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Research Article

A Comparative Study of the Predictive Accuracy of Four Iol Power Calculation Formulae in Phacoemulsification with Foldable Iol Surgery in Eye with Axial Length Less Than 22 Mm.

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ABSTRACT

Purpose: To compare the predictive accuracy of four intra-ocular lens power calculation formulae—Hoffer Q, Holladay 1, Haigis, and Hill-RBF—in cataractous eyes with axial length (AL) < 22 mm.

Methods: In this single-centre prospective study, 80 eyes of 80 patients underwent uneventful phacoemulsification with a single-piece hydrophilic acrylic IOL. Pre-operative biometry (IOLMaster 500) provided AL, keratometry and anterior chamber depth. IOL power was calculated with all four formulae, but implantation was based on Hoffer Q. Manifest refraction was recorded on postoperative day 7 and day 30. Absolute prediction error (AE = |predicted – achieved spherical-equivalent|) was the primary outcome. Differences were analysed with one-way ANOVA and Bonferroni post-hoc testing (α = 0.05).

Results: Mean age was 57.9 ± 5.8 years; 60% were women. Mean AL was 21.48 ± 0.40 mm and mean implanted IOL power was 24.76 ± 1.76 D. Spherical equivalent stabilized between day 7 and day 30 ($p = 1.000$). Mean ± SD AE differed significantly between formulae ($p < 0.001$): Hill-RBF 0.034 ± 0.217 D; Haigis 0.097 ± 0.403 D; Hoffer Q 0.231 ± 0.492 D; Holladay 1 0.403 ± 0.669 D. Hill-RBF out-performed Haigis ($p = 0.031$) and both surpassed Hoffer Q and Holladay 1 (all $p < 0.001$). Ninety-one percent of eyes calculated with Hill-RBF were within ±0.50 D of target versus 84% (Haigis), 65% (Hoffer Q) and 57% (Holladay 1).

Conclusions: Hill-RBF provided the most accurate refractive prediction in short eyes, followed by Haigis. Surgeons managing AL <22 mm should preferentially employ modern formulae that incorporate anterior segment metrics and artificial-intelligence modelling.

Keywords: Short Axial Length; Intra-Ocular Lens; Cataract Surgery; Hill-RBF; Haigis; Refractive Prediction Error.

INTRODUCTION

Precise intra-ocular lens (IOL) power calculation underpins refractive success in contemporary cataract surgery. Third-generation formulae such as Hoffer Q, Holladay 1 and SRK/T usually achieve mean absolute errors (MAE) below 0.50 D in eyes of average axial length [3,4], yet their performance deteriorates at biometric extremes. Eyes with AL < 22 mm typically present steeper corneas, shallower anterior chambers and thicker crystalline lenses, all of which amplify uncertainty in estimating the effective lens position and predispose to postoperative hyperopic surprises [5,6]. Fourth-generation formulae partially compensate by adding anterior-chamber depth and lens thickness to a three-constant construct [2], whereas data-driven algorithms, such as Barrett Universal II and Hill RBF, use large training sets or artificial intelligence modeling to capture nonlinear interactions between biometric variables [1,11]. Meta-analyses and multicentre audits consistently show that these modern methods reduce MAE in short eyes to approximately 0.25– 0.30 D [12,15,16]. Nevertheless, most evidence originates from Western or East-Asian cohorts, and prospective data in Indian populations remain scarce [7]. The present study therefore prospectively compares four widely available formulae—Hoffer Q, Holladay 1, Haigis and Hill RBF—in cataractous eyes with AL < 22 mm at a tertiary center in North India. We hypothesized that the AI-enhanced Hill RBF would yield the lowest MAE, followed by

Haigis, and that both would outperform legacy formulae.

MATERIALS AND METHODS

Study Design and Ethics

A single-centre, prospective comparative study was conducted at the Upgraded Department of Ophthalmology, SMS Medical College & Hospital, Jaipur. Institutional Ethics Committee approval was obtained.

Participants

Inclusion criteria were: age ≥ 45 years, visually significant senile cataract, AL <22.00 mm, and ability to attend follow-up. Exclusion criteria comprised ocular comorbidity (macular degeneration, diabetic retinopathy, corneal ectasia/dystrophy, prior surgery or trauma), intra-operative complications, or inability to obtain reliable optical biometry.

Sample-Size Justification

Based on a prior study reporting SD 0.43 D and minimal clinically important difference 0.19 D, 80 eyes afforded 80% power at α = 0.05 to detect inter-formula MAE differences.

Pre-Operative Assessment

All eyes underwent keratometry, AL and ACD measurement with optical low-coherence interferometry (IOLMaster 500, Carl Zeiss Meditec). Biometric data were entered into four calculators: Hoffer Q, Holladay 1, Haigis (constants optimized per User Group for Laser Interference Biometry), and the online Hill-RBF (version 3.0). Predicted postoperative refractions were recorded; the IOL implanted was the Hoffer-Q recommendation rounded to the nearest 0.50 D.

Surgical Technique

A single senior surgeon (HS) performed all phacoemulsifications under topical anaesthesia via a 2.8 mm clear-corneal temporal incision. Following hydrodissection and in-the-bag nucleus divideand-conquer, cortex was aspirated and a single-piece hydrophilic acrylic IOL (model XYZ, optic 6.0 mm) inserted with viscoelastic protection. Incisions were hydrated; intracameral moxifloxacin (0.1 mL) completed the procedure.

Post-Operative Regimen and Follow-Up

Topical moxifloxacin 0.5% QID and prednisolone acetate 1% QID were tapered over four weeks. Follow-up examinations at day 7 and day 30 recorded uncorrected and best-corrected visual acuity, manifest refraction, and anterior-segment / fundus status.

Outcome Measures

Primary: absolute prediction error at one month = |predicted spherical-equivalent − achieved SE| for each formula.

Secondary: proportion of eyes within ±0.25 D, ±0.50 D and ±1.00 D of target; refractive stability (day 7 vs 30).

Statistical Analysis

Data were analyzed in SPSS v26. Continuous variables are mean ± SD; categorical variables are n (%). Inter-formula AE comparison employed one-way ANOVA with Bonferroni correction. Significance was set at $p < 0.05$.

RESULTS

Participant Characteristics

All 80 enrolled eyes completed the one-month follow-up.

Table 1. Demographic and Biometric Characteristics of the Study Population.

Parameter	Value
Age, years (mean ± SD)	57.9 ± 5.8
Age distribution	47–52 y: 25%; 53–58 y: 35%; 59–64 y: 36.3%; 65–70 y: 3.8%
Sex	Female 48 (60%); Male 32 (40%)
Laterality	Right 37 (46.3%); Left 43 (53.8%)
Mean AL, mm	21.48 ± 0.40
Mean implanted IOL power, D	24.76 ± 1.76

Refractive Stability

Mean spherical-equivalent (SE) on day 7 (0.2188 ± 0.507 D) equalled that on day 30 (0.2188 ± 0.491 D); paired t-test p = 1.000, confirming early refractive stability.

Predictive Accuracy of Formulae

Table 2 Mean Absolute Prediction Error of Four IOL Power Calculation Formulae.

Formula	Mean AE ± SD (D)	Median AE (D)	Eyes within ±0.50 D
Hill-RBF	0.034 ± 0.217	0.02	91%
Haigis	0.097 ± 0.403	0.05	84%
Hoffer Q	0.231 ± 0.492	0.13	65%
Holladay	0.403 ± 0.669	0.22	57%
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ANOVA showed significant inter-group variance (F = 15.6, p < 0.001). Post-hoc analysis demonstrated Hill-RBF < Haigis (p = 0.031) < Hoffer Q and Holladay 1 (both p < 0.001). Haigis also out-performed Hoffer Q (p = 0.004) and Holladay 1 (p < 0.001).

Effect of Axial Length

Spearman correlation between AL and AE was weakly negative for Hill-RBF (ρ = –0.08, p = 0.46) and Haigis (ρ = –0.12, p = 0.28) but positive for Hoffer Q (ρ = 0.21, p = 0.07) and Holladay 1 (ρ = 0.24, p = 0.05), indicating increasing error with shorter AL when traditional formulae were used.

Table 3 Absolute Error Stratified By Axial-Length Quartiles.

AL quartile (mm)	Hill-RBF AE (D)	Haigis AE (D)	Hoffer Q AE (D)	Holladay 1 AE (D)
20.36–20.87	0.06 ± 0.12	0.11 ± 0.29	0.32 ± 0.55	0.55 ± 0.81
20.88–21.27	0.04 ± 0.20	0.09 ± 0.38	0.25 ± 0.46	0.42 ± 0.60
21.28–21.67	0.03 ± 0.24	0.08 ± 0.41	0.22 ± 0.50	0.38 ± 0.67
21.68–21.98	0.02 ± 0.28	0.07 ± 0.43	0.14 ± 0.45	0.26 ± 0.55

DISCUSSION

In this prospective Indian cohort of short eyes, Hill RBF delivered the smallest prediction error (0.034 D) and the highest proportion of eyes within ±0.50 D (91 %), corroborating earlier reports from Turkey (Gökce et al., MAE 0.30 D) and Australia (Kane et al., MAE 0.27 D) [12,9]. Haigis also outperformed both Hoffer Q and Holladay 1, echoing the findings of Srivannaboon et al. and Day et al. that incorporating ACD and LT markedly improves outcomes in AL < 22 mm [7,6]. Our mean errors for the traditional formulae align with Cooke and Cooke's nine-formula comparison, where Hoffer Q (0.29 D) and Holladay 1 (0.34 D) trailed behind modern methods [10]. The weak or absent correlation between AL and absolute error for Hill RBF and Haigis further supports their robustness across the short-eye spectrum, a point stressed in Savini & Hoffer's narrative review [14]. Although Barrett Universal II and the Kane formula frequently rank first in large meta-analyses [15,16], they were unavailable in our software suite during patient recruitment. The superior performance of Hill RBF nevertheless confirms the clinical value of machine-learning approaches, particularly when high refractive accuracy is demanded for premium IOLs, toric implants or minimonovision strategies [8]. Strengths of the present investigation include its prospective design, single-surgeon technique and complete follow-up. Limitations encompass the modest sample size, absence of Barrett/Kane comparators and implantation of IOL powers derived from Hoffer Q, which may have biased results against that formula. Future Indian studies with larger samples and multiple IOL models will clarify whether the 0.03 D advantage of Hill RBF over Haigis translates into clinically meaningful gains, especially in eyes shorter than 20 mm or with extreme keratometry values [13]. In summary, Hill RBF provided the greatest refractive precision in eyes with AL < 22 mm, followed closely by Haigis. Routine adoption of advanced or AI-driven formulae can substantially reduce postoperative surprises and enhance patient satisfaction in this challenging subgroup.

CONCLUSIONS

Hill-RBF delivers the greatest refractive precision in eyes with AL < 22 mm, followed by Haigis. Adoption of advanced formulae can substantially reduce postoperative refractive surprises and enhance patient satisfaction.

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