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EVALUATION OF PREDICTIVE ACCURACY OF FIVE INTRAOCULAR LENS POWER CALCULATION FORMULAE IN CATARACTOUS EYES WITH SHORT AXIAL LENGTH

ANJALI TYAGI
PG Student, Department of Ophthalmology, Sharda School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh.

DIVYA SINGH
Associate Professor, Department of Ophthalmology, Sharda School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh.

ANKITA SINGH
PG Student, Department of Ophthalmology, Sharda School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh.

ABHA GAHLOT*
Professor, Department of Ophthalmology, Sharda School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh. *Corresponding Author Email: abha.gahlot@sharda.ac.in

BHUMIKA CHACHRA
PG Student, Department of Ophthalmology, Sharda School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh.

SHIVANI YADAV
PG Student, Department of Ophthalmology, Sharda School of Medical Sciences and Research, Sharda University, Greater Noida, Uttar Pradesh.

Abstract

Purpose: *To compare the predictive accuracy of five intraocular lens (IOL) power calculation formulae SRK/T, Hoffer Q, Holladay I, Binkhorst, and Barrett Universal II in cataract patients with short axial length (<22.00 mm).* ***Methods:*** *In this prospective observational study, 65 eyes with axial length <22.00 mm undergoing phacoemulsification with posterior chamber IOL implantation were included. Preoperative biometry (axial length, keratometry, anterior chamber depth) was obtained using standard immersion ultrasound. IOL power was calculated using SRK/T, Hoffer Q, Holladay I, Binkhorst, and Barrett Universal II formulae. The actual postoperative spherical equivalent (SE) was measured at 6 weeks. Absolute prediction errors (AE) were determined for each formula and compared statistically.* ***Results****: The mean age was 62.81 ± 5.17 years, with a female predominance. Significant postoperative visual improvement was observed. Hoffer Q showed the lowest mean AE (0.09± 0.09D), indicating the highest predictive accuracy, followed by Barrett Universal II (0.128 ± 0.164) and Holladay (0.227 ± 0.139). SRK/Theoretic and Binkhorst formulae demonstrated higher errors.* ***Conclusion****: Hoffer Q is the most accurate formula for IOL power calculation in short axial length eyes, with Barrett Universal II as a reliable alternative.*

Keywords: *Intraocular Lens Power Calculation, Short Axial Length, Hoffer Q, Barrett Universal II, Refractive Prediction Error, Cataract Surgery.*

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INTRODUCTION

Cataract surgery is the most common type of intraocular surgery performed by ophthalmologists across the world. The first intraocular lens was implanted in 1949 by Sir Harold Ridley, following surgery, the patient had a refractive error of minus 6.00 diopter (D) cylinder at 120 degrees and minus 18.00 diopter (D) sphere[1]. Later on, 18.00 D pre-pupillary lens was introduced by Binkhorst. The patient's refractive error remained the same as it was before cataract surgery. Thus, it became clear that accurate intraocular lens (IOL) power calculation is required and that an implant alone is insufficient. For the refractive outcome of cataract surgery, IOL power calculation is one of the most critical factor[2,3].

At present, IOL implantation is the most common method of visual rehabilitation following a cataract extraction. The third-generation formulae Holladay1, SRK/T, and Hoffer Q use axial length (AL) and corneal height to determine Effective Lens Position (ELP). Recently, the fourth-generation formula for IOL power has come into practice.

Advances in cataract surgery, along with better optical biometry and more refined IOL power-calculation methods, have significantly enhanced postoperative refractive accuracy[4].Gale et al., found that 87% of patients achieved an outcome within ±1D of the target by application of appropriate formulas, and optimizing IOL constants[5].

Emmetropia is the targeted post-operative refraction in most of the patients, while some patients are targeted for residual myopia[6]. When calculating IOL power, axial length is a crucial factor. The IOL power can fluctuate by 2.5–3.0 D for every millimetre variation in axial length. Another crucial element is corneal power. The IOL power changes by 1D when the corneal power changes by 1D[7,8]. In addition to axial length and keratometry, other factors like anterior chamber depth and corneal white-to-white distance may be needed to determine power of IOL[9].

This study prospectively compares the predictive accuracy of five IOL power calculation formulae in short axial length eyes to guide optimal formula selection in clinical practice.

MATERIALS AND METHODS

Study Design and Participants

This prospective observational study was conducted at the Department of Ophthalmology, Sharda Hospital, Greater Noida, from April 2024–November 2025 after approval from the Institutional Ethics Committee. This study adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participant. Sixty-five eyes with axial length <22.00 mm were enrolled based on Slovin's formula. Patients aged >40 years undergoing cataract surgery with posterior chamber intraocular lens (PCIOL) implantation were included. Eyes with preoperative corneal astigmatism >2.0 D, corneal pathology (e.g., keratoconus), prior keratoplasty or refractive surgery, traumatic cataract, or intra-/postoperative complications affecting refractive outcomes were excluded. Preoperative assessment included uncorrected and best-corrected visual acuity, slit-lamp examination, keratometry, intraocular pressure measurement, and immersion ultrasound biometry (axial length, anterior chamber depth, lens thickness). IOL power was calculated using SRK/T, Holladay I, Hoffer Q, Binkhorst, and online Barrett Universal II formulae. Standardized phacoemulsification PCIOL implantation (IOL power selected by Hoffer Q) was performed. Final postoperative refraction was done using an auto-refractor (Huvitz HRK AR) at 6 weeks and spherical equivalent (SE) was calculated. The formula-specific Absolute error (AE) was determined by subtracting the manifest refraction from the predicted refraction calculated by each respective formula.

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Statistical Analysis

Data were compiled in Microsoft Excel worksheet and analysis was done with the help of SPSS version 26.0.The continuous data were summarised as mean with standard deviation, median, range, and categorical data using frequency and percentage. The summarised data are represented with tables, figures, bar diagram and pie chart.

Ethical considerations

Ethical approval was obtained from the relevant institutional ethics committee. Participation was voluntary and anonymity and confidentiality were maintained.

RESULTS

Present study included total of 65 cases fulfilling inclusion criteria with mean age of 62.81±5.17yrs. Among the included cases, 70.8% were female and 29.2% were male with female preponderance in the study [Table 1]. Overall 63.1% right eye and 36.9% left eye underwent phacoemulsification [Table 2]. Most participants had moderate to severe visual impairment, with 49.2% presenting with unaided visual acuity (UVA) of 6/24 and 30.8% with 6/36. Only 15.4% had 6/18 vision and 4.6% demonstrated relatively better vision at 6/12, indicating limited good unaided visual function overall [Fig.1]. Best-corrected visual acuity (BCVA) distribution showed that 38.5% (n=25) achieved 6/12, 36.9% (n=24) achieved 6/18, 23.1% (n=15) had 6/24, and only 1.5% (n=1) remained at 6/36, indicating that the majority attained good postoperative visual acuity [Fig 2].

The study population had a mean age of 62.0 ± 5.2 years, with a median of 63 years, indicating that most participants were older adults, and the overall age range spanned 20 years. The mean intraocular pressure (IOP) was 17.0 ± 3.0 mmHg, with a median value of 17 mmHg and a range of 13 mmHg, suggesting relatively normal IOP levels across the group. Corneal curvature parameters showed mean K1 and K2 values of 45.22 ± 1.56 D and 46.26 ± 1.40 D, respectively, with moderate variability reflected in their ranges (8.55 D and 8.25 D).

Preoperative biometric measurements demonstrated a mean axial length (AL) of 21.15 ± 0.69 mm, a median of 21.36 mm, and a narrow range of 3.31 mm, indicating a generally short axial profile among participants. Lens thickness averaged 3.71 ± 0.76 mm, while the anterior chamber depth averaged 2.60 ± 0.47 mm, both showing moderate dispersion, reflecting anatomical differences within the cohort [Table 3]. The implanted intraocular lens (IOL) power had a mean of 26.1 ± 2.4 D (median 26.0 D; range 10 D), demonstrating moderate variability according to individual ocular parameters.

At 6 weeks postoperatively, the mean refractive outcome was −0.93 ± 0.39 D (median −1.00 D; range 1.25 D) and the mean spherical equivalent was −0.45 ± 0.24 D (median −0.50 D; range 1.38 D), indicating a mild, stable myopic shift close to the intended refractive target [Table 4].Among the IOL power calculation formulas, the SRK/Theoretic formula showed an MAE of 0.37 ± 0.20 D (MedAE 0.36 D; range 0.78 D), while the Binkhorst formula demonstrated a similar performance with an MAE of 0.34 ± 0.15 D (MedAE 0.35 D).

The Holladay formula performed better, with a lower MAE of 0.23 ± 0.14 D and a MedAE of 0.18 D, indicating improved predictive accuracy.The Hoffer Q formula showed the highest accuracy with the lowest MAE of 0.09 ± 0.09 D (median 0.06 D; range 0.39 D), followed by the Barrett Universal II formula with an MAE of 0.128 ± 0.164 D (MedAE 0.080 D; range 0.770 D). Overall, Hoffer Q and Barrett Universal II demonstrated superior predictive performance with the smallest errors and narrowest distributions [Table 5].

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Table 1: Gender distribution

		Frequency	Percent
Gender	Female	46	70.8
	Male	19	29.2
	Total	65	100.0

Table 2: Distribution of eye involved

		Frequency	Percent
Eye	Left	24	36.9
	Right	41	63.1
	Total	65	100.0

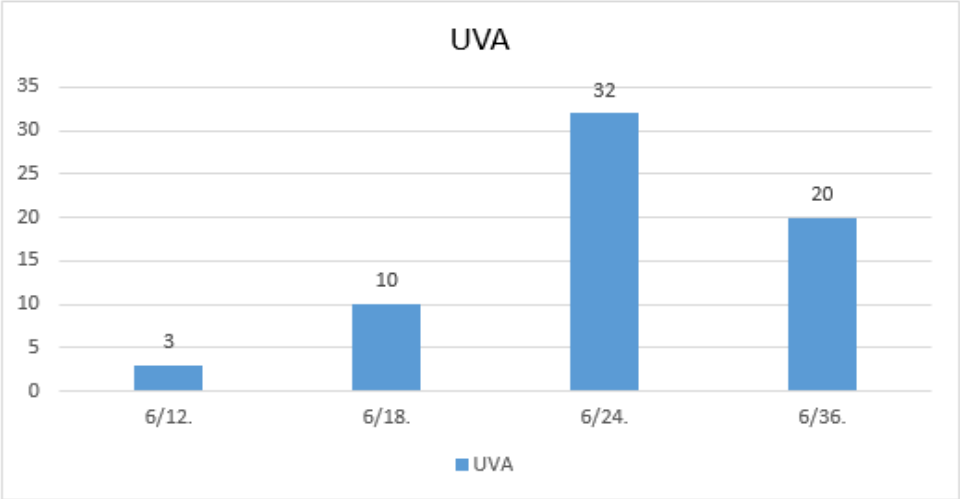

Figure 1: Distribution according to unaided visual acuity of patients

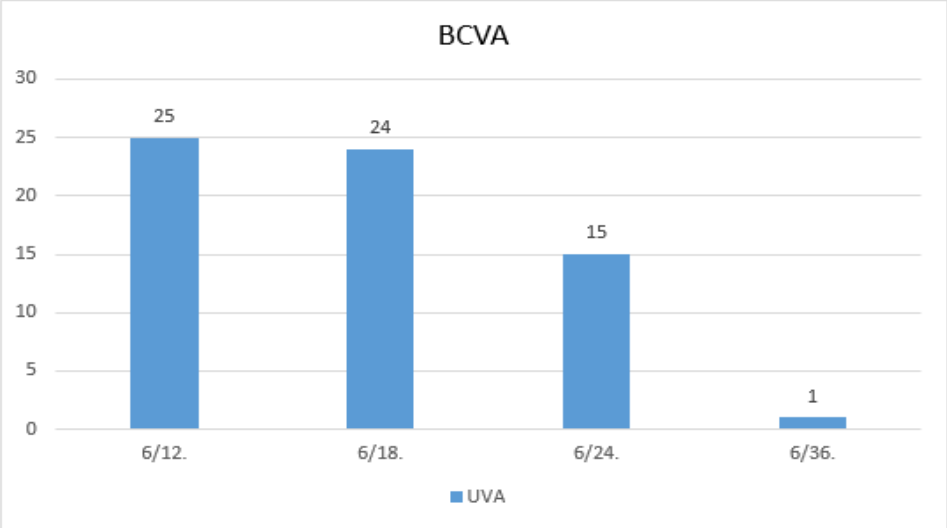

Figure 2: Distribution according to best-corrected visual acuity

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Table 3: Showing mean level of preoperative biometric and ocular measurements

	Mean ± SD	Median	Range
Age(yr)	62.0 ± 5.2	63.0	20.0
IOP	17.0 ± 3.0	17.0	13.0
K1 (D)	45.22 ± 1.56	45.30	8.55
K2 (D)	46.26 ± 1.40	46.37	8.25
Pre-op AL(mm)	21.15 ± 0.69	21.36	3.31
Pre-Op LT(mm)	3.71 ± 0.76	3.87	3.79
Pre-Op ACD(mm)	2.60 ± 0.47	2.62	2.04

Table 4: Showing the mean level of postoperative outcome

	Mean ± SD	Median	Range
IOL (D)	26.1 ± 2.4	26.0	10.0
Refraction Post-Op 6week	-0.93 ± 0.39	-1.00	1.25
SE Post-Op 6week	-0.450 ± 0.236	-0.500	1.380

Table 5: Absolute error (AE) values across different IOL power calculation formulas

	MAE (D) ± SD	MedAE	Range
SRK/Theoretic AE	0.37 ± 0.20	0.36	0.78
Holladay AE	0.23 ± 0.14	0.18	0.56
Hoffer Q AE	0.09 ± 0.09	0.06	0.39
Binkhorst AE	0.34 ± 0.15	0.35	0.60
Barrett Universal II formula AE	0.128 ± 0.164	0.080	0.770
MAE = Mean Absolute error; MedAE= Median of Absolute error			

DISCUSSION

Predicting postoperative refraction in eyes with short axial length (<22.00 mm) is particularly challenging in cataract surgery. Precise intraocular lens (IOL) power calculation is essential in these cases, as even slight variations in biometric measurements can lead to notable refractive errors. These eyes typically have steeper corneas, shallow anterior chambers, thicker lenses, and require higher-powered IOLs, all of which reduce the accuracy of IOL power calculations. Therefore, precise biometry and careful selection of the most reliable IOL formula are essential to optimize refractive outcomes and minimize postoperative error.

This study compared the predictive accuracy of five commonly used IOL power calculation formulae SRK/Theoretic, Holladay I, Hoffer Q, Binkhorst, and Barrett Universal II in eyes with axial length <22.00 mm.

The findings help identify the most reliable formula for short eyes, supporting surgeons in achieving precise refractive targets and optimal postoperative visual outcomes in this challenging group.

The present study included 65 eligible cases with a mean age of 62.0 ± 5.20 years; females constituted 70.8% and males 29.2%, showing female predominance, with the right eye involved in 63.1% of cases and the left eye in 36.9%.

Most participants initially had moderate to severe unaided visual impairment, predominantly at 6/24 and 6/36 levels. However, after correction, the majority achieved good visual outcomes, with most improving to 6/12 or 6/18, demonstrating substantial postoperative visual improvement.

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In study by Kuthirummal N et al., documented with mean uncorrected visual acuity (UCVA) at 1 month postoperatively was 0.23 ± 0.15 LogMAR, while the mean best-corrected visual acuity (BCVA) improved to 0.05 ± 0.09 LogMAR. The mean postoperative refractive error (spherical equivalent) at the same time point was 0.13 ± 0.50 D, with values ranging from –1.25 D to +1.50 D[10].

The mean implanted IOL power was 26.1 ± 2.4 D (median 26.0 D; range 10 D), indicating moderate variability based on individual ocular biometry.

At 6 weeks postoperatively, the mean refractive outcome was −0.93 ± 0.39 D (median −1.00 D; range 1.25 D) and the mean spherical equivalent was −0.45 ± 0.24 D (median −0.50 D; range 1.38 D), demonstrating a mild, stable myopic shift close to the intended refractive target.

Across the various intraocular lens (IOL) power calculation formulae, the prediction errors showed notable differences. The SRK/Theoretic formula demonstrated a mean absolute error (MAE) of 0.37 ± 0.20 D with a median absolute error (MedAE) of 0.36 D and a range of 0.78 D, indicating moderate variability. The Holladay formula performed better, with a lower MAE of 0.23 ± 0.14 D and a MedAE of 0.18 D.

The Hoffer Q formula showed the smallest error among all methods, with an MAE of 0.09 ± 0.09 D, a median of 0.06 D, and a narrow range of 0.39 D, suggesting high accuracy and consistency. The Binkhorst formula produced an MAE of 0.34 ± 0.15 D with a MedAE of 0.35 D, reflecting performance similar to the SRK/Theoretic method.

The Barrett Universal II formula also demonstrated strong accuracy with an MAE of 0.128 ± 0.164 D, a MedAE of 0.080 D, and a range of 0.770 D. Overall, the Hoffer Q and Barrett Universal II formulae showed the best predictive performance, with the lowest errors and tightest distributions.

According to Gokcee SE et al., the Hoffer Q formula produced a myopic refractive prediction error of –0.22 D, whereas the Holladay 2 formula displayed a myopic error of –0.23 D, which is consistent with the results of the current investigation [4].

Dervin E and colleagues reported that the Hoffer Q formula demonstrated a significantly smaller mean predictive error (0.59 ± 0.26 D) than the SRK-T formula (0.78 ± 0.18 D, $p < 0.0001$). Their findings suggest that for eyes with short axial lengths (<22 mm), the Hoffer Q formula provides more accurate IOL power estimations and is recommended as the primary choice [11].

Study by Kuthirummal N et al., concluded that the Barrett Universal gave the lowest mean absolute error and median absolute error and hence was the most accurate formula in predicting postoperative refraction in comparison to SRKII, SRK/T, and Olsen [10].

In contrast, Narvaez J et al. reported that all four evaluated formulas demonstrated similar accuracy in predicting postoperative spherical equivalent (SE) refractive error, with no significant differences in mean absolute error. This consistency persisted across different axial length subgroups, indicating that the formulas performed equally well regardless of axial length [12].

Marilita M et al., concluded that the Haigis formula had a significantly smaller mean absolute estimation error than Holladay1, Hoffer, and SRK/T [13].

Similarly, Srivastava AK and colleagues reported that for eyes with axial lengths under 22.0 mm, the Barrett Universal II, Hoffer Q, Haigis, Holladay 2, RBF method, and SRK/T formulas all showed equivalent precision in estimating IOL power [14].

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CONCLUSION

In eyes with short axial length (<22 mm), accurate IOL power calculation is challenging due to errors in effective lens position prediction and greater sensitivity to biometric variations. This study demonstrates that the Hoffer Q formula provides the highest predictive accuracy with the lowest mean absolute error, in accordance with standard literature recommendations. The Barrett Universal II formula also shows comparable and reliable performance as a modern alternative. In contrast, older formulas such as SRK/T and Binkhorst are less accurate in this subset of patients. Therefore, Hoffer Q followed by Barrett Universal II should be preferred to optimize postoperative refractive outcomes in short eyes.

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