

Longitudinal Biometric Changes and Intraocular Lens Calculation Formula Accuracy in Delayed Cataract Surgery Cases

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Purpose: To compare postoperative refractive error (PE) calculated using intraocular lens (IOL) calculation formulas based on initial and remeasured ocular parameters in cases of delayed cataract surgery.

Patients and Methods: Patients who underwent delayed cataract surgery (ie, postponed for > 3 months) between February 2017 and April 2025 were included. Initial and remeasured ocular parameters were compared, namely axial length, mean keratometric power, anterior chamber depth (ACD), and lens thickness (LT). Expected refractions were calculated using the Sanders-Retzlaff-Kraff/Theoretical (SRK/T), Haigis, Barrett Universal II (BU II), Kane, and Emmetropia Verifying Optical (EVO) formulas. PEs were compared between the initial and remeasured data for each IOL calculation formula.

Results: The study included 57 eyes from 57 patients. Cataract surgery was delayed for an average of 14 months. Comparing the initial versus remeasured data, ACD deeper significantly and LT thinner significantly among the ocular parameters. The mean PE indicated a significant myopic shift for both the Haigis formula (0.02 D to -0.05 D) and EVO formula (0.00 D to -0.06 D) (paired *t*-test: *p* = 0.04, 0.03), while the other formulas had no significant differences. The mean absolute error and median absolute error showed no significant differences among the IOL calculation formulas. Based on the remeasured data, the results of the multiple regression analysis showed that only LT was a significant associated factor in the Haigis formula (estimate = 0.56, *p* = 0.02), whereas no significant associated factors were identified for the EVO formula.

Conclusion: It was suggested that the characteristics of each IOL calculation formula must be taken into consideration when selecting IOL power for delayed surgery.

Keywords: phacoemulsification, ocular parameters, postoperative refractive error, lens thickness

Introduction

In cataract surgery, recent advancements in surgical instruments¹ and biometric technology,² as well as new-generation intraocular lens (IOL) calculation formulas,³ have markedly improved the postoperative refractive accuracy.⁴ IOL power is calculated using various formulas based on preoperative ocular parameters, and the choice of formula used is an important factor affecting postoperative refractive accuracy. These ocular parameters are obtained prior to surgery and include axial length (AL), keratometric power (K), anterior chamber depth (ACD), lens thickness (LT), and white-to-white (WTW). The third-generation Sanders-Retzlaff-Kraff/Theoretical (SRK/T)⁵ formula uses AL and K, while the fourth-generation Haigis⁶ formula uses AL, K, and ACD. New-generation IOL calculation formulas^{3,7} incorporate LT and WTW in addition to AL, K, and ACD as optional elements to improve postoperative accuracy. These baseline ocular parameters are measured when cataract surgery is scheduled. However, in reality, surgery can sometimes be postponed for several months to years due to patient circumstances, financial reasons, or other factors. At that time, a clinical judgment must be made as to whether the initial data remain appropriate for IOL power calculation. Since ocular parameters and cataracts change with age,^{8,9} these ocular parameters should be remeasured in order to properly

recalculate IOL power if surgery is postponed. However, at present, there are still no clear guidelines regarding the most appropriate ocular parameters to use in cases of delayed cataract surgery. Unfortunately, reports that describe these changes over time in the same patients are rare, and thus its impact on the IOL calculation formulas and corresponding postoperative refractive error (PE) remains unclear. This issue is particularly important for new-generation IOL calculation formulas that incorporate multiple ocular parameters, as their sensitivity to temporal changes in ocular parameters may differ among IOL calculation formulas. In other words, if cataract surgery is delayed, selecting an IOL based on initial data can result in PEs due changes ocular parameters. Conversely, selecting an IOL based on remeasured parameters can theoretically account for any changes in these ocular parameters. However, in advanced cataracts, the shape of the eye differs from the original LT and ACD, which may also cause PE.^{10,11} Therefore, changes in ACD and LT associated with cataract progression do not necessarily lead to improved accuracy simply by remeasurement. To address this knowledge gap, this study measured changes in ocular parameters in patients with delayed cataract surgery, predicted refraction based on initial and remeasured data, and compared the PE between various IOL calculation formulas.

Material and Methods

This study is a retrospective paired study of cases in which cataract surgery was delayed.

Ethics Approval and Informed Consent

This study was conducted in accordance with the provisions of the Declaration of Helsinki and was approved by the Kumamoto Clinical Ophthalmology Ethics Review Board (approval number: 2025–6). Informed consent was waived because only anonymized data was used.

Patient Selection

This study included cases wherein delayed cataract surgery (ie, postponed for more than 3 months) was performed between February 2017 and April 2025, with follow-up for 4 weeks after surgery. In-the-bag implantation was performed using a non-toric one-piece hydrophobic acrylic IOL (HOYA iSert Micro [HOYA Surgical Optical, Inc.], Tecnis OptiBlue [Johnson & Johnson Surgical Vision, Inc.],) or a three-piece hydrophobic acrylic IOL (Eternity Fine Natural [Santen Pharmaceutical Co., Ltd.]). The exclusion criteria included diseases that could influence PE other than cataracts, a history of diabetes mellitus (DM) that could influence the cornea or lens,^{12,13} previous anterior or posterior segment surgery, and best corrected visual acuity of less than 20/25 at 4 weeks postoperatively. If surgery was postponed for both eyes, then either the left or right eye was included in the analysis, selected at random. A swept-source optical coherence tomography-based biometer (OA-2000™ [TOMEY Corp. Nagoya-City, Aichi, Japan]) was used to measure ocular parameters (ie, AL, K, ACD [from the corneal epithelium to the lens], and LT) before surgery postponement and after the decision to reschedule surgery. Ocular parameters were measured by multiple experienced orthoptists, and only measurements with a signal-to-noise ratio of ≥ 3 and no warning indications were included. Remeasured data was obtained within two weeks before surgery, after the decision to operate was made.

IOL Calculation Formulas

The following formulas were used for IOL calculation: SRK/T,⁵ a vergence-based, thin-lens theoretical formula; Haigis,⁶ which is also vergence-based and incorporates thin-lens theory with a regression approach; Barrett Universal II (BU II),¹⁴ a ray-tracing-based, thick-lens theoretical formula; Kane,¹⁵ a hybrid model combining regression and artificial intelligence; and Emmetropia Verifying Optical (EVO),¹⁶ which is based on the theory of achieving emmetropia. The BU II formula was used to calculate the implanted IOL power. A-constants were adopted from the User Group for Laser Interference Biometry. For each IOL model, the constants were set as follows. For the HOYA iSert Micro (HOYA Surgical Optical, Inc.), the A-constant was 118.5 with $a_0 = -0.542$, $a_1 = 0.161$, and $a_2 = 0.204$. For the Tecnis OptiBlue (Johnson & Johnson Surgical Vision, Inc.), the A-constant was 119.5 with $a_0 = -0.329$, $a_1 = 0.332$, and $a_2 = 0.203$. For the Eternity Fine Natural (Santen Pharmaceutical Co., Ltd.), the A-constant was 119.6 with $a_0 = 1.860$, $a_1 = 0.400$, and $a_2 = 0.100$.

PE

The expected refraction of each formula was subtracted from the spherical equivalent of the objective refraction using an autorefractometer (model ARK-1a from Nidek Co., Ltd. Nagoya-City, Aichi, Japan) at 4 weeks postoperatively¹⁷ and evaluated as the refractive error. For the mean PE (ME), positive and negative values represent refractive error for hyperopia and myopia, respectively. The ME, mean absolute error (MAE), median absolute error (MedAE), and the proportion of PE were compared between the different IOL calculation formulas using both the initial and remeasured data. A modified version of the method proposed by Fernandes et al¹⁸ was used to rank the IOL calculation formulas based on multiple accuracy metrics, including the ME, standard deviation, MedAE, root mean square error (RMSE),¹⁹ and the percentage of eyes with a PE within ± 0.25 , ± 0.50 , and ± 1.00 diopters (D). Additionally, for the IOL calculation formulas in which a significant difference in PE was observed, multiple regression analysis was performed with the PE as the dependent variable and each ocular parameter as the independent variables.

Statistical Analysis

Statistical analyses were performed using RStudio (version 2025.05.1 Build 513)²⁰ following previously published protocols.¹⁷ Data normality was assessed using the Kolmogorov–Smirnov test. The χ^2 test was used to compare ages between the initial and remeasured data. The paired *t*-test was used to compare ME and MAE between each IOL calculation formula (initial and remeasured data), while the Wilcoxon signed-rank test was used to compare MedAE. McNemar’s test was used to compare the percentage of PEs. Statistical significance was set at $p < 0.05$.

Results

Table 1 shows the subjects and changes in ocular parameters based on the initial and remeasured data. The study included a total of 57 eyes from 57 patients, with a mean postponement period of 14 months (range: 3–54). Regarding the ocular parameters, there were no significant changes in AL or Mean K, but there was a significant deeper in ACD (3.13 ± 0.40 vs 3.16 ± 0.36 mm, paired *t*-test: $p = 0.04$) and a significant thinner in LT (4.69 ± 0.44 vs 4.63 ± 0.39 mm, paired *t*-test: $p = 0.04$).

Table 1 Subjects and Changes in Ocular Parameters

	Initial Data	Remeasured Data	Difference	p-Value
Postponement period (mean, range)	15 months (range: 3–54)			
Male:Female ratio (n, %)	23:34 (40%:60%)			
Age (years)	68.8 \pm 9.7	70.1 \pm 9.6	1.28 \pm 1.1	<0.01 ^{a*}
AL (mm)	24.21 \pm 1.78	24.21 \pm 1.78	0 \pm 0.03	0.80 ^b
Steep K (D)	44.43 \pm 1.28	44.36 \pm 1.27	−0.07 \pm 0.35	0.13
Flat K (D)	43.72 \pm 1.27	43.69 \pm 1.24	−0.03 \pm 0.24	0.30 ^b
Mean K (D)	44.07 \pm 1.25	44.02 \pm 1.24	−0.05 \pm 0.21	0.09 ^b
ACD (mm)	3.13 \pm 0.40	3.16 \pm 0.36	0.04 \pm 0.14	0.04 ^{b*}
LT (mm)	4.69 \pm 0.44	4.63 \pm 0.39	−0.05 \pm 0.19	0.04 ^{b*}
Cataract Grade	2.14 \pm 0.44	2.23 \pm 0.46	0.09 \pm 0.29	

Note: Data are expressed as mean \pm standard deviation, %, range. The grade of cataract was classified using the Emery–Little classification. * Compared to the initial data, the age at remeasurement data was significantly higher (a χ^2 test: $p < 0.01$), the ACD was significantly deeper, and the LT was significantly thinner (b paired *t*-test: $p = 0.04$). An asterisk (*) indicates statistical significance ($p < 0.05$).

Abbreviations: AL, axial length; K, keratometric power; ACD, anterior chamber depth; LT, lens thickness.

Table 2 shows a comparison of the ME based on the initial and remeasured data. The ME demonstrated a significant myopic shift when using both the Haigis formula (0.02 D to -0.05 D) and EVO formula (0.00 D to -0.06 D) (paired *t*-test: *p* = 0.04, 0.03). The other IOL calculation formulas demonstrated no statistically significant differences.

Table 3 compares the MAE and MedAE based on the initial and remeasured data. No significant differences were observed among all IOL calculation formulas in MAE or MedAE (paired *t*-test: *p* > 0.05, Wilcoxon signed-rank test: *p* > 0.05).

Table 4 shows the percentage of PE. No significant differences were observed among all IOL calculation formulas in the percentages of eyes within ±0.25 D, ±0.50 D, and ±1.00 D (McNemar’s test: all *p* > 0.05).

Table 2 Comparison of the Mean Postoperative Refractive Error Based on the Initial and Remeasured Data

	Initial Data (D)	Remeasured Data (D)	Difference (D)	95% Confidence Interval	p-Value
SRK/T	0.01 ± 0.60	-0.03 ± 0.60	-0.03 ± 0.17	-0.11–0.08	0.13
Haigis	0.02 ± 0.61	-0.05 ± 0.59	-0.07 ± 0.24	0.01–0.13	0.04*
BU II	0.05 ± 0.54	0.02 ± 0.54	-0.03 ± 0.22	-0.03–0.09	0.26
Kane	-0.01 ± 0.54	-0.05 ± 0.54	-0.04 ± 0.20	-0.01–0.98	0.12
EVO	0.00 ± 0.54	-0.06 ± 0.56	-0.06 ± 0.20	0.01–0.11	0.03*

Note: Displayed as mean ± standard deviation.* Only Haigis and EVO showed a statistically significant myopic shift (paired *t*-test: *p* = 0.04, 0.03). An asterisk (*) indicates a statistically significant difference between initial and remeasured data (paired *t*-test, *p* < 0.05).

Abbreviations: ME, mean postoperative refractive error; SRK/T, Sanders-Retzlaff-Kraff/Theoretical formula; BU II, Barrett Universal II; EVO, Emmetropia Verifying Optical.

Table 3 Comparison of the Mean and Median Absolute Errors Based on the Initial and Remeasured Data

	MAE (SD)			MedAE		
	Initial Data (D)	Remeasured Data (D)	p-value	Initial Data (D)	Remeasured Data (D)	p
SRK/T	0.46 ± 0.39	0.45 ± 0.39	0.61 ^a	0.34	0.34	0.46 ± 0.39
Haigis	0.47 ± 0.38	0.45 ± 0.39	0.42 ^a	0.36	0.37	0.47 ± 0.38
BU II	0.41 ± 0.36	0.40 ± 0.37	0.61 ^a	0.34	0.29	0.41 ± 0.36
Kane	0.39 ± 0.37	0.39 ± 0.38	0.94 ^a	0.27	0.28	0.39 ± 0.37
EVO	0.39 ± 0.37	0.40 ± 0.39	0.75 ^a	0.28	0.30	0.39 ± 0.37

Note: Displayed as mean ± standard deviation. * MAE and MedAE did not show a significant difference for any of the IOL calculation formulas (^a paired *t*-test, ^b Wilcoxon signed-rank test).

Abbreviations: MAE, mean absolute error; SD, standard deviation; MedAE, median absolute error; SRK/T, Sanders-Retzlaff-Kraff/Theoretical formula; BU II, Barrett Universal II; EVO, Emmetropia Verifying Optical.

Table 4 Distribution of Postoperative Refractive Error

	Initial Data			Remeasured Data		
	≤±0.25 D	≤±0.50 D	≤±1.00 D	≤±0.25 D	≤±0.50 D	≤±1.00 D
SRK/T	38.6	64.9	89.5	33.3	68.4	91.2
Haigis	35.1	64.9	87.7	36.8	70.2	91.2
BU II	43.9	71.9	89.5	42.1	68.4	91.2
Kane	47.4	71.9	91.2	47.4	73.7	93.0
EVO	47.4	68.4	93.0	47.4	73.7	93.0

Note: Displayed as %.

Abbreviations: PE, postoperative refractive error; SRK/T, Sanders-Retzlaff-Kraff/Theoretical formula; BU II, Barrett Universal II; EVO, Emmetropia Verifying Optical.

Table 5 Ranking of the Intraocular Lens Calculation Formulas Based on the Initial and Remeasured Data

	ME (D)	SD (D)	MedAE (D)	RMSE (D)	≤±0.25 D (%)	≤±0.50 D (%)	≤±1.00 D (%)	Rank
Kane (initial data)	-0.01	0.54	0.28	0.54	47.4	73.7	93.0	0.34
EVO (initial data)	0.00	0.54	0.27	0.54	47.8	71.7	91.2	0.34
Kane (remeasured data)	-0.05	0.54	0.28	0.54	47.8	71.7	87.0	0.42
BU II (remeasured data)	0.02	0.54	0.29	0.54	42.1	68.4	91.2	0.60
EVO (remeasured data)	-0.06	0.56	0.30	0.56	47.4	73.7	93.0	0.62
BU II (initial data)	0.05	0.54	0.34	0.54	43.9	71.9	89.5	0.73
Haigis (remeasured data)	-0.05	0.59	0.37	0.59	36.8	70.2	91.2	0.91
SRK/T (remeasured data)	-0.03	0.60	0.34	0.59	33.3	68.4	91.2	0.93
SRK/T (initial data)	0.01	0.60	0.34	0.60	38.6	64.9	89.5	0.95
Haigis (initial data)	-0.08	0.63	0.34	0.63	34.8	65.2	89.1	1.04

Note: The higher the rank, the higher the accuracy.

Abbreviations: ME, mean prediction error; SD, standard deviation; MedAE, median absolute error; RMSE, Root Mean Square Error; SRK/T, Sanders-Retzlaff-Kraff/Theoretical formula; BU II, Barrett Universal II; EVO, Emmetropia Verifying Optical.

Table 6 Multiple Regression Analysis Results for Haigis and EVO Based on Remeasured Data

Predictor	Haigis			EVO		
	Estimate	Standard Error	p-Value	Estimate	Standard Error	p-Value
Intercept	-7.91	3.41	0.03*	-0.52	3.48	0.88
AL	0.01	0.05	0.78	-0.03	0.05	0.62
Mean K	0.09	0.07	0.18	0.01	0.07	1.00
ACD	0.31	0.26	0.25	0.03	0.27	0.92
LT	0.56	0.21	0.02*	0.22	0.22	0.32

Notes: * In the Haigis, only LT was identified as a significant associated factor, whereas no significant associated factors were identified in the EVO. An asterisk (*) indicates a statistically significant difference between initial and remeasured data (paired t-test, $p < 0.05$).

Abbreviations: AL, axial length; K, keratometric power; ACD, anterior chamber depth; LT, lens thickness; EVO, Emmetropia Verifying Optical.

Table 5 ranks the IOL calculation formulas based on the initial and remeasured data. New-generation IOL calculation formulas (EVO and Kane) tended to demonstrate higher accuracy based on the initial data.

Table 6 shows the results of the multiple regression analysis for the Haigis and EVO formulas based on the remeasured data. In the Haigis formula, only LT was a significant associated factor (estimate = 0.56, $p = 0.02$), whereas no significant associated factors were identified for the EVO formula.

Discussion

This study compared the PEs of IOL calculation formulas based on the initial and remeasured ocular parameter data in cases of delayed cataract surgery. The main reasons for surgical delay were cases in which patients experienced improved vision after surgery in one eye and therefore judged that surgery in the fellow eye was not urgent, as well as personal factors such as work-related circumstances and anxiety about surgery. There was a significant myopic shift in ME when using the remeasured data in the Haigis and EVO formulas. Among the ocular parameters, LT demonstrated a statistically

significant decrease. A negative correlation between cortical cataract and LT has been previously documented,²¹ which is in line with our findings. Regarding the PE based on the initial and remeasured data, Yun et al²² reported that the remeasured data had a higher accuracy of IOL power calculation, in contrast with the findings of this study. This difference in results can be attributed to differences in LT associated with DM, since patients with DM have a significantly thicker LT.²³ Although the overall results of previous studies showed no significant difference in LT, their supplementary information indicated that LT was significantly thinner among patients without DM, which is consistent with the changes in ocular parameters observed in this study. Although previous studies did not compare the PE specifically among patients without DM, it is still possible that LT thickening associated with DM masked the LT thinning observed in patients without DM. A significant myopic shift in ME was seen using remeasured data with the Haigis and EVO formulas only. For the Haigis formula, this result can be attributed to the discrepancy between the predicted effective lens position (ELP) and the actual postoperative IOL position. Since the Haigis formula is a thin-lens theoretical formula, it is affected by changes in LT.²⁴ With thinner LT values, the ELP tends to be overestimated, leading to the selection of a higher-power IOL and a subsequent myopic shift in ME. Meanwhile, the EVO formula is known to have a high predictive accuracy.^{7,24–27} While the EVO formula also demonstrated high accuracy based on the remeasured data in this study, it showed even higher accuracy when based on the initial data. (Table 5). In the multiple regression analysis based on the remeasured data, LT was a significant factor in the Haigis formula (estimate = 0.56, $p = 0.02$), showing a tendency toward a hyperopic shift with thicker LT and a myopic shift with thinner LT, whereas no significant associated factors were identified for the EVO formula. The specific algorithm of EVO formula has not been disclosed, and the sample size of this study was small. Thus, the factors contributing to this myopic shift when using the remeasured data in the EVO formula could not be ascertained. The limitations of this study are as follows: the observed change in LT may fall within the range of measurement variability of the biometric device and therefore should be interpreted with caution as a true anatomical change; progression of cataract opacity may impair not only the accuracy of biometric measurements but also fundus visualization, potentially increasing measurement errors, particularly in eyes with posterior staphyloma; and the limited sample size resulted in insufficient statistical power, preventing the identification of definitive factors contributing to the myopic shift. In the supplementary linear regression analysis examining the association between the delay period and changes in ocular parameters, all p values were > 0.05 , and no significant associations were observed. The results of this study suggest that IOL power calculations based on the initial and remeasured ocular parameters may yield different PEs depending on the IOL calculation formula used. Not all IOL calculation formulas demonstrated consistent behavior, and statistically significant differences were observed in some formulas. These findings indicate that, in cases of delayed cataract surgery, the characteristics of each IOL calculation formula should be taken into consideration when determining IOL power. Further studies involving larger and more homogeneous cohorts are warranted.

Conclusion

In cases of postponed cataract surgery, a significant myopic shift was observed when remeasured data were used with the Haigis and EVO formulas. Therefore, it is suggested that IOL power selection in delayed surgery should take into account the characteristics of each IOL calculation formula.

Data Sharing Statement

The datasets generated and/or analysed during the current study are not publicly available due to patient privacy concerns and restrictions imposed by the institutional ethics committee, but are available from the corresponding author on reasonable request.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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