

Ocular Biometry: Surgical Implications in Primary Pediatric Cataract

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ABSTRACT

Purpose: To evaluate ocular biometric characteristics and assess the predictability of refractive outcomes following intraocular lens (IOL) implantation in children.

Study Design: Retrospective chart review.

Place and Duration of Study: Tertiary care hospital in Riyadh, Saudi Arabia from 2021 to 2024.

Methods: This study included children aged 1-6years who underwent cataract surgery with primary or secondary IOL implantation. Demographic, biometric, and refractive data were extracted. Prediction error (PE) was defined as predicted minus actual post-operative spherical equivalent (SE), while absolute prediction error (APE) represented the magnitude of deviation irrespective of direction.

Results: A total of 359 eyes from 235 patients were analyzed. The mean age at IOL implantation was 2.90 ± 1.25 years. The mean axial length (AL) was 21.58 ± 1.60 mm, mean keratometry (K) was 44.22 ± 2.44 D and mean post-operative spherical equivalent (SE) was 1.82 ± 3.12 D, compared to a predicted SE of $+1.80 \pm 1.77$ D. The mean PE was -0.34 ± 3.15 D, and the mean APE was 2.40 ± 2.1 D, reflecting substantial variability in refractive outcomes. Myopic shift was observed at ages 2 and 6years, whereas hyperopic trends predominated at ages 1,3,4, and 5years. The highest APE was noted at 2y of age. No statistically significant differences in PE and APE were observed across age groups ($p > 0.05$). A mild positive correlation was found between PE and AL ($\rho = 0.186$, $p = 0.006$) and a weak negative correlation was observed between PE and K ($\rho = -0.150$, $p = 0.03$).

Conclusion: Despite minimal mean prediction error, refractive outcomes following pediatric cataract surgery remain highly variable. This variability highlights the limitations of current IOL power calculation methods in growing eyes and underscores the need for individualized surgical planning and caution in pediatric patients.

Keywords: Cataract, Pediatric ophthalmology, Intraocular Lens, Refractive Error, Saudi Arabia.

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INTRODUCTION

Cataract is one of the most common causes of visual disability in children. A meta-analysis of 24 childhood cataract studies found an incidence ranging from 1.8 to 3.6/10000 per year.¹ The reported prevalence of

cataract blindness in children ranges from 1 to 4 per 10,000 in developed countries and 5 to 15 per 10,000 in developing countries.² In Saudi Arabia, cataract accounts for 7% of bilateral blindness in children.³

The human eye undergoes extensive anatomical and physiological developmental changes in the postnatal period. Significant changes occur in axial length (AL), cornea, and lens.⁴ The mean newborn's AL is about 16-18 millimeters,⁴ where change of AL is triphasic.⁵ The first phase (0–2 years) is the period where the greatest increase in AL occurs, reaching around 20mm. The second phase (2–5years) is when growth slows to approximately 0.4 mm/year. During

the third phase (5-10 years), AL increases approximately 1mm to its adult length. Axial growth correlates inversely with changes in Kreading and lens power, as K is steep in neonates and flattens significantly by age 6 months.^{6,7}

K measurements in infants range from 47.00D to 48.06.⁵ These readings decrease in the first 6 months at a rate of -0.40D/month, followed by -0.14D/month in the following 6 months and -0.08D/month in the second year of life, reaching adult reading at almost 3years of age.⁵ A study by Sunita et al. reported that the lens flattens with age and that power decreases by 8D in the first 2 years, then by an additional 11.5D, reaching an adult value between 7 and 10years of age.⁵

Recent developments in IOL production and surgical techniques have improved outcomes in juvenile cataract surgery. Genetic testing and counseling can aid in the early detection of hereditary cataracts.⁸ Unlike adults, where calculation is performed in clinic with IOL master most of the time, in pediatric especially preschool age group, IOL calculation is usually performed under sedation or anesthesia. The calculation formulas we use today are designed for adult patients, with some, such as Hoffer Q and Holladay 2, considering eyes with short AL.⁹

Literature on pediatric cataract in Saudi Arabia remains limited. According to one study examining the causes of childhood blindness nationwide, 70% of the population went blind before age two, 34% had congenital cataracts, and 56% had parents with related conditions.¹⁰ Another report showed that up to 79% of pediatric cataract cases might be inherited.¹¹ According to two studies, cataract is the most common cause of blindness in Saudi Arabia, with incidences of 58.2% and 52.6% respectively.^{10,12} In fact, Post-cataract surgery aphakia correction and amblyopia treatment remain the most important factors for better visual outcomes in children.¹³

Recently, a local study reported significant post-operative myopic shift in children who underwent cataract surgery, and it was more in eyes with primary IOL implantation while Glaucoma was the most common reported post-operative complication.¹⁴ In addition, the presence of strabismus and nystagmus may affect visual outcomes, and early intervention may reduce the incidence of amblyopia. However, the overall prevalence of cataracts in Saudi Arabia has not yet been reported.

This study was conducted to investigate the biometric profile including AL and Kreading of

pediatric patients who underwent cataract surgery at tertiary hospital in Riyadh, Saudi Arabia.

METHODS

This retrospective study was conducted at tertiary care hospital in Riyadh, Saudi Arabia. It recruited children aged 1 to 6years who underwent cataract surgery with primary or secondary IOL implantation from 2021 to 2024. Exclusion criteria were secondary cataract, anterior segment dysgenesis, or other ophthalmic diseases. Patients' demographic, pre-operative, intraoperative, and post-operative data were obtained from the medical records. Pre-operative clinical examinations determined the cataract type and affected eye. Intra-operative measurements included corneal diameter, Kreading, AL, target post-operative refraction, and IOL implanted. Post-operative measures included last follow-up, follow-up duration, age, best corrected visual acuity (BCVA), and cycloplegic refraction. IOL power was measured by IOL master (Holladay I formula) and ultrasound A-scan, while Kreading was measured by hand-held Keratometer.

Prediction error (PE) was defined as predicted post-operative refraction minus actual post-operative refraction. After cataract surgery, a negative PE indicates a myopic shift, and a positive PE indicates a hyperopic shift. Snellen visual acuity (VA) was converted into a logarithm of the minimum angle of resolution. Absolute prediction error (APE) was defined as the absolute value of the PE.

The study received ethical approval from the Institutional Review Board of the Saudi Ministry of Health (**#H1RI-15-Jun25-01**). It adhered to the Declaration of Helsinki and current legislation on research involving human subjects, and followed Good Clinical Practice guidelines (GCP). The data's confidentiality was ensured, and the subjects' privacy was protected. Only the principal investigator and the research team had access to the data.

Qualitative data were summarized with counts and percentages, while quantitative data were summarized with mean and standard deviation. The normality of data was assessed with the Shapiro-Wilk Test. Normally distributed data were compared with an independent-samples T-test. Non-normally distributed data were compared with the Mann-Whitney U Test. Non-normally distributed data from more than two groups were compared using the Kruskal-Wallis Test.

Spearman's rho was used to calculate the correlation between non-normally distributed data. Statistical analysis was performed using SPSS version 25 for Windows (IBM, Armonk, NY: IBM Corp.). A p-value <0.05 was considered statistically significant.

RESULTS

Data from 359 eyes of 235 patients were retrospectively reviewed, including 96 (40%) males and 139 (60%) females. Out of 235 subjects, 98 (42%) had unilateral and 137 (58%) had bilateral cataract. The mean post-operative follow-up time was 2.70 ± 1.80 years. The mean age at IOL implantation was 2.90 ± 1.25 years.

Mean visual acuity (VA) was 0.95 ± 1.05 LogMAR (0.30 to 5.00 LogMAR) at baseline (n=37) and 0.77 ± 0.74 LogMAR (0.10 to 5.00 LogMAR) at the last follow-up (n=186). At baseline, 141 eyes (39%) had "fixes and follows" vision, 19 eyes (5.3%) had poor "fixes and follows," and 3 eyes (1.0%) had "follows light" vision. Central steady maintained (CSM) fixation was present in 129 eyes (36%), while 2 eyes (0.5%) had central steady unmaintained (CSUM) fixation and 2 eyes (0.5%) had poor fixation. At the last follow-up, 78 eyes (21.7%) had "fixes and follows" vision, 3 eyes (0.85%) had poor "fixes and follows," and 19 eyes (5.3%) demonstrated CSM fixation.

Holladay I formula was used to calculate IOL power in all patients. For measurements of AL and K, IOL Master was used in 68 eyes (18.8%), while Ultrasound A-scan and hand-held Keratometer were used in 294 (81.2%) eyes. The mean AL (n=355) was

21.57 ± 1.59 mm (17.67 to 28.15mm). Most cases (82.8%) had AL between 20 and 23mm, where AL increased with age. The mean AL was 21.30 ± 1.77 mm in males and 21.73 ± 1.45 mm in females (p=0.001). The mean AL was 21.77 ± 1.62 mm in unilateral cataract cases and 21.49mm in bilateral cases (p=0.178). However, in 2-year-old patients, AL was 21.49 ± 1.10 mm in unilateral cases and 20.68 ± 1.29 mm in bilateral cases (p=0.008). See Table 1 for more details.

The overall mean of Kreading was 44.23 ± 2.45 D (35.9 to 64.4D). For males, it was 45 ± 2.9 D (39.10 to 65D), while in females it was 43.83 ± 2.00 D (35.9 to 50D; p=0.001). See Table 2 for more details. The difference in K-reading between males and females was statistically significant at ages 2 and 4 years (p=0.016 and p=0.003, respectively).

The mean post-operative SE was $+1.82 \pm 3.12$ D (-6.00 to +16.00D). The mean predicted post-operative SE was 1.80 ± 1.77 D (0 to +8.00D). The mean post-operative refractive cylinder was -1.86 ± 1.13 D (-3.00 to -9.00D). The frequency of corneal astigmatism of 1D or more was 86.8%, 2D or more was 58.3%, and 3D or more was 32.7%.

The mean PE was -0.34 ± 3.15 D (-13.00 to 7.25D). The relatively small PE of -0.33D indicated mild hyperopic shift and almost no systemic prediction error. However, the mean APE was 2.40 ± 2.1 D (0 to 13.00D), which revealed large random PE regardless of myopic or hyperopic shift.

The refractive shift was myopic at ages 2 and 6 years and hyperopic at ages 1, 3, 4, and 5 years. The highest APE was at age 2 years, followed by age 1

Table 1: AL measurements of congenital cataract by age, sex, and affected eye.

Factor	Level	≤1Year	2Years	3Years	4Years	5Years	6Years
Sex	Males	20.65 ± 1.78 (n=16)	20.84 ± 1.36 (n=41)	21.46 ± 1.86 (n=33)	21.62 ± 1.67 (n=28)	22.24 ± 2.43 (n=15)	21.17 ± 0.18 (n=2)
	Females	21.13 ± 1.50 (n=44)	21.00 ± 1.22 (n=43)	22.0 ± 1.57 (n=59)	22.14 ± 1.27 (n=47)	22.03 ± 0.81 (n=19)	22.16 ± 0.81 (n=8)
	P-value	0.405	0.586	0.038	0.133	0.749	0.136
	95%CI	-0.54 to 1.31	-0.41 to 0.72	0.04 to 1.49	-0.16 to 1.20	-1.60 to 1.17	-0.39 to 2.38
		21.29 ± 1.57 (n=28)	21.49 ± 1.10 (n=25)	22.06 ± 1.55 (n=21)	22.09 ± 1.68 (n=20)	24.59 ± 3.11 (n=3)	(n=0)
Laterality	Unilateral	20.80 ± 1.56 (n=32)	20.68 ± 1.29 (n=59)	21.91 ± 1.77 (n=71)	21.89 ± 1.36 (n=55)	21.88 ± 1.36 (n=31)	21.96 ± 0.83 (n=10)
	Bilateral	20.80 ± 1.56 (n=32)	20.68 ± 1.29 (n=59)	21.91 ± 1.77 (n=71)	21.89 ± 1.36 (n=55)	21.88 ± 1.36 (n=31)	21.96 ± 0.83 (n=10)
	P-value	0.237	0.008	0.727	0.596	0.270	
	95%CI	-0.33 to 1.30	0.22 to 1.40	-0.70 to 1.00	-0.55 to 0.96	-4.84 to 10.25	
Total		21.03 ± 1.57 (n=60)	20.92 ± 1.29 (n=84)	21.95 ± 1.71 (n=92)	21.94 ± 1.45 (n=75)	22.12 ± 1.70 (n=34)	21.96 ± 0.83 (n=10)

Table 1: The shorter AL was 20.65mm while the longest AL was 22.0mm. The mean AL was 21.58 ± 1.60 mm.

Table 2: *K measurements of congenital cataract by age, gender, and affected eye.*

Factor	Level	≤1Year	2Years	3Years	4Years	5Years	6Years
Gender	Males	44±2.42 (n=16)	45.76±4.00 (n=41)	44.46±1.56 (n=32)	44.58±2.14 (n=28)	44.24±2.77 (n=15)	42.0±0.18 (n=2)
	Females	44.35±2.14 (n=44)	44±2.03 (n=44)	44±2.18 (n=60)	43±1.98 (n=47)	43.54±1.58 (n=19)	43.85±1.69 (n=8)
	P-value	0.348	0.016	0.238	0.003	0.360	0.181
	95%CI	-1.90 to 0.68	-3.11 to -0.33	-1.25 to 0.31	-2.49 to -0.55	-2.24 to 0.84	--1.05 to 4.73
		44.61±2.38 (n=28)	46.0±4.65 (n=26)	44.00±1.80 (n=20)	43.48±2.54 (n=20)	43.24±1.30 (n=3)	(n=0)
Laterality	Bilateral	44.44±2.09 (n=32)	44.38±2.25 (n=59)	44.20±2.05 (n=72)	43.68±2.02 (n=55)	43.91±2.25 (n=31)	43.48±1.68 (n=10)
	P-value	0.773	0.103	0.698	0.730	0.618	
	95%CI	-0.99 to 1.32	-0.35 to 3.56	-1.20 to 0.81	-1.33 to 0.93	-3.39 to 2.04	
		44.52±2.21 (n=60)	44.87±3.24 (n=85)	44.16±1.99 (n=92)	43.62±2.16 (n=75)	43.85±2.18 (n=34)	43.48±1.68 (n=10)
Total							

Table 2: The lowest k-reading was 42.0D and the highest was 46.0D. The mean K was 44±2.2D.

year. There were no statistical differences in PE and APE among age groups ($p>0.05$). There was no significant negative correlation ($\rho=-0.027$, $p>0.05$) between the prediction error and age and a mild positive correlation ($\rho=0.186$, $p=0.006$) between prediction error and AL. In younger patients, the myopic shift was due to an increase in AL, and in older children the hyperopic shift was due to a decrease in Kreading. Moreover, a negative correlation ($\rho=-0.150$, $p=0.030$) was found between PE and K, whereas eyes with $K>43D$ had a trend to have post-operative hyperopic shift.

DISCUSSION

The present study evaluated the ocular biometric characteristics and post-operative refractive outcomes of children aged 1 to 6 years who underwent cataract surgery with IOL implantation. Our findings demonstrate several important trends in AL, K reading, and post-operative refractive behavior that reflect the dynamic nature of ocular growth during early childhood.

Consistent with the well-established pattern of rapid ocular development in the first years of life, the mean AL measurements in our cohort showed age-dependent elongation, with males exhibiting slightly longer AL measurements than females.^{1,2} This aligns with previous pediatric biometric studies reporting sex-related differences in ocular growth.¹⁻³ Additionally, bilateral cataract cases showed slightly shorter AL, a finding reported previously in the literature and possibly reflecting altered ocular

development in congenital cataract eyes.^{3,15} K reading also demonstrated variation by sex, particularly at ages 2 and 4 years, where males tended to have steeper corneas.³ The wide K range in our cohort (35.88D to 64.38D) highlights the biomechanical variability of pediatric cataract eyes and supports prior findings showing that congenital cataract was associated with irregular or atypical K readings.^{3,4}

Post-operative refractive outcomes in our study follow expected developmental trends. Younger children (especially at 2 years of age) demonstrated greater myopic shift post-operatively, consistent with known patterns of ocular elongation after early IOL implantation.^{4,5} Older children showed hyperopic shift due to a decrease in K reading, as AL usually does not increase after 2.5-3 years of age unless there is a pathology.^{16,17} These variations are clinically important, as both AL and K directly impact IOL power calculation accuracy.¹⁸

The mean PE in our study was $-0.33\pm1.4D$, indicating no systematic bias; however, the wide APE range (up to 13.00D) underscores the inherent challenges of achieving predictable outcomes in pediatric cataract surgery, as documented in previous studies.^{1,5,6}

Eyes with AL <22 mm showed post-operative hyperopic errors, whereas longer eyes tended toward myopic shift. This relationship parallels previous findings demonstrating that ocular geometry strongly influences refractive changes following IOL implantation.⁶ Mild correlations between K reading and PE further suggest that corneal shape irregularities contribute to refractive unpredictability.

Our results align with previous pediatric cataract literature and reinforce the need for age-specific considerations when planning IOL power.¹⁸ The observed biometric variability underscores the importance of individualized surgical planning and of counseling families about expected refractive changes over time. Long-term follow-up studies are recommended to enhance understanding of refractive stability in pediatric cataract eyes.

CONCLUSION

This study highlights the significant biometric variability present in pediatric cataract patients and its influence on post-operative refractive outcomes following IOL implantation. AL, K reading, and age at surgery were key factors associated with refractive prediction accuracy. The trends observed, such as the myopic shift in younger children and hyperopic tendencies in older ages, are consistent with normal ocular maturation and emphasize the importance of individualized power selection in this population. Although prediction accuracy has improved with modern formulas, substantial variability remains, underscoring the need for cautious parental counseling and long-term follow-up. Further prospective studies with larger cohorts are warranted to refine age-specific IOL calculation strategies and enhance refractive predictability for pediatric patients.

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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 (KSA:H-01-R-053).

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Authors Designation and Contribution

Saleh A. Al-Khaldi; *Research Consultant: Concepts, Design, Literature Search, Data Acquisition, Data Analysis, Statistical Analysis, Manuscript Preparation, Manuscript Editing, Manuscript Review.*

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