Original Article

Accuracy of Contemporary Intraocular Lens Calculation Formulas Based on Swept-Source OCT Biometry in Eyes with Capsular Tension Ring

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Abstract

Objectives: To compare the refractive prediction accuracy of contemporary intraocular lens (IOL) calculation formulas based on swept-source optical coherence tomography (OCT) biometry in cataract surgery with capsular tension ring (CTR) implantation, and to assess for systematic postoperative refractive tendencies.

Materials and Methods: This retrospective study included 98 eyes of 92 patients who underwent phacoemulsification with in-the-bag IOL and CTR implantation. Preoperative biometry utilized swept-source OCT (ARGOS, Alcon). Refractive prediction accuracy was evaluated for the Barrett Universal II, Haigis, SRK/T, and Holladay II formulas. Main outcomes included mean prediction error, mean absolute error (MAE), median absolute error (MedAE), and percentages of eyes within ±0.25, ±0.50, and ±1.00 diopter (D).

Results: The mean age was 73.0±8.1 years, and the mean axial length was 23.03±1.04 mm. Barrett Universal II yielded the lowest MAE and MedAE (0.36±0.34 D and 0.24 D, respectively), followed by Holladay II (0.40±0.32 D and 0.30 D). Higher MAE was observed with SRK/T (0.45±0.37 D) and Haigis (0.54±0.45 D). MAE differed significantly among the formulas ($p<0.001$), with pairwise comparisons showing that Barrett Universal II and Holladay II performed similarly ($p>0.05$) and better than both Haigis and SRK/T (all $p\leq0.003$). The highest percentage of eyes within ±0.25 D was observed with Barrett Universal II (52.04%), whereas Holladay II showed the highest percentage within ±0.50 D (69.39%), and the two formulas tied within the ±1.00 D range (both 92.86%). Prediction errors were positive for all formulas, indicating a mild hyperopic shift.

Conclusion: In eyes undergoing cataract surgery with CTR implantation, Barrett Universal II and Holladay II showed more favorable refractive prediction accuracy than Haigis and SRK/T. A mild hyperopic shift was observed across all formulas. This finding may be clinically relevant when selecting the target refraction or IOL power in these eyes.

Keywords: Capsular tension ring, cataract surgery, intraocular lens calculation, swept-source optical coherence tomography, refractive outcome

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Introduction

Cataract surgery is currently regarded as a refractive surgical procedure.[1] Therefore, accurate intraocular lens (IOL) power calculation is crucial for achieving optimal visual outcomes. With increasing patient expectations, even minor refractive errors have become clinically significant. Despite advances in biometric technologies and IOL power calculation formulas, refractive prediction errors still occur.[2] These errors are often associated with inadequacies in axial length measurement, keratometry, or the prediction of effective lens position.[3]

Capsular tension rings (CTRs) are commonly used in eyes with zonular weakness.[4] Typical indications include pseudoexfoliation (PEX) syndrome, trauma, and high myopia.[5] CTR implantation increases the stability of the capsular bag and helps maintain IOL centration.[6] Furthermore, it allows surgery to be performed more safely in eyes with compromised zonular support.[7] However, CTR implantation can alter the geometry and tension of the capsular bag.[6] These changes can affect the effective lens position, leading to unpredictable deviations in refractive outcomes.[8] In eyes with PEX, where CTRs are frequently used, it has been reported that the change in anterior chamber depth following phacoemulsification may be more pronounced compared to normal eyes.[9] Therefore, the prediction accuracy of existing IOL calculation formulas in eyes implanted with a CTR must be specifically evaluated from a clinical perspective.[8]

Modern optical biometry devices based on swept-source optical coherence tomography (OCT) provide reliable and reproducible measurements.[10] These devices offer better signal penetration, allowing for accurate axial length measurement even in eyes with dense cataract.[11] They can also improve the accuracy of IOL power calculations by providing detailed anterior segment parameters.[10] Numerous modern IOL calculation formulas have been developed to enhance refractive accuracy.[12] These formulas incorporate multiple biometric variables and utilize advanced theoretical models to better predict effective lens position.[12] However, because capsular bag dynamics may be altered in eyes that have undergone CTR implantation, the predictive performance of these formulas may differ from that in standard eyes. Therefore, it is important to specifically evaluate the accuracy of contemporary IOL calculation formulas in eyes implanted with a CTR.

The aim of this study was to compare the refractive prediction accuracy of contemporary IOL calculation formulas using preoperative swept-source OCT biometry in eyes undergoing cataract surgery with CTR implantation, and to evaluate systematic refractive tendencies that may emerge postoperatively in this patient cohort.

Materials and Methods

This retrospective, single-center study was conducted in the ophthalmology department of a tertiary university hospital. The study was approved by the Dokuz Eylül University Non-Interventional Research Ethics Committee (approval no: 2025/42-22, date: 01.12.2025) and was conducted in accordance with the principles of the Declaration of Helsinki. The requirement for informed consent was waived due to the retrospective nature of the study.

The medical records of patients who underwent phacoemulsification and IOL implantation combined with CTR implantation were reviewed retrospectively for inclusion. Only eyes with in-the-bag IOL implantation and available postoperative refraction data between 1 and 3 months were included. Patients with a history of corneal refractive surgery were excluded. Eyes with irregular astigmatism, combined ocular surgery, corneal pathology affecting keratometry, or sulcus, anterior chamber, or scleral-fixated IOL implantation were also excluded. Furthermore, we excluded eyes that developed intraoperative or postoperative complications that could affect refractive outcomes, as well as eyes with missing postoperative refractive data. For patients who underwent bilateral surgery, both eyes were included if they met the eligibility criteria.

Preoperative biometry was performed using a swept-source OCT-based biometer (ARGOS, Alcon, Fort Worth, TX, USA). Axial length, keratometry values, and anterior chamber depth were recorded. IOL power calculations were performed using the Barrett Universal II, Haigis, SRK/T, and Holladay II formulas. All eyes were implanted with an SA60AT model foldable posterior chamber IOL in the capsular bag (Alcon Laboratories, Inc., Fort Worth, TX, USA). The predicted postoperative refraction value was recorded for each formula. For constant optimization, an independent optimization cohort comprising 50 eyes that underwent uneventful phacoemulsification with the implantation of the same IOL model, without a CTR, was evaluated. The mean prediction error (MPE) of each formula in this cohort was considered the formula-specific correction value and subtracted from the prediction errors in the CTR cohort to obtain the optimized prediction error.[13]

The difference between the postoperative spherical equivalent and the predicted spherical equivalent was defined as the prediction error. For each formula, the MPE, mean absolute error (MAE), and median absolute error (MedAE) were calculated. Additionally, the percentages of eyes with a prediction error value within ±0.25 D, ±0.50 D, and ±1.00 diopter (D) were determined. Subgroup analyses were based on the absolute prediction error of the Barrett Universal II formula. These analyses were performed according to CTR diameter, axial length, anterior chamber depth, mean keratometry, and IOL power. Furthermore, absolute prediction errors were compared between eyes with and without PEX.

Statistical Analysis

Statistical analyses were performed using SPSS Statistics software (version 25.0; IBM Corp., Armonk, NY, USA). The normality of the data distribution was assessed using the Shapiro-Wilk test. Continuous variables were expressed as mean ± standard deviation or median, depending on their distribution. Absolute prediction errors were compared among the formulas using the Friedman test, and post hoc pairwise comparisons were performed when significant differences were detected. For subgroup analyses, the independent samples t-test or Mann-Whitney U test was used, depending on the data distribution. Categorical data were presented as numbers and percentages. A p value < 0.05 was considered statistically significant. To evaluate whether the inclusion of both eyes of the same patient affected the results, a sensitivity analysis was performed by randomly selecting one eye from each patient (n=92).

Results

The study included a total of 98 eyes of 92 patients. The mean age was 73.0±8.1 years, and the mean axial length was 23.03±1.04 mm. The demographic characteristics and biometric data of the patients are summarized in Table 1. In the optimization cohort of 50 eyes without CTR, the MPE was close to zero for all formulas (Barrett Universal II: +0.03 D, Haigis: +0.05 D, Holladay II: −0.06 D, SRK/T: +0.04 D).

MPE values were +0.21±0.45 D for Barrett Universal II, +0.24±0.66 D for Haigis, +0.32±0.49 D for SRK/T, and +0.19±0.48 D for Holladay II. Positive MPE values in all formulas indicated a mild hyperopic shift. MAE values ranged from 0.36±0.34 D to 0.54±0.45 D among the evaluated formulas. The lowest MAE values were observed with Barrett Universal II (0.36±0.34 D) and Holladay II (0.40±0.32 D), followed by SRK/T (0.45±0.37 D) and Haigis (0.54±0.45 D). MedAE was lowest for Barrett Universal II (0.24 D). This was followed by Holladay II (0.30 D), SRK/T (0.33 D), and Haigis (0.44 D).

Table 1. Demographic data and biometric characteristics of the patients

Variable	Value
Eye, n	98
Patients, n	92
Age (years), mean ± SD	73.03±8.10
Gender, male/female, n	46/52
Side, right/left, n	54/44
Axial length (mm), mean ± SD	23.03±1.04
Anterior chamber depth (mm), mean ± SD	3.13±0.43
Mean keratometry (D), mean ± SD	44.12±1.55
CTR diameter, 10-12 mm/11-13 mm, n	68/30

SD: Standard deviation, D: Diopter, CTR: Capsular tension ring

The difference in MAE among the formulas was statistically significant (p<0.001). In post-hoc pairwise comparisons, both Barrett Universal II and Holladay II demonstrated significantly lower MAE values compared to Haigis (both p<0.001) and SRK/T (p<0.001 and p=0.003, respectively). There was no statistically significant difference between Barrett Universal II and Holladay II (p=0.164), or between SRK/T and Haigis (p=0.131).

The percentage of eyes with prediction error values within ±0.25 D was highest for Barrett Universal II (52.04%), followed by Holladay II (41.84%), SRK/T (38.78%), and Haigis (32.65%). Within the ±0.50 D range, Holladay II showed the highest percentage (69.39%), followed by Barrett Universal II (67.35%), SRK/T (65.31%), and Haigis (56.12%). Within ±1.00 D, Barrett Universal II and Holladay II tied at the highest percentage (92.86%), followed by SRK/T (91.84%) and Haigis (85.71%).

Subgroup analysis based on CTR diameter using the Barrett Universal II formula revealed similar refractive outcomes between the groups. The MAE was 0.38±0.35 D in eyes implanted with 10-12 mm rings (n=68) and 0.32±0.32 D in eyes implanted with 11-13 mm rings (n=30). There was no statistically significant difference between the groups (p=0.566). Additional subgroup analyses based on axial length, anterior chamber depth, mean keratometry, and IOL power also showed no significant differences in refractive outcomes (all p>0.05).

Regarding CTR indications, PEX syndrome was present preoperatively in 72 (73.5%) of the 98 eyes included in the study. No significant difference in MAE was detected between eyes with and without PEX (p>0.05 for all formulas). The refractive outcomes for each formula are presented in Table 2. In the sensitivity analysis performed to evaluate the effect of including bilateral eyes (n=92), the relative ranking and statistical significance of the comparisons among formulas were maintained (Friedman χ^2=24.97; p<0.001).

Table 2. Refractive outcomes of intraocular lens calculation formulas

Formula	MPE (D)	MAE (D)	MedAE (D)	≤0.25 D (%)	≤0.50 D (%)	≤1.00 D (%)
Barrett Universal II	+0.21±0.45	0.36±0.34	0.24	52.04	67.35	92.86
Holladay II	+0.19±0.48	0.40±0.32	0.30	41.84	69.39	92.86
SRK/T	+0.32±0.49	0.45±0.37	0.33	38.78	65.31	91.84
Haigis	+0.24±0.66	0.54±0.45	0.44	32.65	56.12	85.71

MPE: Mean prediction error, D: Diopter, MAE: Mean absolute error, MedAE: Median absolute error

Discussion

This study evaluated the refractive outcomes and prediction accuracy of contemporary IOL calculation formulas in eyes that underwent cataract surgery combined with CTR implantation. Preoperative measurements were obtained using swept-source OCT biometry. Overall, the refractive outcomes were acceptable, although a mild hyperopic shift was observed with all formulas. Barrett Universal II and Holladay II stood out among the evaluated formulas with lower absolute error values, while Haigis and SRK/T were associated with higher absolute prediction errors.

The formula used for IOL power calculation is an important factor affecting the accuracy of the refractive outcome. In the literature, it has been reported that formulas incorporating different biometric parameters can provide lower prediction errors in certain patient groups compared to classic formulas.[14] It has been suggested that changes in anterior segment biometric parameters such as anterior chamber depth may influence the prediction error of IOL calculation formulas and may be associated with a hypermetropic prediction bias.[15] In studies based on swept-source OCT biometry, acceptable refractive outcomes were also achieved with formulas commonly used in clinical practice, such as Barrett Universal II, Haigis, SRK/T, and Holladay II.[16,17] In the present study, these formulas were compared in eyes implanted with a CTR. While Barrett Universal II demonstrated the lowest MAE and MedAE values, Holladay II also showed comparable absolute error.

There has been limited research specifically examining the accuracy of refractive estimation in eyes that have undergone CTR implantation. A recent study showed that Barrett Universal II provided lower absolute error values compared to Haigis and SRK/T in highly myopic eyes implanted with a CTR, and the percentage of eyes within ±0.25 D was highest with this formula.[18] Our findings are partially consistent with that study. In the current series, Barrett Universal II exhibited lower absolute error values compared to Haigis and SRK/T. However, Holladay II yielded results similar to Barrett Universal II, with no statistically significant difference between the two formulas. This finding suggests that both Barrett Universal II and Holladay II may be clinically viable options in CTR-implanted eyes measured with swept-source OCT.

Studies using swept-source OCT biometry in routine cataract surgery have reported high refractive accuracy with different IOL calculation formulas. Savini et al.[17] compared the refractive prediction performance of various formulas, including Barrett Universal II and Holladay II, and showed that acceptable results could be obtained with contemporary biometry devices. In the current series, Barrett Universal II was superior in terms of the percentage of eyes within ±0.25 D of target refraction, while Holladay II showed the highest percentage in the ±0.50 D range, and there was no difference between the two for the ±1.00 D range. This outcome suggests that both formulas can provide successful results at different accuracy thresholds in eyes with a CTR.

In our study, the MPE was found to be positive for all formulas, indicating a mild hyperopic shift. Although similar findings have been reported in previous studies related to CTRs, there is no definitive consensus on this matter. A study of patients with PEX revealed a hyperopic tendency both in eyes with and without CTR implantation, with the authors concluding that no specific modification to the formula was necessary solely due to CTR implantation.[19] Intraoperative OCT-based studies have shown that postoperative IOL position is a major source of uncertainty in refractive prediction.[20] Our results parallel these observations. Although the hyperopic shift was mild, it was consistently detected across all formulas. This finding could be taken into clinical consideration during target refraction planning for eyes undergoing CTR implantation. Furthermore, because postoperative anterior chamber depth was not evaluated in the current series, the relationship among CTR implantation, effective lens position, and refractive outcome can only be interpreted indirectly.

A previous study in highly myopic eyes reported that CTR implantation had no marked and consistent effect on refractive outcomes but could enhance the precision of refractive prediction.[21] Another more recent study demonstrated that implantation of a 13 mm CTR in eyes with long axial myopia did not significantly affect formula selection.[22] Similarly, no significant difference was detected in our subgroup analysis based on CTR diameter. Comparable refractive outcomes were obtained with Barrett Universal II in eyes implanted with 10-12 mm and 11-13 mm CTRs. Additional subgroup analyses based on axial length, anterior chamber depth, mean keratometry, and IOL power also revealed no significant differences. These findings suggest that, within the sample limits of our study, CTR diameter and the evaluated biometric variables did not significantly impact refractive prediction accuracy.

Study Limitations

This study has certain limitations, including its retrospective, single-center design. Moreover, due to the lack of postoperative anterior chamber depth data, the relationship between CTR implantation and effective lens position and refractive error could not be directly established. Therefore, deductions regarding effective lens position in our study are indirect, and prospective studies involving intraoperative or postoperative OCT-based measurements are needed to directly evaluate this mechanism. Another limitation is that next-generation formulas such as Kane and EVO 2.0 were excluded from this study because they are not included in the software of the ARGOS biometry device. Further studies should examine the predictive accuracy of these formulas in CTR-implanted eyes.

Conclusion

When evaluated with contemporary IOL calculation formulas, cataract surgery combined with CTR implantation can yield acceptable refractive outcomes. Among the evaluated formulas, Barrett Universal II and Holladay II yielded lower absolute prediction errors, whereas Haigis and SRK/T were associated with higher absolute errors. Additionally, a mild but consistent hyperopic shift was observed across all formulas. This may have clinical significance in the planning of target refraction and IOL power in eyes undergoing CTR implantation.

Ethics

Ethics Committee Approval: The study was approved by the Dokuz Eylül University Non-Interventional Research Ethics Committee (approval no: 2025/42-22, date: 01.12.2025) and was conducted in accordance with the principles of the Declaration of Helsinki.

Informed Consent: The requirement for informed consent was waived due to the retrospective nature of the study.

Declarations

Authorship Contributions

Surgical and Medical Practices: A.D., G.A., Concept: A.D., M.Y., G.A., Design: A.D., M.Y., G.A., Data Collection or Processing: A.D., M.Y., G.A., Analysis or Interpretation: A.D., M.Y., G.A., Literature Search: A.D., M.Y., Writing: A.D., M.Y., G.A.

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