Original Article

Accuracy of Refractive Outcomes in Pediatric Cataract Surgery: A Comparison of Target versus Achieved Hyperopia

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ABSTRACT

Purpose: To compare target hyperopic refraction with achieved postoperative refractive outcomes in pediatric cataract surgery and to identify factors influencing absolute prediction error.

Study Design: longitudinal cohort study.

Place and Duration of Study: Mughal Eye Hospital, July 2024 to December 2024.

Methods: This study included 26 eyes of children aged 1–6 years undergoing cataract surgery with intraocular lens implantation. Preoperative biometric parameters and target refraction were recorded, and postoperative achieved refraction was measured. Statistical analysis included paired t-test, Pearson correlation, and multiple linear regression to evaluate refractive prediction error ($p < 0.05$).

Results: The mean age of the patients was 3.69 ± 1.81 years. Mean axial length was 22.56 ± 1.78 mm, and mean IOL power was 23.33 ± 5.94 D. The mean achieved postoperative refraction was 4.47 ± 1.46 D compared to target refraction of 3.76 ± 1.11 D, resulting in a mean hyperopic prediction error of +0.71 D (95% CI: 0.55–0.86; $p < 0.001$). Absolute prediction error was negatively correlated with age ($r = -0.987$, $p = 0.001$) and axial length ($r = -0.956$, $p = 0.001$), and positively correlated with keratometry ($r = 0.986$, $p = 0.001$) and IOL power ($r = 0.982$, $p = 0.001$).

Conclusion: A consistent hyperopic overshoot relative to target refraction was observed after pediatric cataract surgery. Age and axial length were the most significant contributors to refractive prediction error, highlighting the need for individualized IOL calculations in younger children with shorter axial lengths.

Keywords: Cataract, Congenital, Hyperopia, Intraocular Lenses, Refraction, Ocular, Treatment Outcome.

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INTRODUCTION

Cataract is defined as opacification of the crystalline lens, which disrupts normal visual development. Pediatric cataracts are a major cause of decreased visual acuity in children, accounting for up to 10% of childhood blindness worldwide, with a prevalence of approximately 4.24 per 10,000 live births.[1] These cataracts may be congenital or acquired. Due to the rapidly changing ocular biometry in developing eyes, pediatric cataract surgery poses special challenges in achieving predictable refractive outcomes, despite being essential for visual development. To reduce the risk of myopia in later childhood, target postoperative hyperopia must be carefully considered due to the inherent variability in axial length and corneal curvature.[1]

Timely surgical intervention is critical to prevent amblyopia and to establish binocular vision with stable foveal fixation. For optimal visual development, visually significant unilateral cataracts should be removed between 4 and 6 weeks of age, while bilateral cases ideally be operated before 10 weeks.[2]

Predicting refractive outcomes following pediatric cataract surgery remains a challenge due to the dynamic growth of the pediatric eye. Factors contributing to higher prediction error (PE) include anatomical variability, difficulties in obtaining reliable biometric measurements, and limitations of intraocular lens (IOL) power calculation formulas that are largely derived from adult models.[3] In infants, biometric measurements such as axial length and keratometry often require anesthesia, which can introduce errors. Moreover, most instruments are designed for adult eyes, leading to reduced accuracy in the smaller pediatric globe.[4,5]

Rapid ocular growth in early life further complicates IOL power selection, as axial elongation results in a continuous myopic shift. Importantly, small errors in axial length measurements have disproportionately large effects in children, leading to IOL power selection errors of 4–14 D/mm, compared with 3–4 D/mm in adults.[6]

To mitigate the predictable myopic shift, a hyperopic postoperative target is generally recommended, with the degree of hyperopia inversely related to age at surgery. Emmetropia is typically an acceptable target for children aged 8 years or older. However, achieving the intended hyperopic outcome with precision remains difficult.[7]

This has been pointed out by several works that errors were much larger in eyes with axial lengths less than 20 mm (mean 2.63 D) and in children under 36 months (mean 2.56 D).[8] The Infant Aphakia Treatment Study was the pioneering multicenter trial, which revealed the significant correlation of the short axial length (less than 18 mm) and increased the errors in prediction.[9] Such eyes tended to have less remaining hyperopia than would be expected, a procedure of overcorrection. Equally, implantation with high-power IOLs (s= 30 D) was linked with a lower postoperative hyperopia.[10] These together with anticipated axial elongation increase the risk of long-term serious myopia. Greater myopic shift has also been linked to younger age at surgery and low values of keratometry.[6,11]

Refractive change occurring after pediatric cataract surgery is common and may be significant in the long-term. One study indicated a median pseudophakic refraction of -6.6 D with a span of 11 years where the myopic refraction was larger in children who were surgically operated before the age of two years.[12] Likewise, research observed a myopic shift of -5.02 D in children of age 5-15 years after unilateral cataract surgery and no significant difference in axial length or corneal power.[13] In this regard, these studies show that myopic shift is present in both adult and older age groups, which makes it crucial to plan IOL carefully and follow-up in the long term.[14] This study aims to compare targeted hyperopic refraction with the achieved postoperative outcomes in pediatric cataract surgery. By evaluating the accuracy of IOL power calculations and identifying factors influencing discrepancies, we aim to provide insights for improving refractive predictability in this vulnerable population.

METHODS

After approval from the Institutional Review Board (**0508/IRB/MEHT**), this study was conducted in the Mughal Eye Hospital. Children of 1-8 years of age, with visually significant cataracts and who had undergone cataract surgery with intraocular lens (IOL) implantation were included. Ocular or systemic conditions that may affect the measurement of the keratometry or the axial length, such as corneal disease, glaucoma, retinal dystrophies, uveitis and syndromes of high refractive error, were excluded.

The WHO sample size calculator was used to compute sample size based on the Infant Aphakia Treatment Study (IATS) that indicated the mean absolute prediction error of 1.8 ± 1.3 D. The confidence level of 95% and absolute precision of 0.5 D gave the required sample size of 26 eyes. Recruitment was done by non-probability consecutive sampling.

The partial coherency interferometry (Zeiss IOL Master 500) was used to measure the axial length and keratometry in cooperative kids. In the case of uncooperative patients, handheld keratometry (Nidek KM-500 or Nidek ARC-30) and ultrasound biometry (Sonomed Escalon EZ Scan AB5500 or PacScan 300AP) were used to measure the power under general anesthesia. The A-scan ultrasonography using immersion was given the priority to reduce errors that are caused by contact. The scans were examined by a certified echographer and assessed based on quality; low quality scans were omitted.

IOL power calculation was done using SRK/T formula. The criteria of target postoperative hyperopia were the age-specific guidelines of Enyedi et al.: +6.0 D in 1 year, +5.0 D in 2 years, +4.0 D in 3 years, +3.0 D in 4 years, +2.0 D in 5 years, and +1.0 D in 6 years. Under-correction of refraction was purposely done to create hyperopia to overcome the anticipated shift to myopia with ocular development. Cataract was removed by irrigation and aspiration followed by primary implantation of mon0focal IOL in the capsular bag. In case of lack of capsular support, the IOL was placed in the ciliary sulcus. Primary posterior capsulotomy and anterior vitrectomy was also performed. The retinoscopy was done at one month follow-up after the surgery under cycloplegia. Data was analyzed by calculating spherical equivalent (SE) values (sphere + cylinder/2). IBM SPSS version 26.0 was used for data analysis. Quantitative variables, such as child age, axial length, keratometry, IOL power, target and achieved refraction, prediction error and absolute error were summarized as mean ± SD. Kolmogorov Smirnoff and Shapiro Wilk tests were used to test normality of prediction error. Target and achieved refraction were compared by paired-samples t-test, and Pearson correlation was used to test the relationships between variables. To assess independent predictors of absolute error a multiple linear regression was conducted, and the model fit was reported. A p-value of less than 0.05 was considered statistically significant, and graphs were created to visually show trends in refractive measurements.

RESULTS

Table 1 shows the descriptive characteristics of the study population. The age range was 1-6 years. The minimum axial length was 19.5mm and maximum was 24.9mm. There was a stable hyperopic shift between target and actual refraction.

The data was normally distributed with p=0.57. The postoperative refraction was compared to the preoperative target hyperopic refraction. The average refraction attained was 4.47 ± 1.46 D and the average target refraction was 3.76 ± 1.11 D. The average of the refraction obtained, and the target refraction was +0.71 D (95% CI: 0.55-0.86 D), which showed that there was a slight inclination towards higher hyperopia than was anticipated ($t = 9.31$, $df = 25$, $p < 0.001$). These findings indicate that pediatric patients (on average) had a slightly greater hyperopia than what is target, indicating the existence of a small but consistent prediction error.

Table 1: *Descriptive statistics of study variables (N = 26).*

Variable	Mean	SD
Age of Child (years)	3.69	1.81
Axial Length (mm)	22.56	1.78
Keratometry (D)	44.04	0.90
IOL Power (D)	23.33	5.94
Target Refraction (D)	3.76	1.11
Achieved Refraction (D)	4.47	1.46
Prediction Error (D)	0.92	0.37

SD = Standard deviation; D = Diopters.

Table 2: *Comparison between achieved and target refraction (paired-samples t-test).*

Measure	Mean (D)	SD	SEM	Mean Difference (D)	95% CI of Difference	t	df	p-value
Achieved Refraction	4.47	1.46	0.29					
Target Refraction	3.76	1.11	0.22					
Achieved – Target Refraction				+0.71	0.55 – 0.86	9.31	25	<0.001

Table 3: *Correlation.*

Variable	Child Age	Axial Length	Keratometry	IOL Power	Target Refraction	Achieved Refraction	Prediction Error	Absolute Prediction Error
Child Age (years)	1							
Axial Length (mm)	0.939**	1						
Keratometry (D)	-0.988**	-0.939**	1					
IOL Power (D)	-0.984**	-0.940**	0.990**	1				
Target Refraction (D)	-0.990**	-0.921**	0.996**	0.991**	1			
Achieved Refraction (D)	-0.978**	-0.925**	0.987**	0.982**	0.990**	1		
Prediction Error	-0.853**	-0.754**	0.874**	0.872**	0.888**	0.912**	1	
Absolute Prediction Error	-0.987**	-0.956**	0.986**	0.982**	0.980**	0.968**	0.827**	1

The Pearson correlation analysis showed that Absolute prediction error was strongly negatively correlated with child age (r = -0.987, p < 0.001) and axial length of the eyes (r = -0.956, p < 0.001) meaning that children with lower ages and shorter axial length had higher error rates. On the other hand, absolute prediction error correlated positively with keratometry (r = 0.986, p less than 0.001), IOL power (r = 0.982, p less than 0.001), and target (r = 0.980, p less than 0.001) and achieved refraction (r = 0.968, p less than 0.001), indicating that corneas which were steeper, and those with higher IOL power and hyperopic targets were significantly different. These results show that the achieved refraction was very similar to the planned target, although biometric and demographic variables had a great impact on the accuracy of the postoperative results.

Table 4: *Multiple Linear Regression Analysis.*

Predictor	B	Std. Error	β	t	p
Constant	-4.480	6.916	–	-0.648	0.524
Age of Child	-0.152	0.062	-0.447	-2.438	0.024*
Axial Length (mm)	-0.072	0.028	-0.209	-2.541	0.019*
Keratometry (D)	0.175	0.159	0.256	1.096	0.285
IOL Power (D)	0.010	0.021	0.092	0.451	0.047*

Model: $R^2 = 0.985$, Adjusted $R^2 = 0.982$, F(4,21) = 333.59 p < 0.001*Significant at p < 0.05

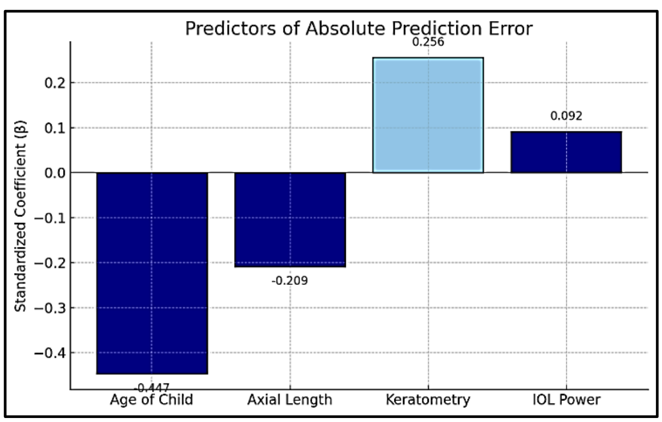

Figure 1: Standardized Coefficients (Beta) Bar Chart.

The effect of age, axial length, keratometry, and IOL power on absolute prediction error in cataract surgery in children was measured using multiple linear regression. This model was very important (F(4, 21) = 333.59, p < 0.001) and the model explained 98.5% of the variance (R 2 = 0.985, Adjusted R 2 = 0.982). Younger age (B = -0.152, p = 0.024) and shorter axial length (B = -0.072, p = 0.019) are some of the predictors that showed more absolute prediction errors. There was small positive influence of higher IOL power (B = 0.010, p = 0.047) whereas the predicate of keratometry was not significant (B = 0.175, p = 0.285). These findings suggest that the age and the axial length are the most critical factors that determine the reliability of postoperative refractive outcomes among children undergoing cataract surgery, and keratometry as an independent variable failed to significantly affect the outcome with other factors held constant.

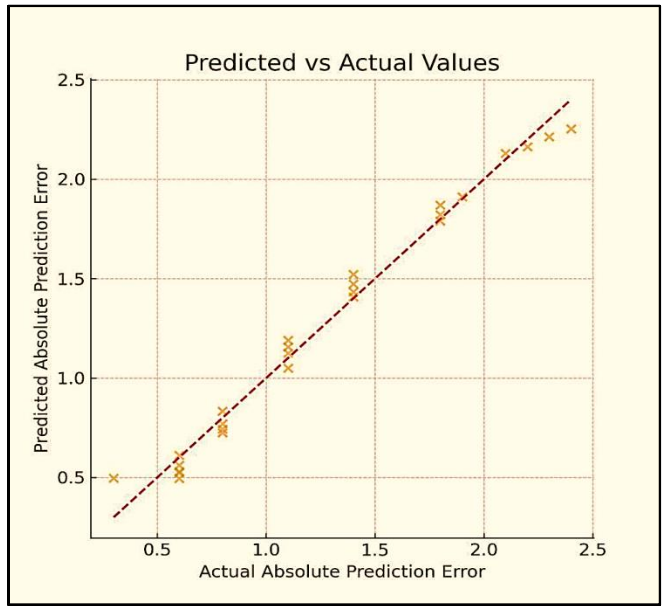

Figure 2: Trend Line.

DISCUSSION

Prediction of refractive results after pediatric cataract surgery is a debatable issue because of gradual eye development and the changes in biometric parameters. The average target refraction in our study was 3.76+ 1.11 D, and the average achieved refraction was 4.47 + 1.46 D, giving a mean prediction error of 0.92 + 0.37 D. This meant that there was a statistically significant hyperopic shift of + 0.71 D (p < 0.001). It showed that the eyes were inclined to obtain a little more hyperopia than desired. Nevertheless, even with this regular deviation, the regression model accounted for 98.5 percent of the variation in the prediction error, indicating that IOL power calculations were accurate but highly dependent on biometric and demographic variables.

Our results agree with those found in the literature that in children with shorter axial length (less than 19 mm), it was difficult to get accurate refractive results.[1] In Infant Aphakia Treatment Study, shorter axial length (less than 18 mm) was associated with greater errors in prediction and reduced hyperopia than expected especially in eyes with high-power IOLs.[8] We also found that the shorter the axial length, and younger the age, the more significant were the prediction errors highlighting the susceptibility of this group to less predictable refractive findings.

The hyperopic shift in our results suggests the use of intentional hyperopic target to settle postoperative myopic shift. Studies have found that pseudophakia in children, particularly the infants below the age of 2 years, causes significant myopic progression with time, which highlights the necessity of age-adjusted under correction.[12,15] Similarly, there were higher rates of myopic shifts in younger children and the rate of shift reduced with the age at which the surgery was performed.[4,16] Younger children in our series exhibit more prediction error and more hyperopic deviation supporting the rationale of higher intentional hyperopia in early pediatric cataract surgery.

Myopic shifts persist in older children although at a lower velocity in comparison to infants and toddlers. The fact that our initial postoperative measurements are consistent hyperopic overshoot, of about 0.7 D, indicates that small initial deviations can increase over time as the ocular growth proceeds. This suggests age-specific hyperopic goals. For example, younger children have more deliberate hyperopia to counter future myopic drift[17]

The inconsistency of prediction error is yet another indicator of shortcomings of existing IOL formulas. It is observed that poor prediction errors were more likely to be linked with deviations of normative biometric parameters, specifically short axial length and high keratometry.[18] Keratometry in our study had significant positive correlation with prediction error but failed to predict independently of axial length and IOL power in multivariate analysis indicating that axial length and IOL power have stronger effects. Increased IOL power was found to be correlated with increased prediction error, which is consistent with previous research on the challenge of obtaining accurate results with high-power IOLs in eyes.

Posterior capsule opacification (PCO) is a well-known complication affecting the refractive stability. According to a study, primary anterior vitrectomy and posterior capsulotomy are associated with a decrease in the occurrence of PCO thus enhancing the predictability of the refractive index.[19,20] In our study, IOL placement and a posterior capsulotomy, was in accordance with the recommendations, limiting the possibility of a confounding effect of PCO in early refractive results.

According to our results, postoperative outcomes are reasonably good with modern methods of pediatric IOL calculation, but with a small and systematic hyperopic overshoot. Age and axial length became the most effective predictors of absolute prediction error, whereas greater IOL power made a small contribution and the significance of higher keratometry was no longer significant. These results are in line with the international evidence and highlight the need to select IOL individually, target hyperopic with age adjustments, and scrutinize biometrics measurements to achieve the best long-term refractive results in children who undergo cataract surgery.

This study has several limitations that should be considered when interpreting the results. The small sample size (26 eyes) limits the statistical power and generalizability of the findings to the broader pediatric population. The study was conducted at a single center over a relatively short duration, which may not reflect variations in surgical techniques, biometry practices, or patient characteristics across different institutions. The wide age range (1–6 years) encompasses periods of rapid ocular growth; however, postoperative refractive outcomes were assessed at a single time point, and long-term refractive changes due to ongoing eye growth were not evaluated. Potential variability in biometric measurements in young children, particularly axial length and keratometry obtained under limited cooperation or anesthesia, may have influenced refractive prediction accuracy.

Factors such as surgical technique variations, effective lens position, laterality, and postoperative visual rehabilitation were not separately analyzed, which may also contribute to refractive outcomes.

Despite these limitations, the study provides valuable preliminary evidence regarding refractive prediction error and its determinants in pediatric cataract surgery, particularly in younger children with shorter axial lengths.

CONCLUSION

Study has shown that the refractive performances of intraocular lens implantation in cataract surgery in children are generally near the desired goal, although a hyperopic overshoot of about +0.7 D was consistently observed. Patient age and axial length also had a significant impact on accuracy of prediction, with younger children and shorter eyes reflecting more errors. Increased prediction errors were also correlated with increased IOL power, but not with keratometry. These observations address the significance of customized IOL power and hyperopic age-adjusted target to maximize long-term refractive outcomes in children.

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Patient's Consent: Researchers followed the guidelines set forth in the Declaration of Helsinki.

Conflict of Interest: Authors declared no conflict of interest.

Ethical Approval: The study was approved by the Institutional review board/Ethical review board **(0508/IRB/MEHT)**.

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Fiza Azhar; Consultant Ophthalmologist: *Concepts, Data Acquisition, Statistical Analysis, Manuscript Preparation, Manuscript Review.*

Noor-ul-Ain; PGR: *Design, Literature Search, Data Acquisition.*

Hira Awais; PGR: *Data Acquisition, Data Analysis.*

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