to a refractive procedure. The accuracy of refractive prediction could be guaranteed in most emmetropic eyes.[1] However, in high myopic eyes with axial length longer than 26.00mm, the accuracy of refractive prediction remains a challenge, often leading to unexpected postoperative hyperopia.[1-2]

The refractive outcome of cataract surgery is influenced by the choice of IOL calculation formula and the accuracy of the various devices used to measure the eye.[3] IOLMaster700 is a new optical biometer based on swept-source optical coherence tomography. It provides a 1050nm laser infrared light with better penetration in eyes with less transparent ocular media or longer axial length (AL) and displays a retinal OCT image to detect fixation status and avoid fixation loss.[4-5] The SRK/T and Haigis formulas are relatively more accurate than other traditional third and fourth-generation formulas in eyes with high myopia,[6] and new generation formulas have been developed these years. The differences in the derivation method and metrics used are summarized in Table 1. Barrett Universal II is a 5-variable thick-lens vergence formula.[7] Hill-Radial Basis Function (Hill-RBF) is an artificial intelligence formula and has been updated to version 3.0.[8] Kane formula is based on theoretical optics as well as regression and artificial intelligence.[9] The Emmetropia Verifying Optical (EVO) formula is a thick-lens formula based on the theory of emmetropization.[9]

The purpose of this study was to investigate the accuracy of IOL power calculation formulas (Barrett Universal II, Hill-RBF3.0, Kane, EVO, SRK/T, and Haigis) in eyes with axial length longer than 26.00mm using an SS-OCT biometer (IOLMaster700). We also evaluated clinical outcomes in subgroups based on axial length.

Methods

Ethical approval

This study was approved by the Chinese Ethics Committee of Registering Clinical Trials and was conducted in accordance with the Declaration of Helsinki. The need for written informed consent was waived because of the retrospective design and the use of de-identified patient data with approval from the General Hospital of PLA. The study was registered with the Chinese Clinical Trial Registry.

Patient selection

Consecutive cataract patients with axial length longer than 26.00mm who had uneventful cataract surgery were enrolled. The right eye was selected if patients had bilateral cataract surgery. Patients with previous trauma or surgery, glaucoma, strabismus, corneal pathology, or severe fundus pathology that may affect the accurate biometry were excluded. Patients with a postoperative corrected distance visual acuity worse than 20/40 were excluded. Patients with missing postoperative refractive outcomes were also excluded.

Preoperative examinations

Standard routine preoperative examinations including a slit-lamp examination, ultrasound biometry, fundoscopy, corneal topography, intraocular pressure, and corneal endothelium calculation were performed. The axial length was measured by one experienced technician using a swept-source optical coherence tomography biometer (IOLMaster700, Carl Zeiss Meditec AG). Keratometry (K), anterior chamber depth (ACD), white to white (WTW), and lens thickness (LT) were also measured.

Surgical technique

Phacoemulsification cataract surgery with a temporal 3.0mm clear corneal incision was performed by the same experienced surgeon (L.Z.H), and one of the following six different IOLs was implanted: Akreos Adapt AO (Bausch&Lomb), Akreos Adapt (Bausch&Lomb), Bigbag (Carl Zeiss Meditec AG), Proming (A1-UV), Tecnis ZCB00 (Johnson&Johnson Vision), and Softec1HD (Lenstec). All patients have been prescribed the same postoperative medications.

IOL power calculation

Six formulas were calculated through their respective websites.[8-12] The Hill-RBF3.0 allows users to enter target refraction between -2.5D to +1.0D. For IOLs with target refraction less than -2.5D, the predicted refraction was obtained by extrapolation. The manufacturer provided or User Group for Laser Interference (ULIB) optimized constants were used for Akreos Adapt AO, Akreos Adapt, Tecnis ZCB00, and Softec HD IOLs.[13] The constants optimized by our hospital were used for Bigbag and Proming A1-UV IOLs.

Postoperative examinations

Manifest refraction was tested by the same experienced technician at least one month after surgery. The postoperative refractive error was defined as the actual postoperative refraction minus the predicted postoperative refraction. A negative value represented a myopic outcome, whereas a positive value indicated a hyperopic outcome. The mean refractive errors of each formula were adjusted to zero by subtracting an amount equal to the mean refractive error from the postoperative refractive error for each eye. After the mean refractive errors were zeroed out, the mean absolute error (MAE), median absolute error (MedAE), and standard deviation of prediction error (SD) were calculated. For each formula, the percentage of eyes with refractive errors within ±0.25D, ±0.50D, ±0.75D, and ±1.00D were also calculated. The subgroup analysis was performed based on the AL for 26.00≤AL<28.00mm, 28.00≤AL<30.00mm, and AL≥30.00mm.

Statistical analysis

Statistical analyses were performed using SPSS (version 26.0, SPSS Inc) and GraphPad Prism 8 (version 8.2.0, GraphPad Inc). Kolmogorov-Smirnov test was used to assess the normality of data. The single-sample *t* test or Wilcoxon signed rank-sum test was used to determine whether the mean refractive errors were different from zero. Friedman's nonparametric test was performed to compare the difference in absolute refractive errors. The posthoc test of Wilcoxon signed-rank test with Bonferroni correction was adopted for multiple comparisons. Cochran's Q test was used to compare the percentage of eyes within a specific range of refraction errors. Adjusted *P* values (by Bonferroni correction) less than 0.05 were considered statistically significant.

Results

65 eyes of 65 patients were evaluated. 39 (60.0%) patients were women, and 50 (76.9%) were right eyes. Demographic characteristics are shown in Table 2. The mean AL was 28.95 ± 2.28 mm, mean corneal power was 43.61 ± 1.34 D, the mean ACD was 3.50 ± 0.43 mm, and the mean LT was 4.31 ± 0.55 mm. The mean IOL power was 10.94 ± 5.23 D. Seven Bigbag, 14 Tecnis ZCB00, 27 Akreos Adapt AO, 10 Akreos Adapt, 5 Proming A1-UV, and 2 Softec HD IOLs were implanted. Based on axial length, 26 (40.0%) eyes had an AL between 26.00mm and 28.00mm, 18 (27.7%) eyes had an AL between 28.00mm and 30.00mm, and 21(32.3%) eyes had an AL longer than 30.00mm.

Clinical outcomes of the whole group

Before the MEs were zeroed out, the MEs for Kane, EVO, Hill-RBF3.0, Barrett Universal II, Haigis, and SRK/T formulas were -0.172±0.402 D, 0.015±0.436 D, -0.040±0.481 D, 0.083±0.472 D, 0.430±0.535 D and 0.300±0.571 D. The MEs of EVO, Hill-RBF3.0, and Barrett Universal II formulas were not significantly different from zero (*P*>0.05). After the MEs were zeroed out, the MAE, MedAE, ME, and SD for each formula of the whole group are shown in Table 3, and the box-and-whisker plots of absolute errors are shown in Figure 1. The lowest MAE value was achieved with Kane (0.323D), followed by EVO (0.335D), Hill-RBF3.0 (0.346D), Barrett Universal II (0.361D), Haigis (0.415D), and SRK/T (0.450D). The lowest MedAE value was achieved with Hill-RBF3.0 (0.240D), followed by EVO (0.285D), Kane (0.298D), Barrett Universal II (0.313D), Haigis (0.360D), and SRK/T (0.370D). The Friedman test revealed a statistical difference between the absolute refractive errors of the six formulas (*P*<0.05), with posthoc analysis showing a significant difference between EVO vs SRK/T, and Hill-RBF3.0 vs SRK/T(*P*<0.05).

The percentage of eyes within a specific range of refractive errors is shown in Table 3, and the distribution of refractive errors is shown in Figure 2. The highest percentage within ±0.50D was achieved with Kane (80.0%), followed by Hill-RBF3.0 (78.5%), EVO (78.4%), Barrett Universal II (75.4%), Haigis (66.2%), and SRK/T (60.0%). With all formulas, the percentage of eyes within ±1.00D was higher than 90.0%, and the highest percentage of eyes with refractive errors within ±1.00D was achieved by the Kane formula (98.5%). The Cochran's Q test confirmed no statistical difference between the percentage of eyes within ±0.25 D, ±0.50 D, and ±1.00 D of refractive errors ($P>0.05$).

Clinical outcomes of the subgroup

The MAE and MedAE for each formula by axial length are shown in Table 4. In eyes with $26.00 \leq AL < 28.00$ mm, the EVO formula had the lowest MAE (0.328D), and Hill-RBF3.0 had the lowest MedAE (0.260D). In eyes with $28.00 \leq AL < 30.00$ mm, the Kane formula had the lowest MAE (0.223D), and Hill-RBF3.0 had the lowest MedAE (0.195D). In eyes with AL ≥30.00mm, the Kane formula had the lowest MAE (0.358D), and Hill-RBF3.0 had the lowest MedAE (0.240D).

The refractive errors for each formula by axial length are shown in Figure 3. In eyes with $26.00 \leq AL < 28.00$ mm, Hill-RBF3.0 and Kane formulas achieved hyperopic refractive errors, while others achieved myopic refractive errors. In eyes with $28.00 \leq AL < 30.00$ mm, all the six formulas achieved myopic refractive errors. In eyes with AL ≥30.00mm, Hill-RBF3.0 and Kane achieved myopic refractive errors, while others achieved hyperopic refractive errors.

Discussion

In this study, we investigated the accuracy of IOL calculation formulas in high myopia using the measurements provided by IOLMaster700. Barrett Universal II, Hill-RBF3.0, Kane, EVO, SRK/T, and Haigis formulas were evaluated.

The benchmark standards for refractive outcomes after cataract surgery was established in the UK National Health Service in 2009, that using optimized A constants and partial coherence interferometry, 55% of patients achieving a refractive error within ±0.50D, and 85% of patients achieving a refractive error within ±1.00D.[14] The outcomes of our study outperformed the benchmark standards, with a refractive error within ±0.50D and ±1.00D achieved by at least 60% and 92.3% of patients. For newer generation formulas such as Barrett Universal II, Hill-RBF3.0, Kane, and EVO formulas, the refractive error within ±0.50D and ±1.00D were achieved by at least 75.4% and 95.4% of patients, indicating an improved outcome.

Accurate refractive prediction remains challenging in cataract patients with high myopia. The largest studies analyzed 2060 high myopic eyes.[1] In 2018, Melles et al.[1] compared 1548 eyes with SN60WF (Alcon) and 512 eyes with SA60AT (Alcon) of AL longer than 25.50mm with the Lenstar LS900, the accuracy of formulas including Barrett Universal II, SRK/T, and Haigis. The Barrett Universal II formula had the best outcome and was less influenced by long axial length. The SRK/T and Haigis performed better than other traditional third and fourth generation formulas. In 2019, Melles et al.[15] evaluated newer formulas including Kane, EVO, and Hill-RBF2.0 using the same dataset, and the Kane formula achieved the lowest MAE, MedAE, and SD in long and extremely long axial length eyes. The Hill-RBF2.0 and EVO formulas were less accurate than Barrett Universal II.

Darcy et al.[16] compared in 637 eyes of AL longer than 26.00mm with the IOLMaster500, the accuracy of formulas including Kane, Barrett Universal II, Hill-RBF2.0, Haigis, and SRK/T. The best formula was Kane with a MAE of 0.329D, followed by Barrett Universal II (0.338D), Hill-RBF2.0 (0.352D), Haigis (0.359D), and SRK/T (0.363D). Similarly, Cheng et al.[17] compared the use of formulas including Kane, Barrett Universal II, Hill-RBF2.0, EVO, and Haigis in 370 eyes of AL longer than 26.00mm with IOLMaster500, and found that the Kane formula yielded the lowest MAE of 0.34D, followed by Barrett Universal II (0.37D), Hill-RBF2.0 (0.38D), EVO (0.40D) and Haigis (0.40D). The Kane formula was comparable to Hill-RBF2.0 and Barrett Universal II in the whole group and was better than Hill-RBF2.0 and Barrett Universal II in extremely myopic eyes with an AL ≥30.00mm. In a study of 79 eyes of AL longer than 26.00mm with OA2000, Rong et al.[18] noted that the MedAE of Barrett Universal II (0.37D) was lower than Haigis (0.46D), and the percentage of eyes within ±0.50D of Barrett Universal II (70%) was higher than Haigis (54%). The refractive errors of the two formulas were lowest in eyes of AL between 28.00mm and 30.00mm. In 2020, several studies with measurements taken by IOLMaster700 were published. In a study of 164 eyes of AL longer than 26.00mm by Zhang et al.,[19] EVO was found to have a MAE of 0.35D and 79.27% of patients achieving a refractive error within ±0.50D, better than Barrett Universal II (0.38D, 73.17%). Carmona-González et al.[20] compared in 115 eyes of AL longer than 25.00mm, the accuracy of formulas including all six formulas analyzed in our study. The lowest MAE was achieved by Barrett Universal II (0.26D), followed by Kane (0.27D), Haigis (0.27D), EVO (0.28D), Hill-RBF2.0 (0.29D) and SRK/T (0.33D).

The Kane formula is based on theoretical optics and incorporates both regression and artificial intelligence components to refine its predictions. Overall, Kane was the most accurate, with the lowest MAE of 0.323D, 80.0% and 98.5% of patients achieving a refractive error within ±0.50D and ±1.00D respectively. The MedAE of Kane was 0.298D, lower than Hill-RBF3.0 (0.240D) and EVO (0.285D). The excellent outcomes with the Kane formula in short, medium, and long eyes have been reported in several studies.[15-16, 21]

The EVO formula is a thick lens formula based on the theory of emmetropization. In our study, the EVO formula achieved the second-lowest MAE of 0.335D, a MedAE of 0.285D, 78.4% and 96.9% of eyes within ±0.50D and ±1.00D respectively, which was comparable to the results of previous studies.[16, 19] In eyes of AL within 26.00mm and 28.00mm, EVO was ranked first with an MAE of 0.328D, while in eyes of AL longer than 28.00mm, EVO had a higher MAE than Kane and Hill-RBF3.0 formulas. This is consistent with the viewpoint of Melles et al.[15] that the emmetropization concept may break down at the extremes of the axial lengths.

The Hill-RBF is the first IOL calculation formula based purely on artificial intelligence and has been updated to version 3.0 in December 2020. To our knowledge, no published study on version 3.0 of the Hill-RBF formula exists to compare our results. Previous studies reported that Hill-RBF2.0 was less accurate than Kane and Barrett Universal II formulas in high myopic eyes.[15-17] In our study, Hill-RBF3.0 had a MAE of 0.346D, the lowest MedAE of 0.240D, 78.5% and 95.4% of eyes within ±0.50D and ±1.00D respectively. Hill-RBF3.0 finished behind the Kane formula, but ahead of Barrett Universal II, indicating that it has improved compared with the previous version. The Hill-RBF3.0 allows users to enter target refraction between -2.5D to +1.0D. For high myopic eyes with target refraction less than -2.5D, refractive predictions were obtained by artificial extrapolation, which led to inconvenience in clinical use. Nevertheless, we still included the dataset obtained by extrapolation in our analysis and achieved a good outcome.

Barrett Universal II is a paraxial ray-tracing thick-lens formula, which accounts for the varying principal planes among different-powered IOLs. It considers the effective lens position (ELP) to be a result of the ACD and a lens factor related to the physical position and the location of the principal planes of the IOL.[2] Barrett Universal II was ranked among the most accurate formulas for high myopic eyes in many studies.[1, 22] In our study, Barrett Universal II, with a MAE of 0.361D, a MedAE of 0.313D, 75.4% and 96.9% of eyes within ±0.50D and ±1.00D, was ranked fourth behind newer formulas including Kane, EVO, and Hill-RBF3.0.

SRK/T and Haigis formulas are traditional vergence formulas, which use different numbers of variables to estimate ELP. SRK/T and Haigis formulas were reported superior accuracy over Holladay1, and HofferQ formulas for high myopic eyes.[6] In our study, Haigis achieved a MAE of 0.415D, a MedAE of 0.360D, 66.2% and 92.3% of eyes within ±0.50D and ±1.00D, while SRK/T had a MAE of 0.450D, a MedAE of 0.370D, 60% and 95.4% of eyes within ±0.50D and ±1.00D. The refractive outcomes of the two formulas were comparable to previous studies.[23-24] SRK/T and Haigis formulas were less accurate than other new formulas as we expected. The advantage is that IOL constants of two formulas could be optimized independently, which is convenient for clinicians.

Based on AL subgroups, Kane was comparable to Hill-RBF3.0, EVO, Barrett Universal II formulas in eyes with an AL between 26.00mm and 30.00mm, and had a superior behavior over other formulas in eyes with an AL longer than 30.00mm. The excellent outcome of the Kane formula in extremely high myopic eyes was also detected in a previous study by Cheng et al..[17] Furthermore, the MAEs and MedAEs were lowest in eyes with an AL within 28.00mm to 30.00mm, as in two previous studies by Rong et al.[18] and Cheng et al..[17] Rong et al.[18] explained that it is the point at which refractive errors change between myopic and hyperopic. In our study, the refractive errors of Hill-RBF3.0 and Kane formulas changed from hyperopia to myopia, and the refractive errors of the other four formulas changed from myopia to hyperopia as axial length got longer, which supported the viewpoint mentioned before. To avoid hyperopic shift, EVO and Barrett Universal II formulas were preferred in eyes with an AL between 26.00mm and 28.00mm, while Kane and Hill-RBF3.0 formulas were the first choices in eyes with an AL longer than 30.00mm.

In our study, preoperative measurements were taken by a swept-source optical coherence tomography optical biometer. IOLMaster700, with a longer wavelength, is more successful at measuring AL through dense cataracts and extremely long eyes.[5] The device provides cross retinal OCT images to detect fixation status and is expected to produce more precise AL measurement in myopic eyes with posterior staphyloma.[4] Moreover, the device measures LT and WTW, which are optional variables in Kane (LT), Barrett Universal II (LT, WTW), Hill-RBF3.0 (LT, WTW), and EVO (LT), and is expected to further refine the accuracy of IOL formulas.

Nevertheless, the refractive outcomes achieved in our study are consistent with results based on other biometers.[17, 21, 24] The reason could be that any clinical differences, such as the range of AL included, the type of IOLs, and the selection of IOL constants, affect the refractive prediction of IOL calculation formulas. When comparing the differences in refractive prediction of different devices, biometric measurements should be carried out on the same group of patients and reduce the influence of any other clinical factors.

Our study had several limitations. 1.Lens constant optimization for new generation formulas was limited because they were not published; instead, the mean refractive errors were simply zeroed out to eliminate systematic errors. Although different from traditional lens constant optimization, that was suggested by protocols of IOL formula accuracy provided by Wang et al..[25] 2. Data from multiple IOL models were included, which might introduce bias due to different IOL models. However, in modern surgery, multiple IOLs are used, and the results may have greater generalizability. 3. A small number of eyes were evaluated in our study compared to other studies, and further studies with a larger sample size are needed to investigate the difference in each subgroup.

Conclusions

In conclusion, newer formulas such as Kane, EVO, Hill-RBF3.0, and Barrett Universal II yielded accurate refractive prediction in eyes with high myopia while using the measurements of IOLMaster700. In eyes with AL ≥30.00mm, the Kane formula was most accurate.

List Of Abbreviations

ACD: anterior chamber depth; AL: axial length; CCT: central corneal thickness; D: diopter; ELP: effective lens position; EVO: Emmetropia Verifying Optical; Hill-RBF: Hill-Radial Basis Function; IOL: intraocular lens; K: keratometry; LT: lens thickness; MAE: mean absolute error; MedAE: median absolute error; SD: standard deviation; SS-OCT: swept-source optical coherence tomography; WTW: white to white

Declarations

Ethics approval and consent to participate

This study was approved by the Chinese Ethics Committee of Registering Clinical Trials and was conducted in accordance with the Declaration of Helsinki. The need for written informed consent was waived because of the retrospective design and the use of de-identified patient data with approval from the General Hospital of PLA.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available

from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This study was supported by the National Natural Science Foundation of China (82070937, 81870640).

Authors' contributions

CZ and ZY contributed to this work equally. CZ collected and analyzed the data, drafted the initial manuscript, and revised the manuscript. ZY coordinated and supervised data collection, drafted the initial manuscript, and revised the manuscript. WQC, YG, and TJM collected the data. ZHL conceptualized and designed the study, critically reviewed the manuscript, and revised the manuscript. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

Authors' information (optional)

References

1. Melles RB, Holladay JT,Chang WJ. Accuracy of Intraocular Lens Calculation Formulas. Ophthalmology, 2018, 125(2): 169-178.
2. Abulafia A, Barrett GD, Rotenberg M, et al. Intraocular lens power calculation for eyes with an axial length greater than 26.0 mm: comparison of formulas and methods. J Cataract Refract Surg, 2015, 41(3): 548-56.
3. Kane JX,Chang DF. Intraocular Lens Power Formulas, Biometry, and Intraoperative Aberrometry: A Review. Ophthalmology, 2020.
4. Yang JY, Kim HK,Kim SS. Axial length measurements: Comparison of a new swept-source optical coherence tomography-based biometer and partial coherence interferometry in myopia. J Cataract Refract Surg, 2017, 43(3): 328-332.
5. Arriola-Villalobos P, Almendral-Gómez J, Garzón N, et al. Agreement and clinical comparison between a new swept-source optical coherence tomography-based optical biometer and an optical low-coherence reflectometry biometer. Eye (London, England), 2017, 31(3): 437-442.
6. Bang S, Edell E, Yu Q, et al. Accuracy of intraocular lens calculations using the IOLMaster in eyes with long axial length and a comparison of various formulas. Ophthalmology, 2011, 118(3): 503-6.
7. Barrett GD. An improved universal theoretical formula for intraocular lens power prediction. J Cataract Refract Surg, 1993, 19(6): 713-20.
8. Hill-RBF Calculator Version 3.0. https://rbfcalculator.com/online/. Accessed 15 January 2021
9. Kane Formula. https://www.iolformula.com. Accessed 10 January 2021
10. IOL Calculator. http://www.eyecalcs.com/WEBCALCS/IOLcalc/IOL.html. Accessed 11 January 2021
11. Barrett Universal II Formula. http://calc.apacrs.org/barrett_universal2105/. Accessed 10 January 2021
12. Emmetropia Verifying Optical (EVO) Formula. https://www.evoiolcalculator.com. Accessed 11 January 2021
13. IOL Con. https://iolcon.org. Accessed 5 January 2021
14. Gale RP, Saldana M, Johnston RL, et al. Benchmark standards for refractive outcomes after NHS cataract surgery. Eye (London, England), 2009, 23(1): 149-52.
15. Melles RB, Kane JX, Olsen T, et al. Update on Intraocular Lens Calculation Formulas. Ophthalmology, 2019, 126(9): 1334-1335.

16. Darcy K, Gunn D, Tavassoli S, et al. Assessment of the accuracy of new and updated intraocular lens power calculation formulas in 10 930 eyes from the UK National Health Service. J Cataract Refract Surg, 2020, 46(1): 2-7.
17. Cheng H, Wang L, Kane JX, et al. Accuracy of Artificial Intelligence Formulas and Axial Length Adjustments for Highly Myopic Eyes. Am J Ophthalmol, 2020, 223: 100-107.
18. Rong X, He W, Zhu Q, et al. Intraocular lens power calculation in eyes with extreme myopia: Comparison of Barrett Universal II, Haigis, and Olsen formulas. J Cataract Refract Surg, 2019, 45(6): 732-737.
19. Zhang J, Tan X, Wang W, et al. Effect of Axial Length Adjustment Methods on Intraocular Lens Power Calculation in Highly Myopic Eyes. Am J Ophthalmol, 2020, 214: 110-118.
20. Carmona-González D, Castillo-Gómez A, Palomino-Bautista C, et al. Comparison of the accuracy of 11 intraocular lens power calculation formulas. Eur J Ophthalmol, 2020: 1120672120962030.
21. Connell BJ,Kane JX. Comparison of the Kane formula with existing formulas for intraocular lens power selection. BMJ open ophthalmology, 2019, 4(1): e000251.
22. Wang Q, Jiang W, Lin T, et al. Accuracy of intraocular lens power calculation formulas in long eyes: a systematic review and meta-analysis. Clin Exp Ophthalmol, 2018, 46(7): 738-749.
23. Wan KH, Lam TCH, Yu MCY, et al. Accuracy and Precision of Intraocular Lens Calculations Using the New Hill-RBF Version 2.0 in Eyes With High Axial Myopia. Am J Ophthalmol, 2019, 205: 66-73.
24. Liu J, Wang L, Chai F, et al. Comparison of intraocular lens power calculation formulas in Chinese eyes with axial myopia. J Cataract Refract Surg, 2019, 45(6): 725-731.
25. Wang L, Koch DD, Hill W, et al. Pursuing perfection in intraocular lens calculations: III. Criteria for analyzing outcomes. J Cataract Refract Surg, 2017, 43(8): 999-1002.

Tables

Table 1. Summary of intraocular lens formulas

Formula	Metrics Used	Derivation Method
SRK/T	AL, K	Theoretical
Haigis	AL, K, ACD	Theoretical
Barrett Universal II	AL, K, ACD, LT*, WTW*	Theoretical
Kane	AL, K, ACD, sex, LT*, CCT*	Theoretical/regression/artificial intelligence
EVO	AL, K, ACD, LT*, CCT*	Emmetropization
Hill-RBF3.0	AL, K, ACD, sex, WTW*, LT*, CCT*	Regression/artificial intelligence

* optional

Table 2. Demographic and biometric characteristics

Parameter	Mean ± SD	Range
Age (y)	61.37 ± 12.62	35, 88
AL (mm)	28.95 ± 2.28	26.00, 33.50
Mean K (D)	43.61 ± 1.34	40.68, 46.27
ACD (mm)	3.50 ± 0.43	2.53, 4.84
LT (mm)	4.31 ± 0.55	3.09, 5.28
IOL power (D)	10.94 ± 5.23	2.0, 19.0
Female sex, n (%)	39 (60.0%)	
Right eye, n(%)	50 (76.9%)	
AL subgroup, n (%)		
26.00≤AL<28.00 mm	26 (40.0%)	
28.00≤AL<30.00 mm	18 (27.7%)	
AL≥30.00 mm	21 (32.3%)	

Table 3. Clinical outcomes of refractive errors for each formula sorted by MAE

Formula	MAE	MedAE	ME	SD	PE≤±0.25D	PE≤±0.50D	PE≤±0.75D	PE≤±1.00D
Kane	0.323	0.298	0.000	0.402	44.6	80.0	93.8	98.5
EVO	0.335	0.285	0.000	0.437	46.2	78.4	95.4	96.9
Hill-RBF3.0	0.346	0.240	0.000	0.481	50.8	78.5	89.2	95.4
Barrett Universal II	0.361	0.313	0.000	0.472	40.0	75.4	92.3	96.9
Haigis	0.415	0.360	0.000	0.535	38.5	66.2	84.6	92.3
SRK/T	0.450	0.370	0.000	0.572	36.9	60.0	80.0	95.4

Table 4. MAE and MedAE for each formula by axial length

AL/Parameter	Kane	Hill-RBF3.0	EVO	Barrett Universal II	Haigis	SRK/T
26.00≤AL<28.00 mm						
MAE (D)	0.363	0.345	0.328	0.354	0.467	0.446
MedAE (D)	0.300	0.260	0.360	0.338	0.375	0.440
28.00≤AL<30.00 mm						
MAE (D)	0.223	0.268	0.244	0.290	0.298	0.344
MedAE (D)	0.220	0.195	0.210	0.273	0.255	0.275
AL≥30.00 mm						
MAE (D)	0.358	0.415	0.420	0.431	0.450	0.545
MedAE (D)	0.318	0.240	0.285	0.317	0.420	0.430

Figures

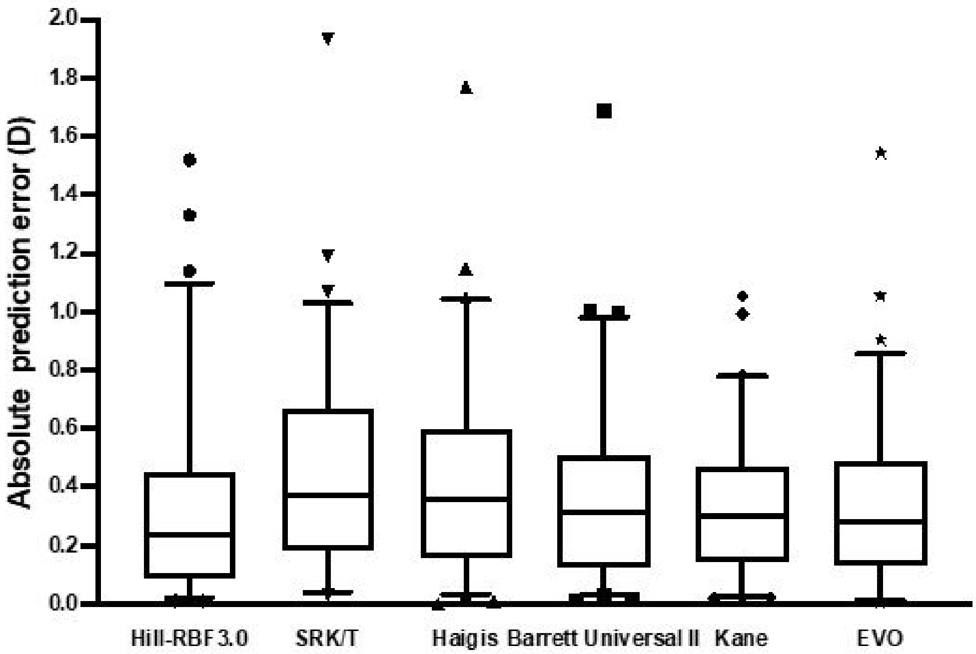

Figure 1

Box-and-whisker plots of absolute errors (in diopters) for each formula

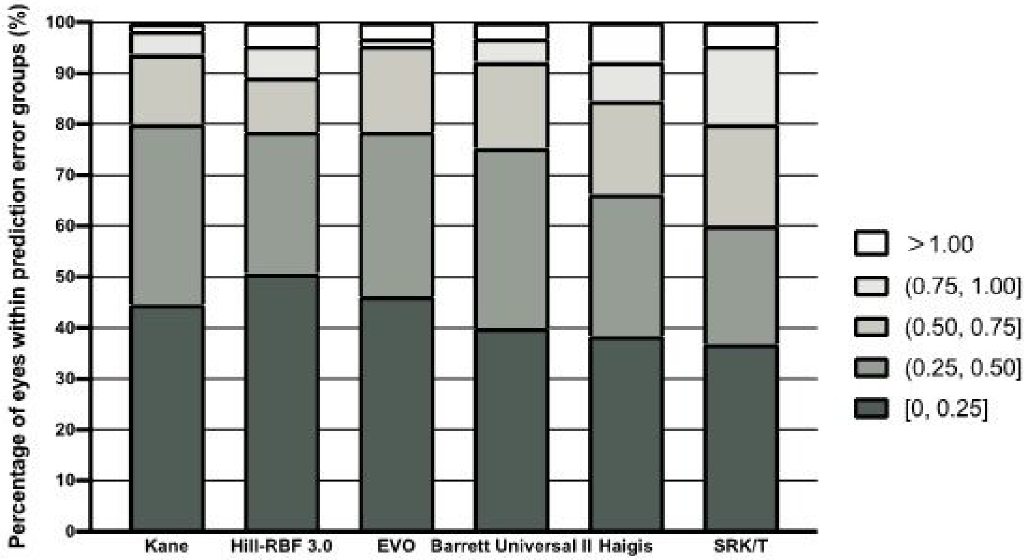

Figure 2

Stacked histogram comparing the percentage of eyes within a certain range of refractive errors for each formula

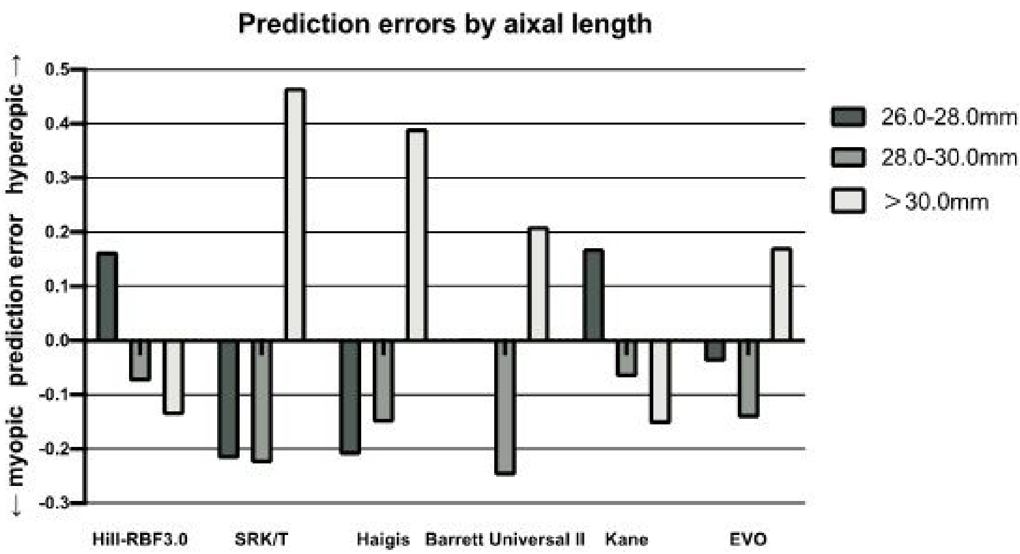

Figure 3

Comparison of prediction errors (in diopters) for each formula (axial length)

Supplementary Files

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

- BMCtable.docx