Title

Intraocular lens power calculation formula accuracy: Comparison of 12 formulas for a trifocal hydrophilic intraocular lens

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Abstract

Purpose: To evaluate the accuracy of 12 intraocular lens (IOL) power formulas; Barrett Universal II, Emmetropia Verifying Optical (EVO), Haigis, Hill-Radial Basis Function (RBF), Hoffer Q, Holladay I, Kane, Ladas Super Formula, Olsen $_{\text{Lenstar}}$, Panacea, Pearl-DGS, Sanders-Retzlaff-Kraff / theoretical (SRK/T). In addition, an analysis of the efficacy as a function of the axial length was performed.

Methods: 171 from 93 patients. 68 male eyes and 103 females eyes. Twelve IOL power formula calculations were studied with one IOL platform (trifocal hydrophilic IOL, FineVision Micro F), one biometer (Lenstar LS 900), one topographer (CSO Sirius Topographer), one surgeon and one optometrist. Optimization were determined to be zeroed mean refractive prediction error. Mean error (ME), mean absolute error (MAE), median absolute error (MedAE) and refractive accuracy within ± 1.00D was calculated. Axial length was split in short and medium eyes.

Results: One hundred and seventy eyes were included. Formulas were ranked by percentage within ± 0.50 diopters and MAE (D). Among all eyes, Olsen 86.55% (0.273D) and Barrett Universal II 86.55% (0.285D). For short eyes (<22.5 mm), Olsen 90.70% (0.273D) and Kane 90.70% (0.225D). For medium eyes, Barrett 89.34% (0.237D) and Pearl 86.89% (0.263).

Conclusion: Olsen and Barrett formula obtained excellent accuracy for overall eyes. Kane and Olsen formula obtained the best results in short eyes. For medium axial length Barret formula achieved the best accuracy results.

Keywords: intraocular lens power; calculation formual; prediction error accuracy; refractive accuracy

Introduction

Intraocular lens cataract surgery implantation is most commonly performed surgical procedure.(1) Cataract surgery is not uniquely an extraction technique and has become a refractive treatment. Many different IOL power calculation formulas are in use today. Accurate ocular biometry is imperative for the cataract management.(2) Corneal refractive power was traditionally estimated from anterior corneal measurements using fictitious refractive index(3) of the cornea under the assumption that the posterior-anterior corneal curvature radii ratio is constant.(3) Kim et al.(3) developed an adjusting method to conventional keratometry and improved the IOL power calculation without changes in the mean data value. Accurate estimation of corneal refractive power is critical for IOL power calculation.(4) Total corneal power (TCP) has taken a special importance in recent years,(5) mainly due to the advent of equipment that automatically offers calculations of TCP.(6)

Previous studies have compared other diverse formulas to calculate IOL powers and observed that third generation deliver excellent results.(7–10) To our standing, none of these studies comprised any trifocal IOL implantation. Melles et al.(10) in a recently multicenter study reported up to 81% and 98% of eyes within ± 0.50 diopters (D) and 1.00 D, respectively. In this work, Barrett Universal II formula achieved the lowest prediction error. Additionally in the update of the previous study,(11) they found that Kane formula was the most accurate IOL power calculator. Multifocal intraocular lenses (MIOLs) have allowed the correction not only sphero-cylindrical refractive errors, but also for presbyopia ones. MIOLs took aim to improve uncorrected near and intermediate visual acuity (UNVA and UIVA) without compromising uncorrected distance visual acuity (UDVA).(12) Refractive success is essential for accurate visual function in MIOLs since any residual defect is worse tolerated compared with monofocal IOLs.(13) Shajari et al.(8) using IOL Master 500 and Panoptix IOL found that Barrett Universal II, Hill-RBF, Olsen or T2 formulas obtained the better results. In addition, Bilbao-Calabuig et al.(14) reported high level of patient satisfaction with a trifocal hydrophilic IOL (FineVision Micro F, PhysIOL SA, Liège, Belgium).

The aim of our study was to examine which formula delivers the most accurate prediction error and refractive accuracy for a trifocal hydrophilic IOL power calculation in the following formulas; Barrett Universal II,(15) Emmetropia Verifying Optical (EVO),(16) Haigis, (17) Hill-Radial Basis Function (RBF),(18) Hoffer Q,(19,20) Holladay I,(21) Kane,(22) Ladas Super Formula,(23) Olsen $_{\text{Lenstar}}$,(24) Panacea, Prediction Enhanced by Artificial Intelligence and output Linearization from Debellemanière, Gatinel, and Saad (Pearl-DGS),(25) Sanders-Retzlaff-Kraff / theoretical (SRK/T).(26) In addition, prediction error and refractive accuracy were calculated for short and medium axial length eyes.

Patients and methods

One hundred seventy-one eyes from 93 patients (68 male eyes and 103 females eyes) were included in this retrospective observational chart review that included all consecutive uneventful phacoemulsification cataract or refractive lens exchange surgeries with trifocal spherical and toric hydrophilic IOL from January 2018 to December 2018 at a private practice clinic (Vistalaser ® Ophthalmology Clinic, Malaga, Spain). This work follow Helsinki Declaration tenets and obtained institutional review (Andalusia, Spain) board exemption. All patients were informed in written and oral form and sign an informed consent statement prior to all surgeries.

Inclusion criteria

Among inclusion criteria were; (1) diagnosis of age-related cataract, (2) lens refractive exchange eyes, (3) uneventful in-the bag placement of trifocal hydrophilic IOL (FineVision Micro F, PhysIOL SA, Liège, Belgium).

Exclusion criteria

Among exclusion criteria; (1) any prior corneal or intraocular surgery, (2) any corneal disease, such keratoconus or presumed keratoconus, (3) contact lens usage during the previous four weeks, (4) irregular and / or high astigmatism (over 4.0 D), (5) topographic abnormalities, (6) any systematic disease with potential impact in visual outcomes, (7) patients with no possible optical biometry measurements due to lens opacities, assessed according Lens Opacities Classification System III (LOCS), (8) intraoperative complication such anterior or posterior capsule tear, vitreous prolapse or zonular dehiscence, (9) postoperative complication such persistent corneal edema or (10) uncorrected distance visual acuity worse than 20/40.

Preoperative, surgical and postoperative procedure

Prior to all surgeries, all patient underwent an optical low-coherence reflectometry (OLCR) biometry with the Lenstar LS 900 (Haag-Streit, Köniz, Switzerland). Keratometry (K1 and K2), axial length (AXL), white-to-white (WTW), lens thickness (LT), anterior chamber depth (ACD) and corneal central thickness (CCT) were collected.

OLCR used an 820 nm infrared laser diode to measure all axial parameters. Keratometry was measured using a 1.3375 index.

Topographer and tomographer examination was carried out with Sirius (CSO, Firenze, Italy). This device combines monochromatic and rotation Scheimplug camera with a Placido disk. One topography and tomography was performed for each eye checking the quality as well as the anterior-posterior coverage. Posterior and anterior corneal face keratometry and asphericity (Q) were collected from Sirius. All preoperative exams and postoperative refraction were performed by a single expertise optometrist (E.C-R). Phacoemulsification and IOL implantation was performed by one surgeon (J-L. G-M) through a 2.2 mm temporal incision under topical double-anesthetic. Postoperative assessment included subjective manifest refraction obtained four weeks after surgeries.

Trifocal hydrophilic intraocular lens

FineVision Micro F is a single-piece aspheric, trifocal, diffractive IOL made of 25% hydrophilic acrylic materials. Diffractive patterns combines two structured effective additions for near distance (+3.50 D) and intermediate distance (+1.75 D) in the second diffractive order. IOL haptics were four and had five degrees of angulation. IOL total diameter was 10.75 mm, optic zone and body diameter was 6.15 mm. Diffractive step modify light amount for near, intermediate and distance according to pupil aperture (apodization). Spherical available powers were from +10.00 D to +35.00 in 0.50 D increment. Manufacturer-labelled A-constant was 118.80.

Formulas and Calculations

From the preoperative eye parameters; AXL, K1, K2, ACD were used for all IOL power formulas. LT in Barrett, EVO, Hill-RBF, Kane, Ladas, Olsen and Pearls-DGS. CCT was used in EVO, Hill-RBF, Kane, Olsen and Pearls-DGS. WTW was used in Barrett, Hill-RBF, Olsen and Pearls-DGS. Additionally, Kane formula need gender and Panacea formula need anterior and posterior corneal face keratometry and asphericity (Q).

Mean error (ME) is defined as the measured postoperative spherical equivalent (SE) minus the predicted SE that was estimated by each IOL power formula. A positive ME means hyperopic refractive outcome while negative ME suggests myopic refractive outcome. In addition, ME, standard deviation (SD), mean absolute error (MAE), median absolute error (MedAE) and percent of eyes within the following SE refractive prediction (± 0.25 D, ±

0.50 D, ± 0.75 D and ± 1.00 D) were calculated. Optimization was done with request assistance by authors of formula. In cases where it was not possible, each formula was optimized to zeroed mean refractive prediction error by subtracting the ME from each individual case. Thus, the standard deviation does not differ from the mean of non-optimized ME. Our patients were separated into two groups by axial length:(10,11) short eyes within AXL ≤ 22.5 mm and medium eyes within AXL > 22.5 mm and < 25.00 mm. Our sample did not obtain a sufficient number of long eyes to establish this individual group.

Statistical analysis

Sample size was assessed with the GRANMO® calculator (Institut Municipal d'Investigació Mèdica, Barcelona, Spain. Version 7.12). Two-sided test was used. Alpha and beta risk were set in 5% and 20%, respectively. Estimated standard deviation (SD) of differences was set in 0.40, Minimum ME expected difference was set in 0.10 and finally loss to follow-up rate was set in 0.10. This achieved a recommended sample size of 140 eyes. Data were analyzed with SPSS statistics software (version 26.0 for Windows; SPSS Inc, Chicago, IL, USA). Descriptive analysis was carried out with values expressed with mean ± SD. Data normality distribution was assessed with Kolmogorov-Smirnov test. Previous studies reported that the use of only one eye has had an effect on the loss of statistical power.(27) Generalized estimating equation (GEE)(28) was used according to our datasheet that included patients with one eyes and other with two eyes, previously published by Hoffer et al.(29) and Wan et al.(4) editorial. After, GEE correlated data for paired eyes, differences in absolute error between formulas were assessed with Friedman test. In significant results, post hoc analysis with Bonferroni correction for multiple comparisons. Significant p value was established with 99%, $p < 0.01$.

Results

One hundred seventy-one eyes from 93 patients were included. Population characteristics expressed in mean ± SD and range were presented in Table 1. Prediction error of each formula and percentage of eyes within different refractive outcome for overall AXL sample were presented in Table 2. Pearls-DGS and EVO obtained the lowest MAE (0.263 D and 0.270 D, respectively) while SRK / T and Ladas achieved the highest MAE (0.301 D and 0.308 D, respectively). Regarding median AE (MedAE), EVO and Olsen reported the lowest value (0.199 D and 0.200 D, respectively) whereas Ladas and Barrett achieved the highest MedAE (0.242 D and 0.250 D, respectively). There was statistically significant difference in MAE between the twelve formulas (χ^2 [11] =

29.98, P < 0.01). The Pearls-DGS achieved statistically significant lower MAE than Hoffer Q, Haigis, Ladas, and SRK/T (P < 0.01). EVO formula obtained statistically significant lower MAE than Ladas and SRK/T (P < 0.01). In accuracy refraction within ± 0.25 D, EVO and Pearls-DGS obtained the highest percentage (58.48%, both), Olsen and Barrett achieved the highest percentage in ± 0.50 D target (86.55%, both) while Ladas and SRK/T reported the lowest value (81.29% and 80.70%, respectively). Barrett reported 98.25% of eyes within ± 0.75 D whereas Ladas only achieved 93.75%. All eyes were within ± 1.00 D only for EVO, Pearls-DGS and Kane IOL power calculators. Accuracy refraction within all formulas and percentages were presented in Figure 1.

In short eyes (AXL ≤ 22.5 mm), prediction error and SD with refractive accuracy were presented in Table 3. Olsen and Kane obtained the lowest MAE (0.225 D and 0.237 D, respectively) and Hoffer Q reported the worst MAE with 0.344. In MedAE, Olsen and Kane again achieved the lowest value, 0.173 D and 0.174 D while Hoffer Q reported the worst result with 0.271 D. Our results showed statistically significant difference between the IOL power formulas (χ^2 [11] = 24.28, P = 0.01). Kane, Olsen and EVO formula reported statistically significant lower MAE than SRK/T (all, P < 0.01). In addition, Kane reported lower MAE than Hoffer Q and Barrett (P < 0.01). The best refraction accuracy within ± 0.25 D were found in EVO, Olsen and Kane while the worst result were found in Hoffer Q formula. Kane and Olsen repeat again with the best results for refraction accuracy within ±0.50 D (90.70%, both). Finally, for the medium eyes (AXL > 22.5 mm and < 25.00 mm) prediction error with SD and refractive accuracy were reported in Table 4. Pearls-DGS and Barrett obtained the best MAE results (both, 0.263) but Ladas reported the highest MAE (0.313 D). In MedAE, Panacea achieved the lowest result (0.178) whereas again Ladas resulted with the highest value (0.266). We did not find statistically significant difference between the twelve IOL power calculators for AXL > 22.5 mm and < 25.00 mm (χ^2 [11] = 18.20, P = 0.08). Regarding refractive accuracy, Panacea and EVO achieved best within ± 0.25 D results with 60.66% of the eyes. Barret obtained the best percentage (89.34% and 98.36%) within ±0.50 and ± 0.75D. All eyes of Barrett, EVO, Pearls-DGS and Kane formula were within ± 1.00 D. Seven eyes achieved long axial length (> 25.00 mm), with mean AXL of 25.90 ± 0.80 mm and mean IOL power was 14.57 ± 2.79 diopters. Due to the low sample of long eyes, an analytical study of this subgroup has not been performed. Finally, a simple resume diagram of the main ideas was presented in Figure 2.

Discussion

We found that modern formulas such EVO or Pearls-DGS achieved the lowest MAE value in overall eyes. The best refractive outcome accuracy were reported by Olsen and Barret. Kane and Olsen IOL formula calculator obtained the lowest MAE and highest refractive accuracy in AXL ≤ 22.50 mm. However, in AXL > 22.50 mm and < 25.00 mm, Barrett and Pearl-DGS reported the lowest MAE and again Barrett obtained the highest refractive accuracy. The MAE has become a simple and efficient system to compare IOL power formula prediction error.(8) MAE does not follow a Gaussian distribution, so median represent data central location. Thus, medMAE is more sensitive to outliers than MAE. Regarding clinical refractive outcomes, eyes percentage within ± 0.25 D, ± 0.50 D, ± 0.75 D and ± 1.00D could estimate accuracy and patient satisfaction.

In terms of MAE, Shajari et al.(8) and Melles et al.(10,11) found that Barret and Olsen resulted in the lowest value, which was similar with our outcomes. Similar conclusions were reported by Cooke et al.(9) and Kane et al.(7) stated that the Barrett Universal II formula to be the most precise. In contrast, our results regarding the Olsen formula disagree with the results of Cooke et al.(9) This could be explained since Cooke's eyes are longer than our sample and they reported worse results for IOL Master than Lenstar. However Cooke et al.(9) and according to our results obtained a better MAE value in short eyes than in medium eyes. In addition, Kane formula reported excellent results in short eyes. This results agree with Connell et al.(22) that reported the lowest MAE in medium length eyes. This has been confirmed in a recent study of Darcy et al.(30) in more than 10,000 eyes where he found that Kane obtained the lowest MAE for both short, medium and long eyes.

Regarding refractive accuracy, for entire AXL there is unanimity regarding the formula with greater effectiveness in terms of postoperative refraction. Barrett Universal II and Olsen formula obtained excellent results over a long series of works(8–11) that compare the result between several IOL power calculators. It is interesting to highlight the results of Shajari et al.(8) that reported bad results to Olsen formula similar to first generation formulas. The reason could be based on the fact that Shajari et al.(8) used partial coherence interferometry (PCI) in the preoperative measurements while previous cited studies(9–11) used optical low-coherence refractometry (OLCR) and achieved excellent results very similar to those reported in this study. Huang et al.(2) stated that there was no difference in the comparison of AXL, K and ACD between the PCI and OLCR. However, the WTW showed a statistically significant disparity among the two technologies. This non-interchangeability could have an effect on the result of the Olsen formula.

Recently, new variables in order to improve the calculation of the power of the IOL have been described. New IOL power formulas based on thick-lens IOL power have been developed with results that resemble the best formulas of thin-lens. Næser et al.(31) found with the Barrett Universal II formula the lowest MedAE (0.18 D); they also showed the second highest percentage of eyes with a prediction error within ±0.5 D (88.7%) and second lowest variance (0.32 D), with very tiny differences with respect to the Barrett Universal II formula. Most current calculation formulas obtain the ELP through different variables. Castro-Alonso et al.(32) have described a point representing the interphase between the cortex-epinucleus complex and the nucleus of the crystalline lens, the intracrystalline interphase point (ICIP). They concluded that the new ICIP parameter is a better predictor of the final position of the IOL than other variables of the anterior ocular segment. Likewise, new research in predictability outcomes has been developed like the study of Fernandez et al.(33) who demonstrated that higher errors of predictability can be due to pupil diameter changes during refraction using multifocal intraocular lens. They suggested to include the pupil diameter in predictability studies for exploring this finding with other multifocal or monofocal IOLs. Although it has not been a purpose of our study and in fact we did not measure or consider any of these points of view, we highly believe that futures studies should incorporate all of these new parameters in order to see if outcomes will be improved.

Within limitations, this study could have higher sample and a long AXL could not perform due to the characteristics of the patient's eyes. Fabian et al.(6) showed that for Haigis and Barrett’s IOL power formulas, applying total keratometry (TK) increased within ± 0.50 D results by approximately 2 %, however we could not include this measurements calculation. As for the strength, risk of bias has been reduced due to the presence of only one biometer, one IOL platform, one tomographer, one surgeon and one optometrist. To the best of our knowledge this is the first study to compare twelve IOL power formulas with a trifocal lens. Our results evidence good outcomes for this trifocal lens in short-medium eyes.

In conclusion, Olsen and Barrett formula obtained excellent accuracy for overall eyes. Kane and Olsen formula obtained the best results in short eyes. For medium axial length Barret formula achieved the best accuracy results. New modern formulas such EVO reported the lowest MedAE with excellent MAE results in overall eyes.

Declarations

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References

1. Aristodemou P, Sparrow JM, Kaye S. Evaluating Refractive Outcomes after Cataract Surgery. Ophthalmology. 2019; 126: 13–8.
2. Huang J, McAlinden C, Huang Y, et al. Meta-analysis of optical low-coherence reflectometry versus partial coherence interferometry biometry. Sci Rep. 2017; 7.
3. Kim M, Eom Y, Lee H, Suh YW, Song JS, Kim HM. Use of the posterior/anterior corneal curvature radii ratio to improve the accuracy of intraocular lens power calculation: Eom's adjustment method. Investig Ophthalmol Vis Sci. 2018; 59: 1016–24.
4. Wang L, Koch DD, Hill W, Abulafia A. Pursuing perfection in intraocular lens calculations: III. Criteria for analyzing outcomes. J. Cataract Refract. Surg. 2017; 43: 999–1002.
5. Savini G, Hoffer KJ, Lomoriello DS, Ducoli P. Simulated Keratometry Versus Total Corneal Power by Ray Tracing: A Comparison in Prediction Accuracy of Intraocular Lens Power. Cornea. 2017; 36: 1368–72.
6. Fabian E, Wehner W. Prediction accuracy of total keratometry compared to standard keratometry using different intraocular lens power formulas. J Refract Surg. 2019; 35: 362–8.
7. Kane JX, Van Heerden A, Atik A, Petsoglou C. Intraocular lens power formula accuracy: Comparison of 7 formulas. In: Journal of Cataract and Refractive Surgery. 2016. p. 1490–500.
8. Shajari M, Kolb CM, Petermann K, et al. Comparison of 9 modern intraocular lens power calculation formulas for a quadrifocal intraocular lens. J Cataract Refract Surg. 2018; 44: 942–8.
9. Cooke DL, Cooke TL. Comparison of 9 intraocular lens power calculation formulas. J Cataract Refract

Surg. 2016; 42: 1157–64.

10. Melles RB, Holladay JT, Chang WJ. Accuracy of Intraocular Lens Calculation Formulas. Ophthalmology. 2018; 125: 169–78.

11. Melles RB, Kane JX, Olsen T, Chang WJ. Update on Intraocular Lens Calculation Formulas. Ophthalmology. 2019; 126: 1334–5.

12. Poyales F, Garzon N. Comparison of 3-month visual outcomes of a spherical and a toric trifocal intraocular lens. J Cataract Refract Surg. 2019; 45: 135–45.

13. de Silva SR, Evans JR, Kirthi V, Ziaei M, Leyland M. Multifocal versus monofocal intraocular lenses after cataract extraction. Cochrane Database Syst. Rev. 2016; 2016.

14. Bilbao-Calabuig R, Llovet-Rausell A, Ortega-Usobiaga J, et al. Visual Outcomes Following Bilateral lmplantation of Two Diffractive Trifocal Intraocular Lenses in 10 084 Eyes. Am J Ophthalmol. 2017; 179: 55–66.

15. Barrett GD. An improved universal theoretical formula for intraocular lens power prediction. J Cataract Refract Surg. 1993; 19: 713–20.

16. Yeo KT. EVO: a new intraocular lens formula. In: XXXV Congress of the ESCRS. Lisbon, Portugal: 2017.

17. Haigis W, Lege B, Miller N, Schneider B. Comparison of immersion ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to Haigis. Graefe's Arch Clin Exp Ophthalmol. 2000; 238: 765–73.

18. Gökce SE, Zeiter JH, Weikert MP, Koch DD, Hill W, Wang L. Intraocular lens power calculations in short eyes using 7 formulas. J Cataract Refract Surg. 2017; 43: 892–7.

19. Hoffer KJ. The Hoffer Q formula: A comparison of theoretic and regression formulas. J Cataract Refract Surg. 1993; 19: 700–12.

20. Zuberbuhler B, Morrell AJ. Errata in printed Hoffer Q formula. J. Cataract Refract. Surg. 2007; 33: 2.

21. Holladay JT, Musgrove KH, Prager TC, Lewis JW, Chandler TY, Ruiz RS. A three-part system for refining intraocular lens power calculations. J Cataract Refract Surg. 1988; 14: 17–24.

22. Connell BJ, Kane JX. Comparison of the Kane formula with existing formulas for intraocular lens power selection. BMJ Open Ophthalmol. 2019; 4.

23. Ladas JG, Siddiqui AA, Devgan U, Jun AS. A 3-D super surface combining modern intraocular lens formulas to generate a super formula and maximize accuracy. JAMA Ophthalmol. 2015; 133: 1431–6.

24. Olsen T. Prediction of intraocular lens position after cataract extraction. J Cataract Refract Surg. 1986; 12: 376–9.

25. Debellemaniere G, Mathieu D, Moran S, et al. Comparison of the PEARL-DGS IOL Calculation Formula With the ASCRS Calculator Formulas in Eyes With Previous Corneal Refractive Surgery. In: The Annual Meeting of the International Society of Refractive Surgery (ISRS). San Francisco, California, USA: 2019.

26. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens implant power calculation formula. J Cataract Refract Surg. 1990; 16: 333–40.

27. Murdoch IE, Morris SS, Cousens SN. People and eyes: Statistical approaches in ophthalmology. Br J Ophthalmol. 1998; 82: 971–3.

28. Koper N, Manseau M. Generalized estimating equations and generalized linear mixed-effects models for modelling resource selection. J Appl Ecol. 2009; 46: 590–9.

29. Hoffer KJ, Aramberri J, Haigis W, et al. Protocols for studies of intraocular lens formula accuracy. Am. J. Ophthalmol. 2015; 160: 403-405.e1.

30. Darcy K, Gunn D, Tavassoli S, Sparrow J, Kane JX. 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: 2–7.

31. Næser K, Savini G. Accuracy of thick-lens intraocular lens power calculation based on cutting-card or calculated data for lens architecture. J Cataract Refract Surg. 2019; 45: 1422–9.

32. Castro-Alonso FJ, Bordonaba-Bosque D, Piñero DP, Latre-Rebled B. Predictive value of intracrystalline interphase point measured by optical low-coherence reflectometry for the estimation of the anatomical position of an intraocular lens after cataract surgery. J Cataract Refract Surg. 2019; 45: 1294–304.

33. Fernández J, Rodríguez-Vallejo M, Martínez J, Tauste A, Piñero DP. New Approach for the Calculation of the Intraocular Lens Power Based on the Fictitious Corneal Refractive Index Estimation. J Ophthalmol. 2019; 2019.

Figure legends

Figure 1. Stacked histogram assessing the percentage of eyes within ± 1.00 diopter of predicted spherical equivalent refraction outcome among the twelve formulas for the trifocal hydrophilic Fine Vision Micro F.

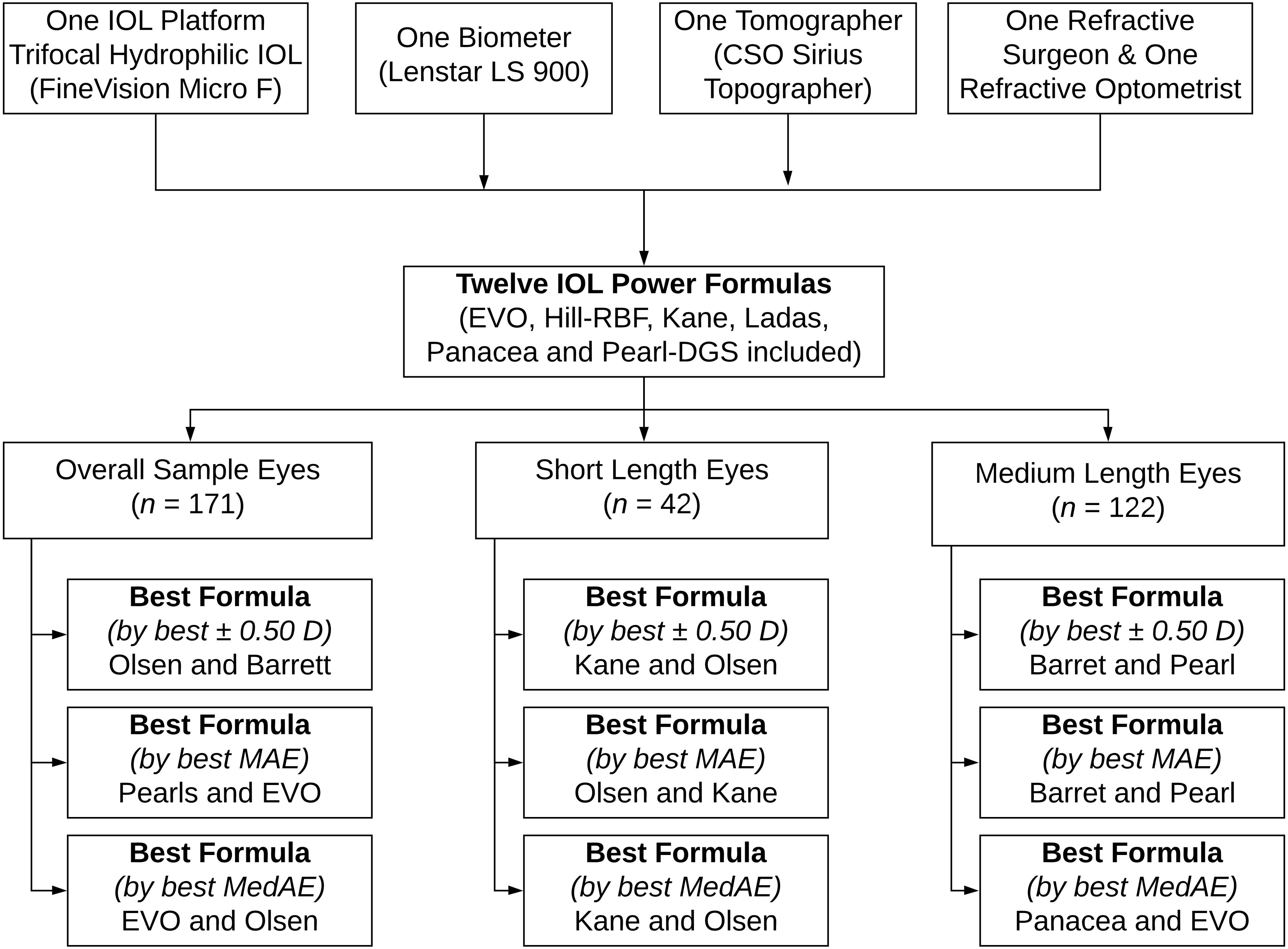
Figure 2. Summary idea diagram

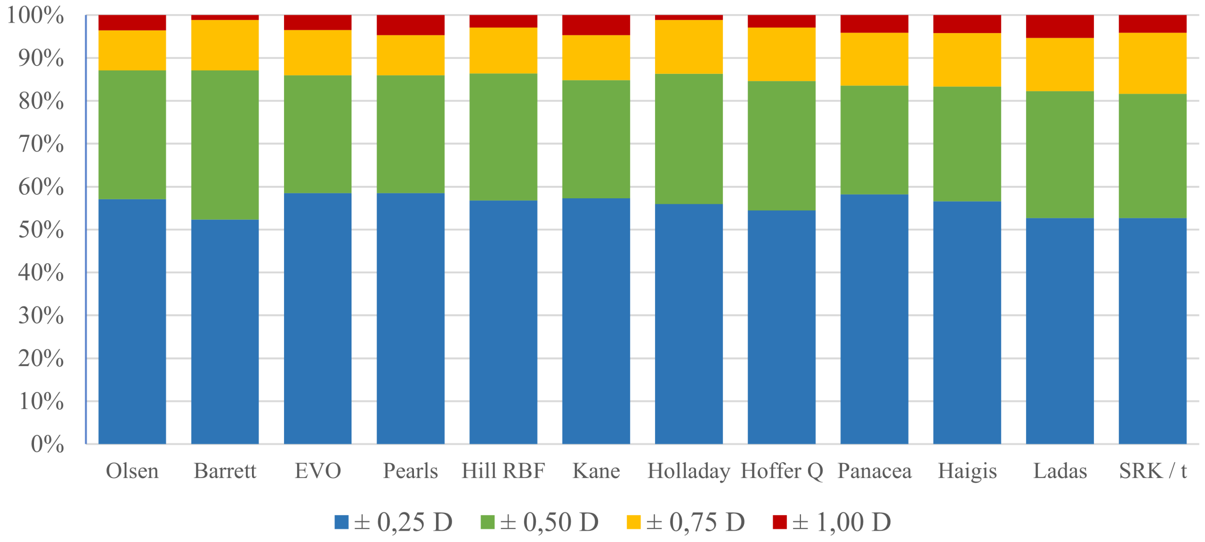
Table 1. Study population characteristics (n=171)	
Parameter	Value
Age (years)	61.04 ± 7.44 (47 to 82)
Sex (Male / Female) %	68 (40%) / 102 (60%)
Eye (Right / Left) %	83 (48.8%) / 87 (51.2)
AXL (mm)	23.16 ± 1.04 (20.33 to 27.15)
AD (mm)	2.64 ± 0.32 (1.82 to 3.49)
ACD (mm)	3.18 ± 0.32 (2.42 to 4.03)
Lens Thickness (mm)	4.45 ± 0.34 (3.09 to 5.51)
K_1 – Biometry (D)	43.18 ± 1.41 (38.97 to 4705)
K_2 – Biometry (D)	43.81 ± 1.39 (40.09 to 47.46)
K_{mean} – Biometry (D)	43.50 ± 1.39 (39.74 to 47.26)
WTW (mm)	12.28 ± 0.43 (11.00 to 13.50)
CCT (μm)	542.47 ± 32.05 (446.00 to 603.00)
AC K_1 – Topographer (D)	43.17 ± 1.41 (38.81 to 47.11)
AC K_1 – Topographer (D)	43.76 ± 1.35 (40.16 to 47.54)
PC K_1 – Topographer (D)	-6.04 ± 0.27 (-6.96 to -4.08)
PC K_1 – Topographer (D)	-6.35 ± 0.22 (-7.12 to -5.85)
Q (eccentricity)	-0.12 ± 0.13 (-0.51 to +0.19)
IOL power	22.51 ± 2.93 (11.00 to 31.00)
Value (Mean ± SD and Range). AXL: Axial Length; AD: Aqueous Depth; ACD: Anterior Chamber Depth; K: Keratometry; D: Diopter; WTW: White-To-White; CCT: Corneal Central Thickness; AC: Anterior Cornea; PC: Posterior Cornea; IOL: Intraocular Lens	

Table 2. Prediction error of each formula (all AXL, n=171)							
Formula	Refractive Prediction Error						
	Opt. ME ± SD (D)	MAE ± SD (D)	Med AE (D)	±0.25 D (%)*	±0.50 D (%)*	±0.75 D (%)*	±1.00 D (%)*
Olsen	0.00 ± 0.353	0.273 ± 0.223	0.200	56.73	86.55	95.91	99.42
Barrett	0.00 ± 0.351	0.285 ± 0.204	0.250	52.05	86.55	98.25	99.42
EVO	0.00 ± 0.348	0.270 ± 0.218	0.199	58.48	85.96	96.49	100.00
Pearls	0.00 ± 0.340	0.263 ± 0.214	0.210	58.48	85.96	95.32	100.00
Hill RBF	0.00 ± 0.364	0.283 ± 0.228	0.230	56.14	85.38	95.91	98.83
Kane	0.00 ± 0.356	0.276 ± 0.223	0.228	57.31	84.80	95.32	100.00
Holladay	0.00 ± 0.364	0.284 ± 0.227	0.238	54.97	84.80	97.08	98.25
Hoffer Q	0.00 ± 0.379	0.296 ± 0.235	0.241	53.80	83.63	95.91	98.83
Panacea	0.00 ± 0.362	0.278 ± 0.232	0.204	57.89	83.04	95.32	99.42
Haigis	0.00 ± 0.390	0.294 ± 0.256	0.225	55.56	81.87	94.15	98.25
Ladas	0.00 ± 0.399	0.308 ± 0.254	0.242	52.05	81.29	93.57	98.83
SRK / t	0.00 ± 0.386	0.301 ± 0.240	0.233	52.05	80.70	94.74	98.83
Opt. ME: Optimized mean error; SD: standard deviation; MAE: mean absolute error; Med AE: Median absolute error; RBF: Radial basis function; * = Eyes with predictive error between ±0.25 D, ±0.50 D, ±0.75 D and ±1.00 D							

Table 3. Prediction error of each formula for short eyes. AXL ≤ 22.50 mm (21.88 ± 0.49 mm) (n=42)							
Formula	Refractive Prediction Error						
	Opt. ME ± SD (D)	MAE ± SD (D)	Med AE (D)	±0.25 D (%)*	±0.50 D (%)*	±0.75 D (%)*	±1.00 D (%)*
Kane	0.00 ± 0.321	0.237 ± 0.214	0.173	65.12	90.70	95.35	100.00
Olsen	0.00 ± 0.313	0.225 ± 0.214	0.174	65.12	90.70	95.35	97.67
EVO	0.00 ± 0.322	0.244 ± 0.207	0.192	69.77	88.37	97.67	97.67
Pearl	0.11 ± 0.323	0.258 ± 0.220	0.210	62.79	86.05	93.02	100.00
Ladas	0.00 ± 0.394	0.283 ± 0.272	0.190	62.79	83.72	97.67	97.67
Hill RBF	0.00 ± 0.397	0.300 ± 0.257	0.221	60.47	83.72	95.35	97.67
Panacea	0.00 ± 0.371	0.286 ± 0.232	0.232	55.81	83.72	95.35	100.00
Barrett	0.00 ± 0.391	0.305 ± 0.240	0.253	54.76	80.95	95.24	97.62
Haigis	0.00 ± 0.434	0.300 ± 0.310	0.180	54.76	78.57	92.86	97.62
SRK / t	0.00 ± 0.409	0.327 ± 0.241	0.238	52.38	78.57	95.24	100.00
Holladay	0.00 ± 0.390	0.300 ± 0.244	0.236	52.38	78.57	95.24	97.62
Hoffer Q	0.00 ± 0.448	0.344 ± 0.282	0.271	47.62	73.81	90.48	97.62
Opt. ME: Optimized mean error; SD: standard deviation; MAE: mean absolute error; Med AE: Median absolute error; RBF: Radial basis function; * = Eyes with predictive error between ±0.25 D, ±0.50 D, ±0.75 D and ±1.00 D							

Table 4. Prediction error of each formula for medium eyes. AXL > 22.50 mm and < 25.00 mm (23.44 ± 0.56) (n=122)							
Formula	Refractive Prediction Error						
	Opt. ME ± SD (D)	MAE ± SD (D)	Med AE (D)	±0.25 D (%)*	±0.50 D (%)*	±0.75 D (%)*	±1.00 D (%)*
Barrett	0.00 ± 0.330	0.263 ± 0.197	0.237	54.92	89.34	98.36	100.00
Pearl	-0.01 ± 0.339	0.263 ± 0.214	0.210	57.38	86.89	95.90	100.00
Holladay	0.00 ± 0.352	0.275 ± 0.219	0.219	54.10	86.89	96.72	98.36
EVO	0.00 ± 0.350	0.271 ± 0.219	0.203	60.66	86.07	95.90	100.00
Hill RBF	0.00 ± 0.354	0.276 ± 0.221	0.240	56.56	86.07	97.54	98.36
Panacea	0.00 ± 0.355	0.266 ± 0.234	0.178	60.66	84.43	95.08	99.18
Olsen	0.00 ± 0.365	0.287 ± 0.224	0.225	55.74	84.43	95.08	99.18
Kane	0.00 ± 0.363	0.280 ± 0.230	0.238	53.28	84.43	95.08	100.00
Haigis	0.00 ± 0.379	0.292 ± 0.240	0.225	56.56	82.79	95.90	98.36
SRK / t	0.00 ± 0.373	0.287 ± 0.237	0.240	53.28	82.79	95.90	98.36
Hoffer Q	0.00 ± 0.359	0.284 ± 0.218	0.233	57.38	81.97	96.72	99.18
Ladas	0.00 ± 0.401	0.313 ± 0.250	0.266	48.36	81.15	92.62	99.18
Opt. ME: Optimized mean error; SD: standard deviation; MAE: mean absolute error; Med AE: Median absolute error; RBF: Radial basis function; * = Eyes with predictive error between ±0.25 D, ±0.50 D, ±0.75 D and ±1.00 D							


One IOL Platform
Trifocal Hydrophilic IOL
(FineVision Micro F)
One Biometer
(Lenstar LS 900)
One Tomographer
(CSO Sirius
Topographer)
One Refractive
Surgeon & One
Refractive Optometrist
Twelve IOL Power Formulas
(EVO, Hill-RBF, Kane, Ladas,
Panacea and Pearl-DGS included)
Overall Sample Eyes
(n = 171)
Short Length Eyes
(n = 42)
Medium Length Eyes
(n = 122)
Best Formula
(by best ± 0.50 D)
Olsen and Barrett
Best Formula
(by best MAE)
Pearls and EVO
Best Formula
(by best MedAE)
EVO and Olsen
Best Formula
(by best ± 0.50 D)
Kane and Olsen
Best Formula
(by best MAE)
Olsen and Kane
Best Formula
(by best MedAE)
Kane and Olsen
Best Formula
(by best ± 0.50 D)
Barret and Pearl
Best Formula
(by best MAE)
Barret and Pearl
Best Formula
(by best MedAE)
Panacea and EVO



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Olsen
Barrett
EVO
Pearls
Hill RBF
Kane
Holladay
Hoffer Q
Panacea
Haigis
Ladas
SRK / t
± 0,25 D
± 0,50 D
± 0,75 D
± 1,00 D