Review Article

Pediatric IOL power calculation: Factors and considerations

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This narrative review aims to compare and document various studies on pediatric intraocular lens (IOL) power calculation, highlighting the differences from adult IOL power calculations and assessing the need for accurate ophthalmic biometry and targeted refraction to improve visual outcomes and reduce amblyopia risk. A comprehensive search of the PubMed database was conducted using keywords such as "pediatric cataract surgery," "IOL power calculation," "ocular biometry," and "IOL formulas." Relevant articles were identified by evaluating titles and abstracts, followed by full-text examination. References were reviewed for thorough coverage. Pediatric eyes pose unique challenges for IOL power calculation due to smaller size, changing axial length, and corneal curvature. Accurate biometry, particularly axial length and keratometry, is crucial. Studies comparing IOL formulas, primarily developed for adults, show varying prediction errors in pediatric cases. Newer-generation formulas such as Barrett's Universal II and Kane demonstrate superior accuracy compared to older formulas (e.g., SRK/T). Undercorrection strategies account for myopic shifts due to eye growth, but consensus on the best formula and target refraction is lacking. Premium IOLs, such as multifocal and toric, offer benefits but require further long-term evaluation. Accurate IOL power calculation is critical for optimal visual outcomes in pediatric cataract surgery. While newer IOL formulas show promise, the unpredictable nature of eye growth and myopic shifts complicates long-term predictions. Premium IOLs offer potential advantages but necessitate careful consideration. Continuous advancements in IOL technology and personalized approaches to target refraction are essential to improve the quality of life of pediatric patients.

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Pediatric cataract is a leading cause of treatable childhood blindness.[1] Timely diagnosis and treatment are essential to prevent deprivation amblyopia.[2,3]

The standard practice for treating pediatric cataracts involves primary intraocular lens (IOL) implantation post-cataract extraction in children aged 7 months and above.[4–6] Multiple studies, including the Infant Aphakia Treatment Study (IATS), have concluded that there are no advantages of primary IOL implantation over aphakia in infants aged 6 months or less.[7–9] Accurately determining the IOL power poses a significant challenge in the long-term care of children undergoing cataract surgery.[10]

Pediatric eyes are different from adult eyes: they are smaller in size at birth, with changing axial length (AL) and corneal curvature over a period. This difference between adult and pediatric is not only because of shorter AL but also because of the proportion of anterior chamber to posterior chamber, with shallowness of AC and steeper corneas.[11] Thus, it introduces larger errors in IOL prediction when normal adult formulas are applied for power calculation.[12–14] These challenges in the calculation of the required power may be because of a myriad of factors, including inaccurate biometry, unpredictable growth of the child's eye, difficult refraction, an additional component of strabismus, and the child's inability to communicate.

Several studies have evaluated the accuracy of various IOL formulas developed for adult eyes when predicting refractive errors post-surgery in infants and young children. However, consensus on the most effective IOL formulas that yield minimal error from targeted postoperative refraction remains elusive.[10,15–17]

Correct IOL power calculation can lead to a potentially better visual acuity in the operated eye and thus lesser chances of long-term amblyopia and need for IOL exchange. The aim of this narrative review article is to compare and document the various studies to understand the differences in pediatric IOL power calculation as compared to adult IOL powers and to assess the amount and need for targeted refraction.

Methods

The methodology involved in the study encompassed an exploratory search of the PubMed and Medknow databases, employing specific keywords such as "pediatric eyes," "congenital cataract keratometry and axial length," "pediatric ocular biometry," "IOL formulas in children," "IOL power calculation," "undercorrection pediatric cataract," "myopic shift," and "IOL pediatric long outcomes." This search aimed to

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identify relevant literature pertinent to the research objectives. A total of 172 studies were found relevant to the topic. The titles and abstracts were evaluated to ascertain their relevance to the study topic. Additionally, references cited within the identified articles were searched to ensure comprehensive coverage of the articles related to all the ocular biometric parameters, IOL formulas, postoperative target refraction, multifocal and toric IOLs, and myopic shift. Duplicate entries were identified and eliminated. After excluding case reports and case series with less than five cases, 69 articles were included. After the first revision, 13 new relevant articles were also added as advised, making a total of 82. Of these, 33 were retrospective observational studies, 27 were prospective observational studies, six were randomized control trials, eight were review articles, two were systematic review articles, and five were either statistical or IOL power calculator models. To ensure methodological rigor, the quality of included studies was assessed by two independent reviewers. Any disparities in judgment were resolved through discussions and consensus.

Discussion

1. Importance of biometry

Biometry serves as the foundation for various formulas used in pediatric cataract surgery as the accuracy of any formula is as good as the input of the biometric parameters. The unique challenges posed by infants and young children, including poor cooperation and fixation, necessitate specialized techniques for biometric assessment. Traditional machines requiring a sitting posture with an upright head for biometry are impractical for infants and young children. Consequently, handheld and mobile devices are utilized, often requiring examinations under sedation or general anesthesia to ensure accurate measurements.

AL: Among biometric parameters, errors in AL measurement have the most profound implications, given their significant impact on IOL power calculation.[18] Due to limited cooperation in the clinical environment, AL measurements in infants and young children frequently need to be performed under general anesthesia. A-scan ultrasound biometry, which typically employs 10-MHz ultrasonic waves, is the standard method for measuring AL in children, relying on instrument-set sound velocity for accuracy. Variability in settings across instruments can impact accuracy, with some using average velocity for the entire eye while others using individual velocities for different eye parts. Ultrasound biometry can be conducted using contact or immersion methods. Studies have employed and compared both these techniques in the pediatric population. Contact A-scan measurements generally yield shorter AL values than immersion A-scan measurements, including in pediatric eyes due to corneal compression by the AL probe that reduces the measurement of anterior chamber depth (ACD). Pediatric eyes are more prone to compression due to lower corneal and scleral rigidity.[19] A randomized study by Trivedi *et al*.[20] demonstrated that AL measurements made by the contact technique were on average 0.24–0.32 mm shorter than those made by the immersion technique. The immersion technique, involving a coupling fluid between the cornea and ultrasound probe, prevents corneal indentation and provides more accurate AL measurements in children compared to contact scans.[19,21] A study by Ben-Zion *et al*.[22] indicates that contact AL measurements can be comparable to immersion scans if corneal indentation is avoided during measurement. A-scan by the immersion technique requires more practice and experience and is usually less preferred in the operating room setting by surgeons for pediatric eyes when the child is under general anesthesia and the duration of time is crucial. Preferring instruments that display the oscilloscope screen over those that just report a numerical value for AL helps in better clinical decision-making and avoids potential errors.[20] Ensuring alignment of the probe with the optical axis is crucial to avoid eccentric scans, which can be monitored by observing spike patterns on the oscilloscope screen while adjusting the probe position. Displaying a straight, steeply rising echo spike signifies proper alignment when the ultrasound beam is perpendicular to the retina. Repeated measurements should be obtained until consistent readings with sharp retinal spikes are obtained, and preference should be given to the reading with the deepest ACD. Measurement of the AL of the fellow eye, especially in cases of bilateral cataracts, helps in decision-making for IOL power calculation by recognizing gross potential errors in measurement and reducing prediction errors (PEs).[23] However, in unilateral cataracts, significant differences in AL between the affected eye and the fellow eye have been reported and thus should not be used interchangeably.[24] Instruments measuring optical biometry based on partial coherence interferometry (PCI), including IOL Master (Carl Zeiss Meditec, Jena, Germany) and LenStar (Haag-Streit AG, Koeniz, Switzerland), can be used in older and cooperative children. They use non-contact scans and provide high reproducibility and accuracy but have poor reliability in children with dense cataracts and inadequate fixation.

Keratometry: It plays a crucial role as the second most influential parameter following AL in the determination of IOL power for an eye. While theoretically, the use of a speculum during keratometry may raise concerns regarding its potential impact on the keratometry values, a study by J Jethani *et al*. concluded that there is no significant difference in their measured values in the pediatric population with or without the speculum.[25,26] However, care should be taken to ensure that the speculum of appropriate size is used and the integrity of the corneal epithelium is not compromised. Attention must be paid to ensure that the cornea is adequately moist to prevent overestimation of the steepness while also avoiding pooling of water, which can induce errors in measurement. Keratometry should precede any contact procedures to avoid changes in corneal curvature that can be induced by contact with any device or probe.[27] Keratometry measurements can be done using either manual keratometers or automated keratometers, which can further be either tabletop instruments that are commonly used in adults and older cooperative children or handheld keratometers. A study done on 404 eyes of patients aged 5–16 years revealed no significant difference in the measurements obtained by a manual keratometer (measuring central 3 mm) and that by a handheld automated keratometer (central 3–3.3 mm).[28] Similar results were also reported by Noonan and colleagues on comparing the Nidek handheld automated keratometer with a manual Zeiss keratometer in adults.[29] However, manual keratometers are more time-consuming and operator-dependent, which can prolong the duration of surgery in the setting of general anesthesia, making it a less preferred mode of investigation.[30] Although handheld keratometers are typically preferred for intraoperative keratometry measurements because of their convenience and portability, especially for children under sedation, their slightly higher keratometric values compared to automated keratometry may affect the IOL power calculation.[26] For older children capable of adequate fixation, keratometry should be obtained as in adults using automated keratometers using PCI, which shows high accuracy, reproducibility, and reliability.[31,32] A minimum of three readings helps in reducing the error and should be taken to get a more reliable reading. Corneal curvature changes with the growth of the eye, with corneas of younger children being steeper than those of older children.[24,33] The literature reports multiple studies that have summarized average normative keratometry values in pediatric eyes with and without cataracts in different age groups in populations of different ethnicities. These can help surgeons corroborate their findings in the operating room and prevent potential PEs in IOL power. Vasavada *et al*. did not report any significant difference in the mean keratometry values between eyes with unilateral and bilateral cataracts, which was concordant with that reported by Hasan *et al*. and Asbell *et al*.[24,26,34] Conversely, the study by Trivedi *et al*.[33] did demonstrate steeper corneas in monocular cases compared to bilateral cataracts as well as in eyes with unilateral cataracts when compared to the fellow unaffected eye. However, the latter was only significant in infants less than 6 months.

ACD and lens thickness (LT): In newer-generation formulas, including fourth and fifth generation, parameters influencing the effective lens position (ELP) have been included. Thus, an error in the measurement of these values can affect the IOL power calculation. Intraoperative ACD has a significant impact on the position of the IOL postoperatively.[35] ACD and LT can be measured using intraoperative ultrasonic biomicroscopy and have shown age-related correlations: ACD has a positive correlation, whereas LT has a negative correlation with age.[36] It has been demonstrated that in adults, a 1-mm measurement error in preoperative ACD corresponds to the change of postoperative refraction of 0.32 D.[37] In older children, optical coherence tomography-based machines and Scheimpflug imaging are employed to measure these values and incorporate them in power calculation. These measurements provide insights about the IOL position in the immediate follow-up period. However, as the eye grows, disproportionate anterior to posterior growth can alter the ELP, potentially leading to myopic or hyperopic shift. Dense proliferative capsular opacification over time may also modify the ELP, leading to unexpected refractive errors. Nonetheless, a 10-year follow-up study, the IATS, did not reveal a significant contribution of variation in ELP to PE in refraction.[38]

White-to-white (WTW) measurement, conducted with calipers, assists in determining whether an IOL can be safely implanted as small corneal diameters may not accommodate an IOL. This is because a small WTW measurement indicates a small sulcus-to-sulcus diameter and, consequently, a small bag diameter.[39] Implanting an IOL in such cases may cause crowding and increase the risk of complications, including secondary glaucoma, pigment release, and corneal decompensation.[40] The authors do not implant IOL in eyes with WTW less than 9 mm to prevent these potential complications.[23] Additionally, a model proposed in the study by Ghoreishi *et al*.[41] calculated sulcus-to-sulcus diameter from WTW measurements in adults, which aided in decision-making for the sizing of the IOL. Newer (fourth)-generation formulas, including Holladay 2, use WTW in addition to other parameters for IOL power calculation, thus making the measurement of this parameter more essential.

2. IOL power calculation

Current IOL power calculation formulas for pediatric patients are largely extrapolated from adult data, raising concerns regarding their applicability in children. The IOL formulas used for pediatric IOL power calculation range from second-generation formulas, including Sanders-Retzlaff-Kraff (SRK) II regression formula based on AL and K; third-generation formulas, including Holladay-1 and Hoffer Q with added parameters of ACD and corneal curvature, Holladay 2 that included ELP and WTW, and a theoretical formula – SRK/T; and newer-generation formulas, including Barrett's Universal (BU) II and Kane's.[42–45]

Comparisons of these IOL formulas for achieving the most accurate postoperative targeted refraction have been extensively studied over the years. The majority of the literature has segmented their pediatric cohort into groups based on ALs to compare these formulas. A few of these studies have also compared the predictive accuracies of these formulas in different pediatric age groups.

The PE in postoperative refraction is calculated as the difference between actual postoperative refractive error and predicted refractive error by each formula.

Numerous studies have consistently evaluated the efficacy of four main earlier-generation formulas—SRK-T, Holladay 1 and 2, and Hoffer Q—in predicting refractive outcomes. Literature reports suggest no significant difference in the accuracy of mean PEs across all IOL power calculation formulas.[15,46] Nihalani *et al*.[13] conducted a study using the SRK II, SRK/T, Holladay 1, and Hoffer Q formula encompassing 135 pediatric eyes from 96 children and revealed a tendency toward increased PE in children ≤2 years old, those with shorter ALs (AL ≤22 mm), and corneas with mean K >43.5 D. In addition, the prediction accuracy was better in office measurements compared to those conducted under sedation, likely due to better fixation in older children. Trivedi and colleagues conducted a comparative study to assess the accuracy of various formulas for IOL power calculation. They found that the Holladay 2 formula exhibited lower PE and absolute prediction error (APE), especially in eyes with AL <22.0 mm, even without preoperative refraction data, compared to the Holladay 1, Hoffer Q, and SRK/T formulas.[47] Moreover, in cases of microphthalmos (AL <19 mm), Inatomi demonstrated the superior accuracy of SRK/T formula compared to empirical formulas for IOL power calculation; Trivedi also reported that the SRK II formula showed the least variability overall, while the Hoffer Q formula displayed greater variability.[15,48] In concordance with these studies, the IATS, a landmark multicenter trial on pediatric IOL implantation, also concluded that SRK/T and Holladay 1 yielded good results with minimum PEs.[49]

Several studies have explored the use of newer-generation formulas, especially Barrett's Universal formula, in pediatric IOL calculation. In a comprehensive analysis by Lin *et al*.,[50] focusing on 110 pediatric eyes, newer-generation formulas, including Barrett, Emmetropia Verifying Optical formula (EVO), and Kane, demonstrated superior accuracy and a reduced mean PE, particularly in patients older than 2 years with AL >21 mm. Similarly, Rastogi's comparison of formulas highlighted BU2 as yielding the lowest mean APE across all eyes, irrespective of AL, when contrasted with Holladay, Hoffer Q, and SRK/T.[51] Shmueli *et al*.[52] conducted a study involving 120 eyes, revealing no significant overall difference in PE among the formulas examined. However, BU II exhibited consistent PE across varying ALs, K-readings, and ages, suggesting its reliability in diverse pediatric populations. Moreover, Rastogi *et al*.'s[17] recent investigation emphasized the non-inferiority of the Hill-RBF method, which employs artificial intelligence and operates independently of specific anatomical features. Their study, comprising 99 eyes of children aged 4–18 years, positioned the Hill-RBF method on par with the BU II, SRK/T, Holladay 1, and Hoffer Q formulas in terms of predictive accuracy, showcasing its potential as an effective alternative in pediatric eye care.

Most of these studies have demonstrated a tendency for a higher PE in shorter ALs and younger children. With better anesthesia, availability of IOLs, sophisticated surgical equipment, and early diagnosis, there has been a trend toward early surgical intervention and IOL implantation in increasingly younger children, raising a query of the most accurate formulas, especially in children <2 years of age. Kekunnaya *et al*.[53] assessed the predictive accuracy of various formulas (SRK II, SRK/T, Holladay, and Hoffer Q) in smaller eyes of 128 eyes of children <2 years of age, finding SRK II to be the most predictive among them, despite all formulas exhibiting high absolute PE. In an observational study by Vasavada *et al*.[10] of 117 eyes of children with a mean age of 2 years, the SRK/T and Holladay 2 formulas had the lowest PE. Additionally, customizing the lens formula constant significantly reduced PE for all formulas, with the exception of Hoffer Q. Similarly, Lin *et al*.[50] demonstrated that in children aged <24 months, EVO followed by SRK/T showed the maximum accuracy when compared to BU2, Haigis, and Kane. Conversely, no significant difference was found in the PE of BU2, Hoffer Q, and SRK/T in children aged <2 years in a recent study of 150 eyes.[52] Although these studies provide a fair idea regarding the utility of these IOL formulas, it is difficult to reach a consensus on the most accurate formula, more so in the given age group, because of the rapid anatomical changes in the eyeball during that age.

While most of these formulas achieve a relatively acceptable postoperative target, none of these formulas have been shown to demonstrate a clear superiority across various studies and all age groups. A study by Mezer *et al*.[12] revealed that none of the five formulas (theoretical and regression) they studied achieved satisfactory refractive outcomes in the early postoperative refractive period, implying the need for informed preoperative consent and IOL formulas that are adapted to pediatric dimensions. These inconsistent results and inability to achieve the targeted postoperative refractions stem from a multitude of factors, including errors in ocular biometric measurements, optically dense cataracts, the density of vitreous that can influence the speed of ultrasound and potentially falsify the power calculation, and the postoperative changes in the ELP over time.[54,55] Increasing the gain to achieve high-amplitude spikes from the retina and sclera and manually aligning the gates to the correct posterior lens spike in dense cataracts can prevent erroneous measurements of the AL.[56] Incorporating the accurate refractive index of the vitreous into the formula can help minimize these errors by reducing its modest but significant effect on AL and ELP.[57] To avoid errors in targeted refractive error, the pediatric IOL calculator, a computer-based tool, has been developed by McClatchey *et al*.[58] to estimate refractive error postoperatively after pediatric cataract surgery in aphakic as well as pseudophakic children. This open-access software uses AL, K, IOL, and the Holladay formula to predict initial refraction, providing accurate results for pseudophakic and older children, though it does not account for outliers.

The data of preoperative AL and K may not always be available or reliable. Aphakic refraction could be used either preoperatively, intraoperatively, or postoperatively for both primary and secondary IOL calculations in adults and children. For primary IOL implantation using this method, the anterior chamber must be formed after aspirating the lens to refract the aphakic eye using either an autorefractometer or a retinoscope. This approach utilizes refractive vergence formulas instead of traditional axial vergence formulas. Recent studies suggest that intraoperative wavefront aberrometry using devices such as the Optiwave refractive analyzer can yield postoperative outcomes comparable to conventional biometry methods in adults undergoing routine cataract surgery, provided the eye can be aligned in the center with the fixation light.[59,60] However, its efficacy in pediatric cases remains unclear. Further research is needed to evaluate its suitability for pediatric cataract procedures given the age-related considerations surrounding IOL implantation recommendations.

With an increase in the availability of normative data for pediatric ocular biometry, the rate of change of these parameters in normal, pseudophakic, and aphakic eyes; differences in postoperative PEs in unilateral and bilateral cataracts; long-term changes in the ELP; and long-term refractive outcomes of different IOL formulas in Indian as well as western population, there is a growing interest toward using this information in IOL formulas that are based on artificial intelligence to achieve the desirable targeted refraction postoperatively. These formulas could surpass the accuracy of the current formulas by using the available normative data of the given population to infer the PE and reduce it to the minimum.

Currently, there is no consensus on the minimum age for IOL implantation. Commonly, authors cite an AL of 17 mm and a WTW of 9 mm as thresholds for IOL implantation in the pediatric population.[23] That being said, flexibility exists based on individual factors such as age, systemic health, ocular condition, and the status of the other eye. These criteria are not rigid and should be tailored to each case.

3. Undercorrection

As the AL of the eye grows in proportion with the lens and cornea, the refraction of a normal infant's eye stays close to emmetropia.[61] With the growth of the eye, there is a myopic shift, even in pseudophakic eyes, which forms the basis of undercorrection in pediatric eyes. The younger the kids and shorter the ALs, the more the targeted undercorrection. Eyes with ALs <20 mm, children <3 years old, shallow anterior chambers, and steep corneal curvatures are prone to significant PEs.[46,62] A study found that less than half of the eyes were within 1.00 D of the target refraction, with the greatest errors observed in eyes that had ALs of <18 mm.[63] The recent report of the IATS has found, at 5 years, refractive errors ranging from +5.00 to as high as −19.00 D, the inability to predict elongation of AL in infantile eyes being the primary reason for such a wide range of refractive errors.[64]

Different authors have devised different formulas to devise the best possible targeted refraction in the postoperative period to potentially achieve emmetropia in adulthood. Although one can never predict the exact AL growth, different regression formulas have helped us determine the amount of hyperopia that needs to be targeted to get the best possible refractive outcomes. Various authors have recommended approaches that involve a progressive undercorrection strategy.[65–69] These are summarized in Table 1. However, a study by the authors on biometric changes in Indian pediatric cataract and postoperative refractive outcomes noted a lower rate of AL growth and keratometry changes in Indian eyes as compared to Western eyes, implying the need for less undercorrection in emmetropic IOL power for Indian eyes.[70] Residual hyperopia is generally considered more amblyogenic than residual myopia and must be carefully avoided if possible and followed for possible anisometropic amblyopia. Hence, we prefer an undercorrection of –20% for children <6 months, 10% at 1 year, 5% at 2 years, and 2% at 5 years.[23] Due to the rapid growth of the eye during the first year of life, delays in postoperative refractions may not accurately indicate PEs due to eye growth and myopic shift.

The amount of undercorrection also depends on whether it is a unilateral or bilateral cataract. In unilateral (or bilateral asymmetrical) cataracts, there is a higher risk of amblyopia because of stimulus deprivation and postoperative anisometropia.[71] Thus, a few authors, including the authors of this study, aim for a lesser postoperative hyperopia as compared to a child of the same age with bilateral symmetrical cataracts.

Dupessey in a recent study discussed a new method to target emmetropia at 15 years of age.[72] The new method was based on a logarithmic regression model predicting normal eye growth published by Bach *et al*.[73] The AL measured by interferometry or ultrasound before implantation was compared with the AL predicted by Bach at the same age. The AL at 15 years old and thus the myopic shift between implantation and 15 years was predicted using this calibrated formula. This myopic shift was converted into diopters, and it served as target refraction to calculate a theoretical IOL power aiming for emmetropia at 15 years.

Despite all these formulas, it is almost impossible to reach the targeted state as it depends on a number of other factors, such as hereditary factors, status of the other eye, compliance with glasses, age at formation of cataract and age at which the eye was operated, surgical complications, variability in IOL position due to capsular fibrosis, and postoperative intraocular pressure. Thus, additional refractive correction may be required in a significant proportion of these children because of the high variability of refractive outcomes.

4. Premium/Toric IOLs

The decision to implant a premium IOL in pediatric patients is complex, involving multiple factors that affect the child's visual development and presenting several dilemmas and surgical challenges. A literature review of premium IOLs in pediatric eyes demonstrated favorable refractive outcomes. The results were more pronounced in children aged >4 years, while no significant advantage was reported in the visual development of the children of multifocal IOL over monofocal IOL when implanted in infancy. There was a significant improvement in binocular vision and stereopsis, especially after binocular implantation of multifocal IOLs.[74–77] These positive results are likely due to reduced risk of amblyopia from accommodative loss and near blur, improved chances of developing binocularity, and the elimination of the need for bifocals.[74] Early models of multifocal IOLs were associated with higher incidences of IOL decentration and posterior capsule opacification. However, newer models have shown significantly better safety profiles. Despite these advancements, long-term outcomes of multifocal IOLs, particularly concerning refractive shift, capsular contraction, and their role in amblyopia management, require further investigation.[78] In this regard, the enhanced monofocal and extended depth of focus IOLs can be possible options that can provide some of the advantages of the multifocal IOL, including better intermediate vision and lesser dependence on bifocals, while avoiding some of their disadvantages, including the refractive shift and problems associated with IOL decentration. However, there is sparse literature reporting the visual outcomes of these IOLs in the pediatric population, and their safety and advantage over monofocal IOLs need to be elucidated. A study by Vasavada *et al*.[79] highlighted that toric IOL implantation in children with a mean age of 7.5 years improves visual acuity and reduces postoperative astigmatism in nearly all cases of non-traumatic cataract surgery. However, preoperative manual marking for toric IOLs can be challenging, especially in younger children. The use of gravity or bubble-based markers is often unreliable in children due to their lack of cooperation, making image-guided systems a preferable alternative for achieving accurate and reliable positioning, especially in children who

Table 1: Summary of undercorrection of IOL formulas for the pediatric population

IOL power calculation formulas/age	1	2	3	4	5	6	>/=7
Dahan and Drusedau (% emmetropia)	80	90	90	90	90	90	90
Prost (% emmetropia)	80	80	85	85	90	90	90
Khokhar (% emmetropia)	80 90	95	96	97	98		Emmetropia from 9
Crouch (targeted postoperative refraction)	4	3.5	2.5	2.5	2	1	1 Emmetropia from 9
Enyedi (targeted postoperative refraction)	6	5	4	3	2	1	Emmetropia
Trivedi and Wilson (targeted postoperative refraction)	6	5		4	3	2	1.5 at 7 years 1 at 8 years 0.5 at 10 years Emmetropia at >/=14 years
Chen (difference from SE of fellow eye)		1.25	1.25	1.25	Emmetropia		

can sit upright for preoperative assessment. Surgeons adopt different age cutoffs for implanting premium IOLs, generally avoiding their use in very young children to prevent refractive surprises due to unstable keratometry and increasing AL. Therefore, careful consideration and individualized assessment are crucial when deciding to use premium IOLs in pediatric patients, balancing the potential benefits against the risks and challenges associated with their use.

5. Long-term follow-up and outcomes

The long-term outcomes of pediatric IOL power and the myopic shift following pediatric cataract surgeries are influenced by the natural growth of the eye. The myopic shift is often unpredictable and depends on a myriad of factors, including age, initial AL, laterality of the cataracts, and postoperative rehabilitation.

The eye's growth is particularly pronounced between the ages of 1 and 3 years, during which the greatest rate of refractive change occurs. After this period, refractive growth tends to follow a more linear trend.[69] Some studies have reported myopic shifts greater than 8–17 D with a moderate amount of individual variability.[80] Younger age at the time of surgery is associated with a higher myopic shift, particularly within the first year post-surgery. This was demonstrated in a study of 22 eyes from 14 infants observed over nearly 15 years, where younger patients exhibited more significant shifts.[81] In patients with congenital or developmental cataracts who underwent cataract extraction and primary IOL implantation between the ages of 2 and 3 years, the myopic shift varied based on preoperative AL. The 5-year long-term outcomes of the IATS also revealed a significant myopic shift in eyes where the IOL was implanted in infancy with the maximum rapid shift during the first 1.5 years of life.[82] Sukhija *et al*.[83] evaluated the long-term outcomes of primary IOL implantation in 26 eyes of children aged <2 years over at least 8 years and demonstrated excellent results and controlled myopic shift (+1.6 at 2 weeks to −1.4 at 8 years).

Eyes with longer preoperative ALs experienced a slower myopic shift compared to those with average preoperative ALs three years after surgery.[84] A study by Cornejo and Boza did not find any statistically significant correlation between preoperative AL and myopic shift. However, on subgroup analysis, they found that shorter ALs lead to a higher myopic shift in bilateral cataracts.[85] This was also reported by Trivedi and Wilson, who demonstrated a larger AL elongation in eyes postoperatively which had shorter preoperative AL than their fellow eyes compared to those that had longer AL.[86]

Trivedi *et al*. also demonstrated a relationship between the laterality of the cataract and myopic shift. There was a statistically significant myopic shift at 3 years in unilateral cataracts as compared to bilateral ones. Similar results were also reported in the studies by Cornejo *et al*. over a period of 3 years and by Vasavada *et al*. over almost 5 years.[85–87]

Once a significant myopic shift occurs, an IOL exchange may be necessary to prevent spherical and chromatic aberrations associated with high concave lenses and to address high anisometropia and aniseikonia in cases of unilateral pseudophakia. However, literature on the rate of IOL exchange in pediatric pseudophakia is sparse. Kraus *et al*.[88] studied IOL exchange for high myopia in 15 pediatric pseudophakes, finding that most of these patients had unilateral cataracts and required resurgery approximately 6 years after the initial surgery, with a mean spherical equivalent of −9.6 D. Comprehensive postoperative management is essential to optimize visual outcomes and control the multifactorial myopic shift for pediatric patients undergoing cataract surgery.

Wilson and colleagues introduced a surgical advancement of temporary polypseudophakia. This technique involves placing an IOL in the bag along with a secondary "piggyback" lens in the sulcus, both calculated using a specialized pediatric IOL calculator. As the child approaches emmetropia or experiences a myopic shift, the piggyback IOL, contributing 20% of the total power, can be removed to achieve a more emmetropic refraction.[89]

Postoperative compliance with refractive correction and occlusion therapy can potentially influence the extent of the myopic shift by its effect on AL elongation and amblyogenicity. During the COVID-19 pandemic, there was an increased use of digital devices, reduced compliance with corrective eyewear and amblyopia therapy, and lack of follow-up for nearly 2 years.[90] This trend underscores the importance of consistent postoperative care and monitoring.

With the trend of implanting IOLs in increasingly younger children and the availability of more advanced IOL options and equipment, there is a growing need for comprehensive reviews that assess various IOL formulas and the factors influencing postoperative refractive outcomes. Our article fills this gap by examining the key elements that affect IOL power calculation in the pediatric population, supported by an extensive literature review. Additionally, it summarizes the diverse postoperative target regimens followed across the globe, along with a thorough discussion on their influence on long-term outcomes. By enhancing our understanding of how the eye behaves in the long term, achieving precise postoperative refractions tailored to each individual child seems possible.

Conclusion

Comprehensive postoperative management plays a crucial role in optimizing visual outcomes and controlling multifactorial myopic progression for pediatric patients undergoing cataract surgery. The importance of precise ocular biometry cannot be overstated as it forms the foundation for selecting the appropriate IOL power. Various IOL formulas are available, ranging from the SRK/T formula, which is widely used for its reliability in pediatric eyes, to newer formulas such as the Barrett Universal II, which may offer improved accuracy in specific cases.

The use of premium IOLs in the pediatric population presents unique opportunities and challenges. Multifocal and toric IOLs can offer significant benefits, such as improved visual acuity, potentially reduced risk of amblyopia, and reduced postoperative astigmatism. However, the long-term outcomes, especially concerning refractive stability, capsular contraction, and amblyopia management, require further investigation.

One of the most significant challenges in pediatric cataract surgery is managing the myopic shift, which varies widely among individuals. Factors such as the age at surgery, preoperative AL, and postoperative compliance with refractive correction and occlusion therapy all play crucial roles. The COVID-19 pandemic has highlighted the impact of external factors on myopic progression, emphasizing the need for consistent follow-up and management.

Given the considerable variation in myopic shift, predicting long-term refractive outcomes for individual patients remains challenging. When selecting the target refraction in infants, aiming for low-to-moderate hyperopia is advisable. This approach balances the risk of high myopia in adulthood against the potential for poor long-term visual acuity due to high postoperative hyperopia.

The field of pediatric cataract surgery continues to evolve, with ongoing developments in IOL technology offering the promise of even better outcomes. The ideal IOL would provide accommodation and prevent posterior opacification, aiming to achieve emmetropia by the age of 15–18 years with a single surgical intervention. Progress in IOL development holds promise for lenses that can adapt to ocular growth and changing refractive needs, potentially reducing the need for additional surgeries and enhancing the quality of life for young patients.

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