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IOL calculation in vitrectomized eyes – comparison of ten formulas and two measure modes of a well-established biometer

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Abstract

Purpose

To evaluate formulas for intraocular lens (IOL) calculation in post vitrectomy eyes and compare two measurement modes of the IOL Master 700 (Carl Zeiss, Germany).

Methods

In this two center, consecutive case series (University Clinic Frankfurt and Luebeck), post-vitrectomy eyes receiving phacoemulsification were included. Preoperative assessments included biometry using vitreous-body or post-vitrectomy mode and best corrected visual acuity (BCVA). Calculation was performed using ten formulas. Postoperative refraction (SE) and BCVA was obtained. Mean prediction error (MPE), mean and median absolute prediction error (MAE, MedAE, RMSAE), and number of eyes within a certain range (± 0.5D, ± 1.0D, ± 2.0D) from target refraction were compared.

Results

Fifity-two eyes from 52 patients (54.7 ± 11.2 years) were included. Kane showed the lowest MedAE (Table 2, 0.29D), followed by EVO and Cooke (both MedAE 0.31D), RBF (0.32D), Pearl DGS (0.34D), Hoffer QST and BUII (both 0.35D), LISA PPV (0.39D), LADAS (0.68D), and Haigis coming in last at 0.75D. Post-hoc analysis reveals that all formulas performed better than LADAS and Haigis ($p \leq 0.001$), except for LISA PPV. Highest number of eyes within ± 0.5D was found in BUII (69%), followed by RBF and Kane (67% each). A non-significant trend of lower MedAE in eyes measured with the post-vitrectomy mode was found.

Conclusion

Using modern formulas for IOL calculation in post vitrectomy eyes reaches moderate predictability but does not the accuracy of unoperated eyes. There was no significant benefit of using the post-vitrectomy mode over the vitreous-body mode for AL measurements in our patients.

Background

Retinal and vitreous body surgery using pars plana vitrectomy (PPV) has become a standard procedure in modern ophthalmology (1, 2). Typical condition treated by PPV are retinal detachment (RD), diabetic retinopathy, macular hole, epiretinal membranes, and endophthalmitis (3). At the end of the procedure, a substitute (silicone oil [SO], gas, or air) for the vitreous body is given into the vitreous cavity depending on the surgical indication (4, 5) In cases with coexisting opacifying cataract a combined procedure of vitrectomy and phacoemulsification (phacovitrectomy) is often performed. However, this approach

appears to be associated with a higher risk of IOL related complications.(6) In younger patients, the crystalline lens is still sufficiently clear to be preserved. Nevertheless, exposure of the lens to oxygen and intraoperative stress during these procedures will accelerate cataract formation(7), and most of these eyes will require cataract surgery within months or years after the initial intervention (4).

Intraocular lens (IOL) power calculation in post-vitrectomy eyes is more challenging compared to healthy eyes(8). Prior ocular surgery can influence biometric measurements; in particular, axial length (AL) measurements may vary in post-PPV eyes. This is attributed to changes in the refractive index of the vitreous cavity and potentially altered effective lens position (ELP), including a posterior shift, which may result in a more hyperopic refractive outcome in phacovitrectomy eyes(9).

Even small inaccuracies in AL measurement can substantially affect postoperative refractive prediction error, with 0.1 mm deviation corresponding to approximately 0.22 diopters (D) in a 23 mm eye(10). Similar considerations apply in eyes filled with silicone oil (SO)(11–13), where AL correction can improve IOL power estimation(12).

Given that the vitreous consists predominantly of water and has a similar ultrasound (US) velocity to aqueous humor (1530 m/s),(10) ultrasound-based measurements would be expected to remain largely comparable in post-PPV eyes. However, this does not account for optical properties. Changes in refractive index after vitreous removal may therefore influence on axial lenghth measurements obtained using partial coherence interferometry (PCI), such as the IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany).

To compensate for these effects, a post-vitrectomy measurements mode IOL calculation in eyes with gas or air. Nevertheless, refractive predictability remains reduced, depending on the formula is used (14). Studies comparing different IOL calculation formulas and measurement modes in post-vitrectomy eyes are scarce, remain limited, especially those including a sufficient number of cases.

Therefore, this investigation aims to evaluate the IOL power calculation in post-vitrectomy eyes using ten different modern formulas, including artificial intelligence (AI)-based approaches, and to compare two vitreous cavity modes (post-vitrectomy vs. standard vitreous body setting) of the IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany).

Methods

Study design

This trial is a two center, retrospective, consecutive case series conducted at the Department of Ophthalmology, University Medical Center Schleswig Holstein, Campus Luebeck, Germany, and Department of Ophthalmology, Goethe-University, Frankfurt am Main, Germany. Medical records of all patients who underwent phacoemulsification with IOL implantation at both centers with a history of prior vitrectomy (without SO) between January 2016 to January 2026 were reviewed. The study protocol was

approved by the local Ethics Committee of the University of Luebeck, Germany as a two-center trial and adhered to the tenets of the Declaration of Helsinki. Due to the retrospective nature and anonymized data, no patient informed consent was needed.

Inclusion and Exclusion Criteria

Eyes meeting the following inclusion criteria were eligible for analysis: pseudophakia with a monofocal IOL history of prior pars plana vitrectomy without SO-tamponade. Availability of complete IOLMaster 700 biometry data, postoperative manifest refraction and visual acuity measurements and uncomplicated intra- and postoperative course.

Eyes were excluded if they had a history of corneal surgery, use of the SO-measurement mode in the IOLMaster, pseudophakia with an IOL other than an monofocal lens, ocular comorbidities potentially affecting postoperative refraction, or missing pre- or postoperative data.

Preoperative and postoperative assessment

Preoperative biometric parameters, including keratometry, axial length (AL), anterior chamber depth (ACD), lens thickness (LT), central corneal thickness (CT) and white-to-white (WTW) horizontal corneal diameter, were obtained using a partial coherence interferometry integrated in the IOLMaster 700 (Carl Zeiss Meditec AG, Jena, Germany). Measurements were performed using either the “post-vitrectomy” or “vitreous body” mode of the device, as applicable.

Postoperative refraction was assessed by a trained ophthalmic nurse using an autorefractometer (Topcon, Tokyo, Japan)

Intraocular lenses, Calculation, and Surgery

Only patients implanted with one of the following monofocal IOLs were included: **1.** AAB00 (Johnson & Johnson, CA, USA). hydrophobic acrylate, 6mm monofocal aspheric, optic and 13m total diameter. **2**. SA60AT, (Alcon, Fort Worth, Texas, USA). Hydrophobic acrylate, a 6mm monofocal, optic and 13mm total diameter. **3.** SN60AT (Alcon, Fort Worth, Texas, USA): Same as SA60AT but with blue-light filter. **4.** Vivinex (HOYA, Singapore), hydrophobic acrylate, 6mm monofocal optic, 13mm totl diameter. IOL constants for all lenses were optained from the ULIB data base (LISA PPV, LADAS Super Formula, Haigis) or by the ESCRS online IOL calculator.

Pars plana vitrectomy used 3 or 4 ports (23 Gauge or smaller) and filling the vitreous cavity with gas (SF_6) or air afterwards. Standard phacoemulsification was performed using a 2.2mm clear corneal incision. The lens was always implanted into the capsular bag.

Calculation of the prediction error

The formulas evaluated were Cooke K6, Hoffer QST, Pearl DGS, Haigis, Barrett Universal II (BUII), RBF 3.0, EVO, LADAS Super Formula, LISA PPV, and Kane. Calculation was performed March 2026 with the latest

available versions of the said formulas. A refractive index of 1.332 was used for all calculations (standard index of IOL Master 700).

The predicted residual refraction (spherical equivalent, SE) at the spectacle plane (vertex distance 12mm) for the implanted IOL was calculated for each formula and by using the actual postoperative refraction (SE) the prediction error was calculated. A positive value would be a hyperopic, a negative value a myopic prediction error.

Example: Measured refraction: +0.5D, postop refraction: -0.5D = +1.0D hyperopic prediction error (the predicted refraction is more hyperopic than the achieved).

Outcome measures

The percentage of eyes within ±0.5D, ±1.0D, and ±2.0D of target refraction, mean prediction error (MPE), mean absolute error (MAE), median absolute error (MedAE), root mean square absolute error (RMSAE), and maximum respectively minimum of PE (range) were calculated and evaluated for every formula.

Statistical analysis

Available data was tested for normal distribution by a Kolmogorov Smirnov test. The MPE is only reported descriptively, since it doesn't reflect the outcomes adequately. To compare differences MedAE a Friedman test was used and, if a significant difference was found, a post hoc analysis with a Wilcoxon signed-rank test or paired t-test was performed. The percentage of eyes within ±0.5D, ±1.0D, and ±2.0D was compared with a Cochrane Q test. The p values were Bonferroni corrected if needed, p values under 0.05 were considered statistically significant. Statistical analyses were performed using Excel 2011 (version 16.101.3; Microsoft, WA) and SPSS (version 29.0; IBM, NY). Violin and split-violin plots are used to visualize the distribution of the AE and PE (Figure 1 and 3).

The sample size estimation was performed with the G*Power 3.1 Software (Heinrich Heine University Duesseldorf Germany). Based on a difference between the groups of 0.1D with a standard deviation of 0.2D at least 47 eyes were needed with power = 80% and α = 0.05.

Results

Preoperative Data

We included 52 eyes from 52 patients (35% female) with a mean age of 54.7 ± 11.2 years. Postoperative VA improved from 0.34 ± 0.21 to 0.61 ± 0.29 (decimal). Mean postoperative refraction (SE) was − 1.20D ± 1.25 (-3.75 to 1.75D). The preoperative biometry can be found in Table 1.

Table 1
Patient demographics (n = 52)

Age (years)	**Mean**	**SD**	**Min**	**Max**
	54.7	**11.2**	**27**	**80**
AXL (mm)	24.96	1.67	22.46	30.5
Kmean (D)	42.08	1.34	39.17	44.90
ACD (mm)	3.34	0.44	2.34	4.39
LT (mm)	4.41	0.45	3.38	5.44
CT (mm)	558.8	33.3	505	665
IOL power (D)	19.54	3.72	10.5	26.5
Postop SE (D)	-1.20	1.25	-3.75	1.75
Preop VA (decimal)	0.34	0.21	0.05	0.8
Postop VA (decimal)	0.61	0.29	0.10	1.2
SD = standard deviation, D = diopter, Kmean = mean keratometry, ACD = anterior				
chamber depth, LT = lens thickness, CT = corneal thickness, IOL = intraocular				
lens, SE = spherical equivalent, VA = visual acuity				

Table 1 here

Root mean square and median Absolute Error

Kane showed the lowest MedAE (Table 2, 0.29D) and RMSAE (0.31D), followed by EVO andCooke (both MedeAE 0.31D and RMSAE 0.61 to 0.64D), RBF (0.32 and 0.62D), Pearl DGS (both 0.34D and 0.63D), Hoffer QST and BUII (both 0.35D and 0.63 to 0.65D), LISA PPV (0.39D, 0.66D), LADAS (0.68D and 0.83D), and Haigis coming in last at 0.75D and 0.88D. Using Friedmans ANOVA shows a highly significant difference in-between the formulas ($p < 0.001$). Post-hoc analysis reveals that all formulas performed better than LADAS and Haigis ($p \leq 0.001$), except for LISA PPV that still showed a significance difference to Haigis ($p = 0.006$). There was no difference found between Haigis and LADAS ($p = 0.225$). No difference was found between long (> 26mm) and normal eyes (p from 0.151 to 0.941) for any formula.

Table 2
Formula performance for all eyes

Formula	Cooke K6	EVO	RBF	Hoffer QST	Kane	Pearl DGS	BUII	LADAS	LISA PPV	Haigis
MPE ± SD	-0.01 ± 0.81	0.04 ± 0.80	0.09 ± 0.73	0.02 ± 0.83	0.07 ± 0.83	-0.04 ± 0.81	-0.05 ± 0.83	-0.59 ± 0.89	0.10 ± 0.86	0.70 ± 0.86
MAE	0.53	0.51	0.50	0.54	0.53	0.53	0.55	0.80	0.56	0.89
MedAE	0.31	0.31	0.32	0.35	0.29	0.34	0.35	0.68	0.39	0.75
RMSAE	0.64	0.61	0.62	0.63	0.61	0.63	0.65	0.83	0.66	0.88
Range	-3.14 to 2.09	-2.96 to 2.21	-2.05 to 2.32	-2.88 to 2.28	-2.94 to 2.14	-3.09 to 2.15	-2.73 to 2.13	-4.04 to 1.95	-3.21 to 2.45	-2.48 to 3.14
Percentage and number of eyes within ± xD from target refraction										
± 0.5D	65% (34)	62% (32)	67% (35)	62% (32)	67% (35)	65% (34)	69% (36)	38% (20)	62% (32)	35% (18)
± 1.0D	88% (46)	87% (45)	87% (45)	85% (44)	83% (43)	83% (43)	85% (44)	75% (39)	87% (45)	67% (35)
± 2.0D	96% (50)	96% (50)	96% (50)	96% (50)	94% (49)	96% (50)	94% (49)	96% (50)	92% (48)	94% (49)

MPE = mean prediction error, SD = standard deviation, MAE = mean absolute error, MedAE = median absolute error, RMSAE = root mean square absolute error, D = diopter

Table 2 here

Mean Numerical Prediction Error

The MPE is shown in Table 2 including standard deviation and range. Since the MPE does not describe the performance of the calculation formula as precisely as the MAE and MedAE, we deliver only descriptive data without p values. The MPE was relatively close to zero except for LADAS with a rather myopic (-0.59D) and Haigis with a rather hyperopic PE (0.70D).

Percentage within Target Refraction

The highest number of eyes within ± 0.5D from target refraction (Table 2, Fig. 2) was found in BUII (69%, 36 eyes), RBF and Kane (67%, 35 eyes each), Pearl DGS and Cooke (65%, 34 eyes), EVO, Hoffer QST, and LISA PPV (62%, 32 eyes each), LADAS (38%, 20 eyes), and again Haigis (35%, 18 eyes). Using Cochranes Q shows a significant difference ($p < 0.001$) with all formulas performing better than LADAS and Haigis ($p < 0.001$ for all post hoc comparisons). Regarding eyes ± 1.0 from target refraction all formulas ($p < 0.001$) performed better than Haigis, except for LADAS ($p = 0.102$). There was no difference in eyes within ± 2.0D.

Subgroup analysis: Post-Vitrectomy vs. Vitreous-Body mode

Comparing eyes using the IOL Masters “vitreous body” mode for AL measures (n = 34) to eyes using the “post-vitrectomy” mode (n = 18) reveals no significant intra-formula difference in terms of MedAE or eyes within target refraction ($p > 0.05$, Table 3, supplemental Fig. 1) within the formulas itself, but still showing that regardless of the mode used, Haigis and LADAS performed worse than the rest of the formulas ($p < 0.05$). There is a trend towards a lower AE and a higher number of eyes within target refraction in eyes using the post-vitrectomy mode and looking at the split-violins plot shows that there was a wider spread of the PE with a higher standard deviation in vitreous-body mode. Still, none of this reach significance.

Table 3
Formula performance for eyes using post-vitrectomy or vitreous body mode

Post-vitrectomy mode (n = 18)										
Formula	**Cooke K6**	**EVO**	**RBF**	**Hoffer QST**	**Kane**	**Pearl DGS**	**BUII**	**LADAS**	**LISA PPV**	**Haigis**
MPE ± SD	0.14 ± 0.68	0.18 ± 0.66	0.15 ± 0.66	0.17 ± 0.68	0.13 ± 0.67	0.12 ± 0.68	0.15 ± 0.63	-0.42 ± 0.63	0.25 ± 0.67	0.81 ± 0.64
MAE	0.47	0.45	0.45	0.46	0.43	0.46	0.39	0.67	0.46	0.81
MedAE	0.28	0.28	0.27	0.25	0.24	0.36	0.20	0.65	0.29	0.62
Range	-1.0 to 1.96	-0.98 to 1.96	-0.89 to 1.96	-0.89 to 1.88	-1.04 to 2.06	-1.01 to 1.88	-0.48 to 1.96	-1.14 to 1.31	-0.57 to 2.15	0.04 to 2.50
Percentage and number of eyes within ± xD from target refraction										
± 0.5D	67% (12)	72% (13)	78% (14)	72% (13)	72% (13)	72% (13)	83% (15)	33% (6)	67% (12)	39% (7)
± 1.0D	89% (16)	89% (16)	89% (16)	89% (16)	83% (15)	83% (15)	89% (16)	78% (14)	89% (16)	72% (13)
± 2.0D	100% (18)	100% (18)	100% (18)	100% (18)	94% (17)	100% (18)	100% (18)	100% (18)	94% (17)	94% (17)
Vitreous body mode (n = 34)										
MPE ± SD	-0.09 ± 0.86	-0.04 ± 0.87	0.05 ± 0.77	-0.05 ± 0.90	0.04 ± 0.91	-0.12 ± 0.86	-0.16 ± 0.91	-0.69 ± 1.0	0.03 ± 0.95	0.64 ± 0.96
MAE	0.56	0.55	0.53	0.59	0.59	0.56	0.63	0.88	0.62	0.93
MedAE	0.33	0.35	0.40	0.42	0.34	0.30	0.40	0.71	0.43	0.86
Range	-3.14 to 2.09	-2.96 to 2.21	-2.05 to 2.32	-2.88 to 2.28	-2.94 to 2.14	-3.09 to 2.15	-2.73 to 2.13	-4.04 to 1.95	-3.21. to 2.45	-2.48 to 3.14
Percentage and number of eyes within ± xD from target refraction										
± 0.5D	65% (22)	56% (19)	62% (21)	56% (19)	65% (22)	62% (21)	62% (21)	41% (14)	59% (20)	32% (11)
± 1.0D	88% (30)	85% (29)	85% (29)	82% (28)	82% (28)	82% (28)	82% (28)	74% (25)	85% (29)	65% (22)
± 2.0D	94% (32)	94% (32)	94% (32)	94% (32)	94% (32)	94% (32)	91% (31)	94% (32)	91% (31)	94% (32)

MPE = mean prediction error, SD = standard deviation, MAE = mean absolute error, MedAE = median absolute error, D = diopter

Table 3 here

Discussion

We present the results of a retrospective, consecutive, two-center case series comparing ten different formulas for IOL power calculation in post-vitrectomy eyes undergoing phacoemulsification. While previous studies have evaluated various modern formulas in this setting(15, 16), none has directly compared different AL measurement modes, specifically the post-vitrectomy and vitreous-body modes. Others studies have relied on ultrasound-based AL measurements and older formulas such as SRK/T and SRKII (17). When compared with treatment-naïve eyes, post-vitrectomy eyes generally demonstrate higher MAE and a lower proportion of eyes within the target refraction range (18).

In the present study, 52 eyes from 52 patients were included. The lowest MedAE and RMSAE (ANOVA: $p < 0.001$) were observed in the Kane formula (0.29D and 0.31D), followed by Cooke and EVO (both MedAE 0.31D and RMSAE 0.61 to 0.64D), RBF (0.32 and 0.62D), Pearl DGS (both 0.34D and 0.63D), Hoffer QST and BUII (both 0.35D and 0.63 to 0.65D), LISA PPV (0.39D, 0.66D), LADAS (0.68D and 0.83D), and (0.75D and 0.88D). Comparable AE have been reported by Tan et al (15) in their subgroup of 28 eyes following vitrectomy without SO tamponade, where the vitreous cavity is effectively filled with aqueous humor. In their analysis, MedAE values for BUII were similar, whereas EVO, Kane, and LADAS showed slightly higher accuracy in our cohort. Conversely, the Haigis formula performed better in their study than in ours. The number of eyes within ± 0.5D was slightly lower tin their series (49% to 61% depending on the formula used).

Similarly, Lamson et al. reported on 60 eyes of 57 patients using LADAS, BUII, and RBF formulas, demonstrated a higher MedAE values and a lower proportion of eyes within the target refraction compared with our findings. Althoug additional studies exist on combined procedures or SO-filled eyes, data specifically addressing vitrectomized without SO remain limited.

Interestingly, our results suggest a higher predictability than those cited reported by Lamson, Tan, and Lee et al., while still being inferior to outcomes than treatment-naïve eyes using modern formulas (18). Comparison of the two AL measurement modes in this study demonstrated a trend towards lower PE and AE when using the post-vitrectomy mode. This finding supports the clinical relevance of built-in correction algorithms for previously operated eyes, analogous to the SO mode of the IOL Master 700. However, this difference, likely due to the limited sample size the subgroup analysis.

A tendency toward a more hyperopic refractive outcome than predicted was observed when using the vitreous-body mode. This may be explained by a posterior shift of the effective lens position due to the altered vitreous support after vitrectomy and reduced stability of the zonular capsular bag system. Similar observations have been reported in the literature (15–17).

Several limitations of this study must be acknowledged. First, its retrospective nature introduces potential bias, including variability in the timing of postoperative refraction measurements. Second,

different IOL models were used across the two centers. However, subgroup analysis showed no significant differences between lenses. Additionally, this variability relects routine clinical practice in most ophthalmic centers. Third, no IOL constant optimization was performed, which as well reflects real world practice in a relatively small cohort and is consistent with published reccomendationsfor reporting IOL calculation outcomes 1´(19). Strengths of this study include its multicenter design, adequate sample size for this specific population, and the evaluation of a broad range of modern and Ai-based IOL calculation formulas.

Conclusion

In conclusion post-vitrectomy eyes demonstrated higher MAE and MedAE compared with treatment-naïve eyes achieving target refraction. Among the evaluated Kane, Cooke, and EVO formulas showed the highest accuracy. Based on our fondings, the Haigis and LADAS formulas performed less favorably and should not be used when more modern formulas are available.

Declarations

Acknowledgment

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Conflict of interests:

M. Brinkmann: *Travel reimbursement and lecturing for* Roche and Abvie, *Lecturing for* Samsara Vision, *Travel reimbursement from* Carl Zeiss Meditec

K. Kaiser: *Lecturing for* Oculus

Jakob von Below: none

C. Geis: none

S. Rhode: none

S. Grisanti: *Consultant, Research or Lecturing* for Alcon, Allergan, Amiplant, ARC Laser, Bayer, Ciromed, Heileberg Engineering, Human Optics, iStar, Novartis, La Science, Microptix, Pfizer, Pixium, Phi-Stone, Refocus, Roche, Santen, Second Sight, Thrombogenics, Transcend, Carl Zeiss Meditec

T. Kohnen: *Consultant, Research and Lecturing for* Alcon, Oculus, Schwind, Staar, Tarsus. *Consultant and Lecturing for* Ziemer. *Research and Lecturing for* Teleon Surgical. *Consulting for* Abbvie, Geuder, LensGen, Santen, Stadapharm, Thieme, Zeiss Meditec. *Lecturing for* Allergan*,* Bausch & Lomb, Johnson & Johnson, MedUpdate, streamedup.

C. Lwowski: *Travel reimbursement from* Amgen and Carl Zeiss Meditec

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Figures

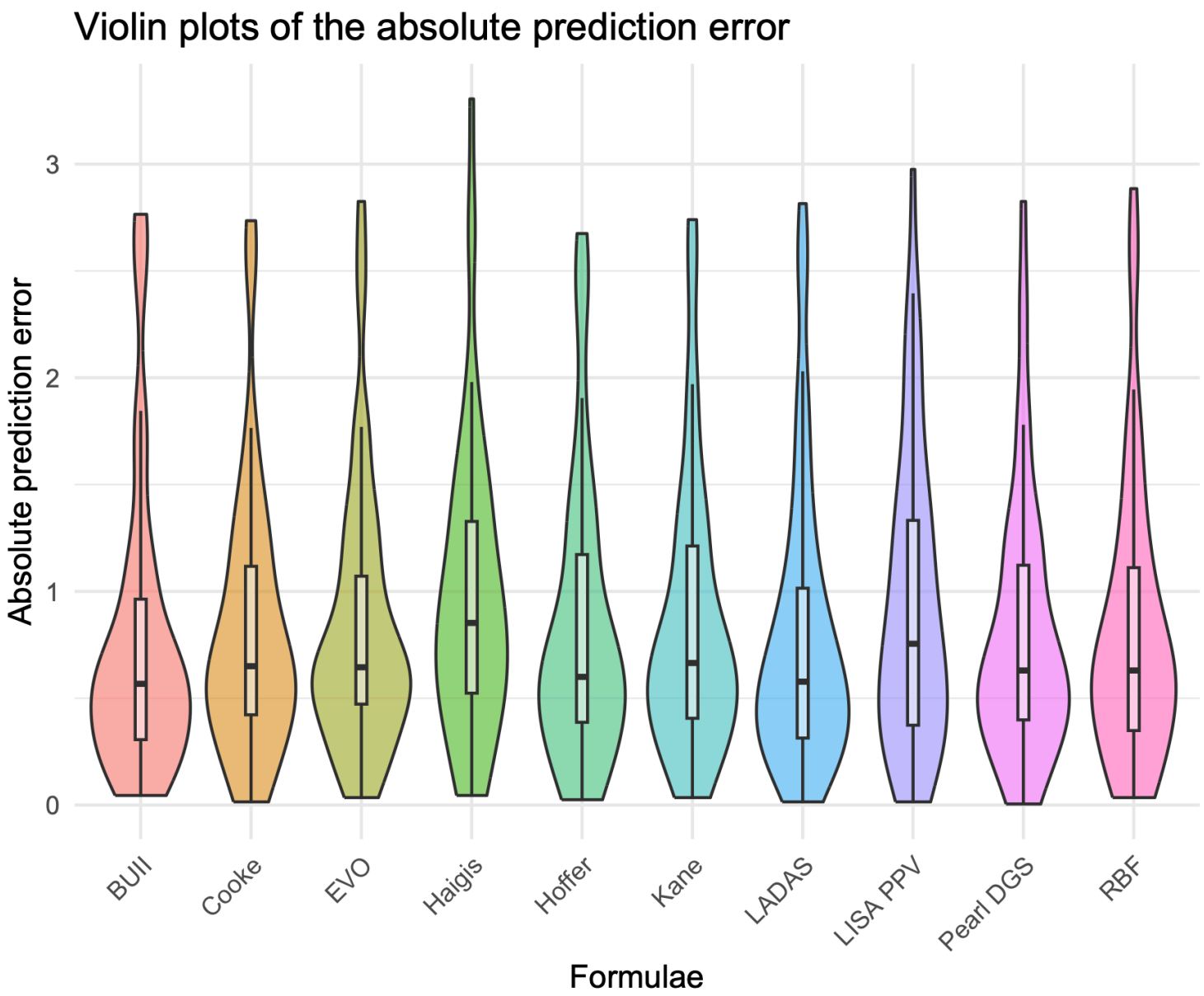


Figure 1

Violin plots of the absolute prediction error in diopter for all formulas and all eyes

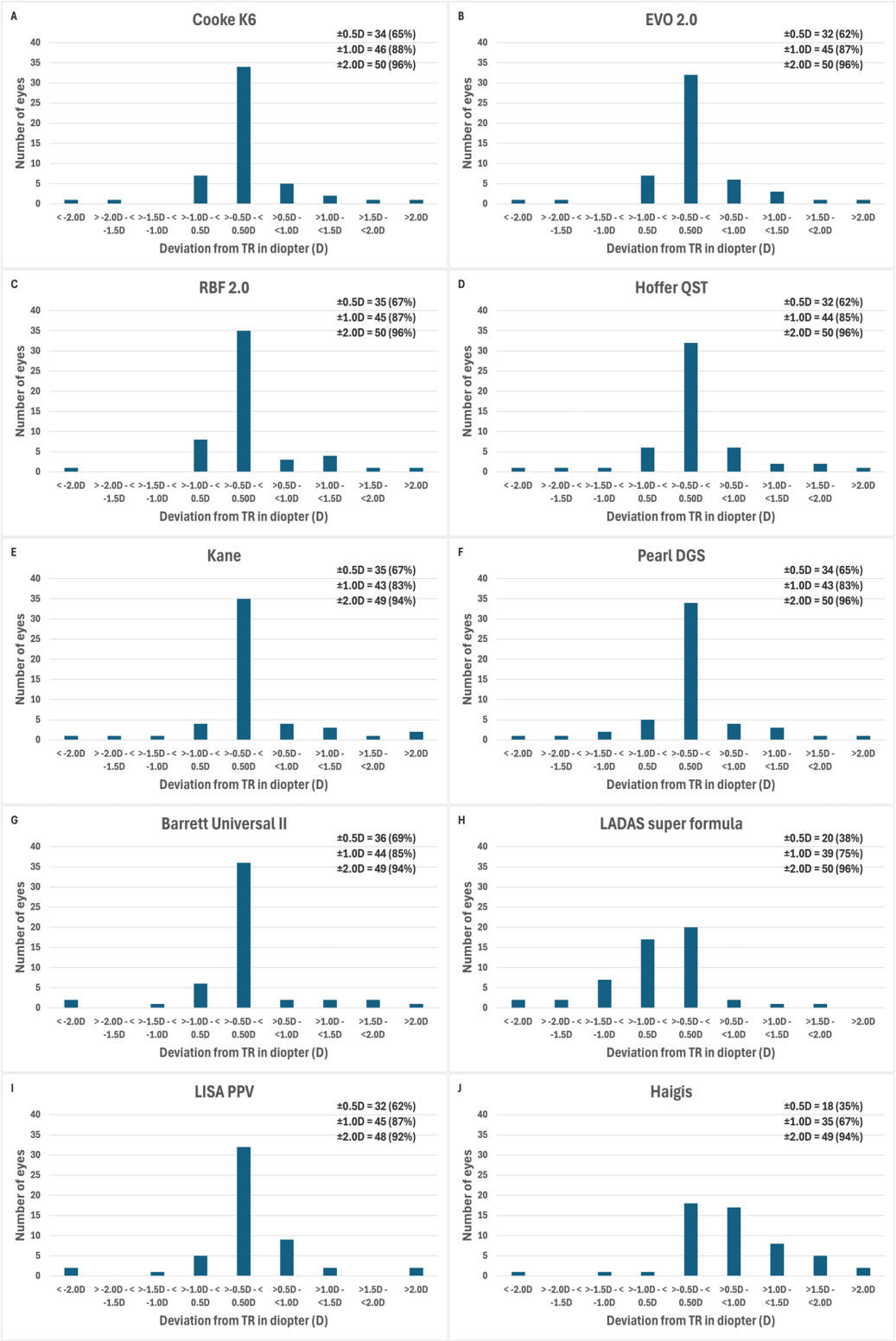


Figure 2

Distribution of the prediction error and number of eyes within a certain range from target refraction.

Supplementary Files

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- Supplementaltable1.pdf
- Supplementaltable2.pdf
- Supplementalfigure1.png
- CRediT.docx