REVIEW

Pediatric intraocular lens power calculations

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Purpose of review

To implant an appropriate intraocular lens (IOL) in a child, we must measure the eye well, calculate the IOL power accurately and predict the refractive change of the pseudophakic eye to maturity. The present review will concentrate on recent studies dealing with these issues.

Recent findings

Immersion A-scan biometry is superior in measuring the axial length of children. Current IOL power calculation formulas are very accurate in adults, but significantly less accurate in children. Several studies point to the high prediction errors encountered particularly in shorter eyes with all available IOL formulas. Postoperative refraction target remains controversial, but low degrees of overcorrection (i.e. hyperopia) may not adversely affect eventual best-corrected visual acuity.

Summary

Although pediatric IOL power calculations suffer from significant prediction error, these errors can be decreased by careful preoperative measurements. IOL power calculation formulas are most accurate in the older, more 'adult'-sized eye. The smallest eyes have the most prediction error with all available formulas. Individual circumstances and parental concerns must be factored into the choice of a postoperative refractive target.

Keywords

intraocular lens power calculation, myopic shift, pediatric cataract surgery, pediatric intraocular lens implantation

INTRODUCTION

The first study on intraocular lens (IOL) implantation in children was published by Hiles [1] in 1977. Since then, surgical techniques, instrumentation and lens design have markedly improved, leading to earlier and safer pediatric intraocular lens implantation. Accurate determination of an appropriate IOL power is still a major challenge in pediatric cataract surgery.

Axial length increases dramatically in the first 2 years of life then grows at a slower rate into the second decade of life [2]. The steep cornea of infancy flattens and stabilizes in the first 18 months of life [2]. The power of the crystalline lens declines as it grows and its curvature decreases throughout childhood [2]. Because the implanted IOL is constant in power, as the child's eye continues to grow after surgery, the pseudophakic eye often undergoes a significant myopic shift. The degree of this shift varies with age at time of surgery [3]. Refractive surprises can occur early in the postoperative course due to inaccurate IOL power calculation and later from this myopic shift. The problem is further confounded by the diverse etiologies, morphology and age at presentation of pediatric cataracts.

MEASUREMENT INSTRUMENTATION

Accurate IOL calculation requires accurate preoperative measurements of corneal curvature, anterior chamber depth and axial length. Measurement acquisition in children can be problematic in that the instrumentation is calibrated for adults and requires patient cooperation.

Partial coherence interferometry renders consistently accurate measurements in the adult and can be used in the older, cooperative child. There are currently two commercially available biometric

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KEY POINTS

- Immersion A-scan ultrasound biometry is more accurate that the contact method and is preferred whenever possible as errors in the measurement of axial length can be significant in the calculation of IOL power, especially in children.
- All current IOL power calculation formulas have high predictive errors in the shortest eyes.
- Postoperative refraction target is still controversial, but low degrees of hyperopia do not seem to adversely impact long-term visual acuity.
- Parents should be counselled preoperatively regarding target refractions that will require spectacle wear and challenges in obtaining long-term emmetropia.

devices. Both the IOLMaster (Carl Zeiss Meditec, Jena, Germany) and the Lenstar (Haag-Streit AG, Koeniz, Switzerland) have been used in children [4,5]. Their use in the younger child is limited by cooperation. They are also not useful in the dense cataracts more commonly encountered in children.

When cooperation is a challenge, measurements are obtained under anesthesia. Hand-held keratometry obtained under anesthesia suffers from lack of patient fixation and centration that can cause error. One can increase reliability by averaging out several readings per eye. Inaccuracies of measurement cause power errors of 0.8–1.3 diopters in both adults and children [6]. Instrumentation does not appear to be a significant source of error. Gorig *et al.* [7] compared the performance of two hand-held keratometers (Alcon vs. Nidek KM-500) on anesthetized dogs and found the results comparable.

Whereas accurate keratometry measurements are important, axial length measurement is a more significant source of error in IOL power calculation. Inaccurate axial length measurement can account for 3–4 diopters for each millimeter difference in IOL power in adults. This error can increase to 4–14 diopters or higher in pediatric eyes [6]. Measurement of axial length under anesthesia is accomplished with A-scan ultrasound biometry, using either applanation or immersion techniques. In the applanation method, the probe comes in contact with the cornea and may indent the soft and flexible pediatric eye. This may induce measurement artifact in the form of shorter axial length and anterior chamber depth measurements. Immersion A-scan uses a coupling fluid between the cornea and probe to reduce corneal indentation. Immersion A-scan has been shown to be more accurate than applanation [8▪], but this method has limitations in small eyes and globes with shallow anterior chambers or other anomalies.

INTRAOCULAR LENS POWER CALCULATIONS

Formulas for IOL power calculations are mainly derived from studies in adults. They fail to take into account the shorter axial length, steeper corneas and shallower anterior chamber depths of children. The empirically derived regression formulas, such as the Sanders–Retzlaff–Kraff (SRK) formula and the later SRK II are based on mathematical analysis of postoperative results in adults. They are most accurate for eyes in the average axial length range. The theoretical formulas use geometric optics to calculate effective IOL position in the eye. They are considered more reliable in predicting IOL power in adults. Third-generation theoretical formulas such as Holladay 1, Hoffer Q and SRK/T, vary the effective IOL position in relation to axial length and corneal curvature. The Holladay 2 formula uses additional factors in its calculation of IOL power: white-to-white corneal diameter, anterior chamber depth, age, lens thickness and preoperative refraction.

Several recent studies have been published which compare the prediction accuracy of the different IOL power calculation formulas in children in the immediate postoperative period. None of these studies measures refractive changes over time. Mezer *et al.* [9] evaluated the refractive outcome in the 2–6 month postoperative period in 49 patients using two regression formulas (SRK, SRK II) and three theoretical formulas (Holladay 1, Hoffer Q, SRK/T). The mean age at time of surgery was 6–7 years with a range from 18 months to 17 years. All five IOL power calculation formulas were unsatisfactory in achieving target refraction. The mean difference between the predicted and actual postoperative refractions with all formulas ranged from 1.06 to 1.2 diopters. Nihalani and VanderVeen [10] conducted a retrospective study of 135 pediatric eyes that underwent cataract extraction and primary IOL implantation. Sixty-nine of these eyes had an axial length shorter than 22 mm. Twenty-two patients were under the age of 2 years. Refraction was measured at 4–8 weeks postoperatively and compared with the target refraction to determine prediction error. The mean predictability of all four formulas was comparable with 57% of patients having a prediction error greater than 0.5 diopters. A trend towards greater prediction errors was seen in children less than 2 years of age, axial length less than 22 mm and mean keratometry reading greater than 43.5. In younger children and in short axial lengths, the Hoffer Q yielded more predictable results. Overall, the SRK II, SRK/T and Holladay 1 formulas tended to undercorrect, whereas the Hoffer Q had an equal number of undercorrections and overcorrections.

The prediction error of the Holladay 2 formula was evaluated in a study of 45 pediatric eyes [11▪]. In this study, one required Holladay 2 variable was missing due to the inability to obtain preoperative refraction in the densely cataractous pediatric eye. The prediction error of the Holladay 2 formula was compared with that of the Holladay 1, Hoffer Q and SRK/T formulas at the initial postoperative refraction. The Holladay 2 formula had the least prediction error for all pediatric eyes and specifically for the subgroup of eyes less than 22 mm in length. The authors conclude that the Holladay 2 formula can be used despite the lack of preoperative refraction.

Pediatric Intraocular Lens (IOL) Calculator [12] is a computer program using the Holladay 1 algorithm and pediatric normative data for axial length and keratometry readings as established by Gordon and Donzis [2]. It is designed to calculate the postoperative pseudophakic refraction of a child in the immediate postoperative period and then to predict the refractive change as the child grows. Jasman *et al.* [13] compared the prediction error of the SRK II formula versus Pediatric IOL calculator at 3 month postoperatively. Thirty-one children were randomized to IOL calculation using either SRK II formula or Pediatric IOL calculator for a refraction target of emmetropia for those patients using the SRK II formula and a predicted refraction of emmetropia at 2 years of age for the Pediatric IOL calculator. In this study, 87% of patients were over the age of 3 years. No statistical difference was noted in prediction error between SRK II and Pediatric IOL calculator.

IOL power calculation in children less than 2 years is especially problematic. Kekunnaya *et al.* [14▪▪] retrospectively compared SRK II, SRK/T, Holladay 1 and Hoffer Q formula predictions of immediate postoperative refraction in children less than 2 years of age. One hundred and twenty-eight eyes underwent cataract surgery and primary IOL implantation with a mean age at surgery of 11.7 months. The authors found prediction errors were large for all formulas. SRK II had the lowest prediction error (2.27 ± 1.69 D) but this is, nonetheless, a large prediction error. The advantage of the SRK II formula in this study may be in the fact that prediction error was not affected by age, mean keratometry value or axial length. Age did not affect the absolute prediction error for any of the four formulas. Axial length affected the absolute prediction error for the Holladay 1 and Hoffer Q formulas. The error increased with shorter axial lengths. Higher prediction errors were seen in flatter corneas using the SRK/T formula. These results are in contrast to the findings of Nihalani and VanderVeen [10] wherein the Hoffer Q formula produced the least prediction error. The study by Nihalani and VanderVeen *et al.* [10] may have been underpowered in this age group as only 22 study patients were under the age of 2 years in their study. In addition, the Hoffer Q formula uses a standardized anterior chamber depth (ACD) in its calculation and this ACD is based on adult eyes. The smaller axial lengths, shallower anterior chambers and variability in IOL position in the youngest eyes may contribute to the prediction errors encountered in the study by Kekunnaya *et al.* [14▪▪]. Mezer *et al.* [9] discuss factors that affect the position of the IOL in the pediatric eye as a source of variability of measurement. Residual capsular fibrosis, soft sclera and possibly pars plana entry wounds for primary capsulotomy may alter IOL position. Centration is also a concern.

The Infant Aphakia Trial found large predictive errors in their prospective study of IOL implantation in infants under the age of 7 months [15▪]. Forty-nine infants received IOLs based on the Holladay 1 formula. IOL power was targeted to produce an initial refraction of +8.00 in infants aged 4–6 weeks and +6.00 in infants 7 weeks and older. Measurement of refraction at 1 month after operation revealed that only 41% were within 1 D of target refraction. The greatest prediction errors were seen with eyes less than or equal to 18 mm in axial length.

The current state of the literature points to the need for improved IOL power calculations in pediatric cataract surgery, especially in children with the shortest axial lengths.

REFRACTION TARGET

The child's increasing axial length causes a myopic shift in the refractive state. The degree to which the refraction shifts is influenced by the age of the child at the time of surgery, surgical technique and hereditary factors [16]. Although most pronounced in the first years of life [17], this myopic shift has been reported to continue after 10 years of age [18].

McClatchey has proposed a table (Table 1) [19] to aid the surgeon in determining a postoperative refraction target based on age. The table assumes typical pseudophakic eyes without unusual circumstances. The Pediatric IOL calculator [12] was also designed to predict eventual adult refraction. This open access computer program was written for Windows 5 (trademark) and has not been updated for more recent Windows versions. Both of these

Table 1. Predictions for typical[a] pseudophakic eyes

			Predicted refraction (D) at a given age (year)[a]				
Age at Surgery (yr)[b]	IOL Power[c]	Initial Postop[c]	1	2	4	8	20
−0.15	30.0	+12.00	2.31	0.79	−0.73	−2.24	−4.23
−0.06	29.3	+9.00	2.53	1.03	−0.47	−1.96	−3.92
0.00	28.2	+8.00	2.78	1.31	−0.15	−1.61	−3.53
0.25	26.9	+7.00	3.68	2.24	0.81	−0.61	−2.49
0.5	26.0	+6.50	4.02	1.71	−0.59	−2.86	−5.81
1	24.5	+5.00	5.00	2.61	0.37	−1.84	−4.71
2	22.3	+4.00		4.00	1.85	−0.28	−3.04
3	22.3	+3.00			2.10	−0.04	−2.82
4	22.0	+2.25			2.25	0.12	−2.64
6	21.0	+1.50				0.63	−2.08
8	20.4	+1.00				1.00	−1.69

Adapted from [19].
[a]The rate of refractive growth (RRG) for children with surgery at age more than 0.5 year is assumed to be −5.4 D; for children with surgery at age less than 0.5 years it is assumed to be −3.3 D after age 0.25 year. The predictions for infants with surgery at age less than 0.25 year are theoretical. Variations in RRG and initial ocular measurements will significantly affect these predictions: the large variance in RRG will lead to a large range of ultimate refractions; these are the expected means.
[b]The age groups in the first two rows are premature babies (e.g. −0.06 year is equivalent to 37 weeks corrected gestational age, 3 weeks before due date).
[c]IOL power and initial refractions are for example only and are not our recommendations. Assumed A-constant = 118.0. All IOL powers and refractions are given as diopters.

tools are based on average eyes and refractive changes. Their usefulness is limited by their inability to predict 'outliers'.

Several issues come into play when we target a refractive goal in children. One can aim for initial hyperopia to compensate for the expected myopic shift. The child will require refractive correction and the treatment of amblyopia will be more difficult due to hyperopic anisometropia. Initial postoperative emmetropia will aid amblyopia treatment but the eye will eventually become myopic. Initial postoperative mild myopia provides spectacle – free near vision but the risk of high myopia in adulthood. At present, no consensus exists. Recent studies of this issue differ in their conclusions. In their study of the visual deficits produced by anisometropia, Levi *et al.* [20] have shown that 3 diopters of hyperopic anisometropia will cause amblyopia in over 40% of patients and contribute to reduced stereopsis. Lowery *et al.* [21▪] found that low early postoperative hyperopia (+1.75D to +5.00D) yielded better long-term corrected visual acuity in unilateral pseudophakes regardless of refractive error in the fellow eye. In contrast to the unilateral pseudophakic visual results, this study showed that initial postoperative refractive error was not a significant factor in eventual best-corrected vision of bilateral pseudophakes. The children in this study were slightly older than those studied by Lambert *et al.* [22▪▪], who found no correlation between initial postoperative refractive error and best corrected visual outcome or rate of myopic shift in unilateral pseudophakes. Both studies were retrospective with small sample sizes. The variation in findings may reflect population differences as observed by Trivedi *et al.* [18].

Family situation and parental concerns should be included in decisions about postoperative refraction. Contact lenses and spectacles can be used to manage postoperative anisometropia, either planned or unplanned. Both modalities can be modified over time to deal with subsequent myopic shifts. Progressive add or bifocal spectacles will be needed postoperatively for near and intermediate distance work, so spectacle correction can also address anisometropia. Contact lens use is more problematic as its use runs counter to the original purpose of placing intraocular lenses.

Several surgical innovations have been proposed to address the dynamic refractions of pediatric pseudophakes. Wilson *et al.* [23] proposed temporary polypseudophakia wherein a permanent IOL is placed within the capsular bag, with a second 'piggyback' IOL placed in the ciliary sulcus. This second lens can be removed when the myopic shift occurs, maintaining a more or less emmetropic refraction throughout childhood. Pediatric Piggyback IOL Calculator [24], a Microsoft Excel for Windows spreadsheet, was developed to aid in the choice of powers for the anterior and posterior lenses. On the basis of this novel graphical spreadsheet calculator, it is recommended that the anterior IOL have 20% of the total required IOL power. The anterior IOL can then be removed when the child's myopia equals half of the anterior IOL power.

The use of an adjustable IOL has also been proposed to deal with changes in refraction due to the myopic shift of pediatric pseudophakes. Jahn and Schopfer [25] reported promising short-term results in 35 adults eyes using the Acri.Tec AR-1 (Acri.Tec, Hennigsdorf, Germany), a mechanically adjustable polymethylmethacrylate IOL. The power of this particular lens can be reversibly adjusted by changing the position of the optic via two small paracentesis wounds in the cornea. To the author's knowledge, there have been no studies utilizing this type of lens in children.

A light-adjustable intraocular lens (LAL, Calhoun Vision, Inc, Pasadena, California, USA) uses a proprietary photoreactive silicone macromer within a silicone matrix IOL for a one-time power adjustment. Targeted ultraviolet light using a digital light-delivery device (Carl Zeiss Meditec, Jena, Germany) modifies the lens curvature. Once the desired lens adjustment is achieved, the entire IOL is irradiated to polymerize the remaining photosensitive macromers and 'lock-in' the IOL power. Short-term results in adult eyes showed no additional endothelial damage to the pseudophakic eye [26], but a trend towards mild hyperopia was observed [27]. One interesting complication occurred with noncompliance to UV protection spectacles during the prelock-in postoperative period. The light-adjustable lens was exposed to sunlight for several hours and developed a paracentral elevation, necessitating explantation [28]. The use of this lens has not been reported in children. The one-time adjustment window and the strict adherence to UV-protection during the prelock-in period, as well as the need for multiple shifts in power over time would make it problematic in children.

CONCLUSION

As pediatric cataract surgery techniques continue to refine and the age at implantation of an IOL continues to become younger, the need for more accurate IOL power calculations increases. More studies on the ideal postoperative refractive state and novel approaches to a variable refractive solution are warranted.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
■ of special interest
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Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 454).

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