Review Article

Intraocular lens power calculation formula in congenital cataracts: Are we using the correct formula for pediatric eyes?

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The major challenge these days in pediatric cataract surgery is not the technique of surgery or intraocular lens (IOL) used but the postoperative refractive error. Amblyopia occurring due to postoperative refractive error which the child has; destroys the benefit obtained by a near-perfect and timely surgery. Even if we settle the debate as to what should be the ideal postoperative target refraction, there is a postoperative surprise that is not explained by our conventional insights of an accurate power calculation in children. The role of IOL power calculation formulae in affecting the postoperative refractive error should not be underestimated. Therefore, which age-appropriate formula is to be used for children is unclear. This review is an update on major IOL power calculation formulas used in pediatric eyes. We have tried to define why we should not be using these formulas made for adult eyes and review the literature in this regard.

Key words: Biometry, intraocular lens power, pediatric cataract

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Intraocular lens (IOL) implantation for all ages is being largely endorsed by pediatric ophthalmologists throughout the globe. With advances in surgical techniques and instrumentation, primary IOL implantation is now largely being accepted in infants as well.[1-4]

The major challenge after a well-done pediatric cataract surgery is the postoperative refractive error. This refractive error depends largely on the power of the IOL and the postoperative target refraction. Since an inaccuracy in the power calculation might result in a permanent visual disability, it is crucial to obtain an accurate IOL power. Ocular biometry is the single most important factor influencing the precision of IOL power in children. Biometry is, in turn, affected by measurement errors in children and IOL calculation formulae. Examination under anesthesia precludes the cooperation needed for the examination. Even after an accurate measurement, the type of ultrasound used[5] (immersion vs. contact), the velocity of ultrasound used,[6] the keratometry method, as well as the site of IOL implanted, can all affect the IOL power calculation largely [Table 1].

The IOL power calculation formulae (IOLCF) also are a source of variability in power determination and have a very crucial role in this regard. Various IOL formulas have been designed for adult eyes but presently there are no formulae for the pediatric eye. There are some inherent difficulties in the pediatric eye making IOL power calculation difficult. We cannot use the adult formulas in pediatric eyes because of their shorter axial lengths, higher keratometry, and smaller anterior chamber depths. The IOLCF designed for adults only has been tested for accuracy in children.[7-18] There is no consensus as to which is the best formula for children.

In this article, we review the literature on the accuracy of adult IOL prediction formulae when used for pediatric IOL power calculations.

History of IOL calculation formulas

IOLCF have been evolving since their inception in 1967.[19] The modern formulae are based on the equation given by Fyodorov. It is based on axial length, keratometry, vertex distance, effective lens position, and desired refraction postoperatively. These formulae are often classified based on their derivation into theoretical, regression, or both. Regression formulae are empirically derived from normative data on adult eyes using corneal power and axial length to derive the IOL power. The SRK formula was formulated by Sanders, Retzlaff, and Kraff based on a large number of postoperative results in adults. It is the most widely used formula and along with its modifications, is now in use for decades. Examples of regression formulae include SRK I and SRK II.

In the original formulae, the anterior chamber depth was presumed constant as the IOLs were designed for the anterior chamber. The SRK II formula was thus modified to include the anterior chamber depth and axial length while formulating the A constant derived by the manufacturer.

Theoretical formulas on the other hand work on theoretical principles using geometrics on a schematic or reduced eye. SRK

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Table 1: Factors causing inaccuracy in pediatric IOL power calculation

Axial length and Keratometry measurement errors
Uncooperation during examination and fixation errors
Supine position used for measurements
Instruments designed for adult eyes
Different biometry and anatomical differences from adults
Using adult formulae
Cataract extraction with posterior capsulotomy and anterior vitrectomy may affect the effective lens position
Target refraction and growing myopic shift

T, Holladay, Haigis, and Hoffer Q are theoretically derived advanced formulas. These IOLCF underwent evolution as per generations. The first-generation formulae presumed anterior chamber depth (as proxy for effective lens position) to be constant at 4 mm. They worked best for axial lengths in between 22.5 and 25 mm. Later, axial length was found to be predictive of anterior chamber depth. The anterior chamber depth varied with the axial length and the second-generation formulae evolved (Hoffer). As the production of IOLs evolved, the depth was now calculated using both axial length and corneal curvature as determinants of effective lens position in the third-generation formulas (Holladay, Hoffer Q).

Various modifications have been made to improve the efficacy of IOLCF. Fourth-generation formulae use preoperative lens thickness, anterior chamber depth, and white-to-white diameter in addition to the axial length and keratometry, to calculate effective lens position. Newer formulae work on calculations of actual lens position and use only one constant that is Surgeon Factor (SF; originally the A constant) calculated from the surgeon's experience. The newer Holladay 2 formula takes anterior segment measurements, patient's age, and refraction preoperatively as further variables and the Haigis formula has swapped keratometry with preoperative anterior chamber depth to improve precision.

SRK/T formula combines the principles of regression as well as theoretical formulae.[20] The formula uses retinal thickness in addition to axial length and keratometry to calculate the postoperative anterior chamber depth.

Although newer theoretical IOL calculation formulas are reported to be more efficacious in adults, there is little evidence to show that they perform better than regression formulas in children.

Why not use the adult formulae in children?

All IOLCF designs have been formulated for adults. The accuracy of these formulas is largely dependent on axial length, hence in adults, the choice of the formula is based on it. In adults, Holladay 2 or Hoffer Q are useful for eyes with axial length less than 19 mm. For axial lengths between 22.0 and 24.5 mm, we can use Hoffer Q, Holladay 1, and SRK/T with similar efficacy. The SRK/T and Holladay 2 perform the best in eyes with the axial length between 24.5 and 26.0 mm and the SRK/T is superior to other formulas in axial length greater than 26.0 mm.[21,22]

The accuracy of each formula depends on many variables like axial length, anterior chamber depth, lens thickness, IOL position, and/or A constant. Hence, the accuracy of prediction of refractive errors in pediatric eyes is less than the adult eyes in all IOLCF used. The mean prediction error observed in pediatric patients using these formulae is much more than adult population by all formulae.

There are a lot of reasons why we should not use the adult formulae in children, measurement errors, postoperative target refraction, and different biometry. In addition, dense cataract and dense vitreous may reduce ultrasound transmission. Pediatric eyes are shorter hence require high-powered IOLs. In short eyes, an error of 1 mm in axial length can introduce an error up to 3.75-D in the IOL power.[23] Children are often uncooperative for examination and hence there is an inaccuracy in axial length and keratometry measurements due to the supine position used to obtain these. The target refraction is not emmetropic as in adults.[8] Measurement errors prevail as the instruments are designed for adult eyes with a fixed velocity, which is less than in the eyes with cataracts resulting in an error of up to 0.25 D.[24] Office measurements in children are more accurate than those taken under anesthesia and hence measurement errors confound the results due to lack of fixation in children.[9] Most importantly, errors arise because of the different biometry in children and assumptions made in the IOLCF. Their biometrics are not only different than an adult but also different than an anatomically normal (noncataractous) pediatric eye. It is reasonable to argue that pediatric eyes are not "small adult eyes" and hence the adult regression formulae for shorter eyes should not be used.[25] Regression formulae when derived had very few short eyes and they were based on adult biometrics. On the other hand, theoretical formulae are based on adult schematic eye and hence should perform better being based on optical principles.[10] These formulae could be theoretically extrapolated better in children by proportionately downsizing the variables to pediatric dimensions. The problem in this context is that the differences of the pediatric dimensions for a cataractous eye versus a normal eye are not clearly elucidated. The anterior segment to posterior segment ratio of an infant is large. The capsular bag also contracts and causes changes in effective lens position. Current IOLCF do not take into account the variable site of IOL implantation, shallow anterior chamber, dynamic vitreous pressure, and the postoperative capsular contraction in children. Higher the lens power; more are the changes in refraction by the displacement of the lens position.[26] The anterior chamber depth in the formulae is either assumed from the manufacturer's A constant or calculated in theoretical formulae based on axial length and biometry.

Finally, the target refraction for all pediatric IOL power calculations is not emmetropia as in adult eyes that may affect the results of the same IOLCF.[14,20] Postoperative refraction has a 27% chance of causing an error in IOL power calculation.[27] Axial elongation and decrease in corneal curvature in all children bring about a myopic shift, which affects the refractive state and hence the IOL power that we choose. Even the presence of cataracts and their surgical removal influence the dioptric power of the eye.[28] The errors obtained in a pediatric eye in the predicted error may be very large and are reported to range up to 14.3 D by different formulas[11] with mean errors reported around 1.06.[12] Only 21% of the patients fell into the acceptable clinical error of 0.5 D and 34.4% into ±1D in a study previously published.[12] Furthermore, the axial length and the keratometry affect the prediction errors by all formulae.[13] This variability increases as the axial length decreases below 19 mm. By SRK II, there is an error of 2.5 D/mm of axial length but it is not constant at all axial lengths. The general tendency is a lesser error in eyes with longer axial length and larger keratometry.[7,14] Where the eye is smaller than 20 mm, the prediction error could be up to 2.63 D, which is an amblyogenic factor in itself.[15] This sensitivity to changes in axial length is increased in children up to an error of 4 to 14 D per mm of axial length and is not even uniform with all IOLCF.[14]

Which formula is the least inaccurate?

So, which is the best adult formula to be used for a child? Since all formulas give erroneous results in children, the question should be: which is the least inaccurate IOLCF when used in children. Postoperative results after pediatric cataract surgery using different formulas have shown extreme variability in refraction. Adult formulas have been tested in very few extremely short eyes <20 mm. The accuracy of five formulae (SRK, SRK-II, SRK/T, Holladay 1, and Hoffer Q) was compared in 206 children and all were found unsatisfactory by Mezer *et al*.[16] and equivalent in another study.[9,15,17] Nihilani *et al*.[9] got an accuracy of 43% within 0.5 D by all formulae. The results of the study by Andreo *et al*.[17] revealed little difference between SRK II, SRK/T, Holladay I, and Hoffer Q formulas in eyes of all axial lengths. The two most commonly used formulae SRK/T and SRK-II were found to be equal in predicting errors in 101 pediatric eyes.[12] All formulae behaved equally in another study.[18] The SRK-T has shown greater accuracy when the mean predicted error was compared in some studies[10] and was found not to be as accurate in others.[8] In the short adult eyes also the Holladay 2 and Hoffer Q showed equivalent results, although it is not fair to extrapolate these results in pediatric eyes.[22]

The infant aphakia treatment study, which is the largest trial on pediatric intraocular lens implantation found that the Holladay 1 and the SRK/T gave the minimum possible errors. Overall, SRK/T was found to give the minimum average prediction error (0.3 D) and Hoffer Q the highest error (2.3 D). They also stated that half of the patients would have a refractive error up to 1 D with SRK/T as well as Holladay 1. SRK II tends to undercorrect the power in pediatric eyes. They concluded that that SRK/T and Holladay 1 yield good results in infants and they preferred Holladay 1.[13] Hoffer Q is reported as the most accurate in very few studies.[9] and also reported to be the worst in some study.[11,12] Study by Nihilani *et al*.[9] was the first to report the best prediction error with Hoffer Q for short pediatric eyes. However, their better predictability from Hoffer Q compared with all formulae was equal and not statistically significant. Hoffer Q was also likely to overcorrect when the error exceeds 0.5 D because of a greater number of short eyes in their cohort. However overcorrection in children is not advisable at all. Similar results were seen in the study by Neely *et al*.[12] where they found that there was a tendency for the Hoffer Q formula to overestimate the IOL power significantly in pediatric eyes. As age, axial length and diameter of the cornea decreased, the accuracy of the Hoffer Q formula went down.

Pediatric IOL calculator uses computerized software for IOL power calculation that is calculated from pediatric aphakic models. It is a modification of the SRK II formula using the Holladay algorithm and predicts the refraction of a growing child with operated cataract and IOL.[7] The pediatric IOL calculator was compared with the SRK II in 31 pediatric eyes and found comparable. The mean prediction error was 1.14 D with the calculator, which could predict within ±0.5 D in 46.67% of eyes.[7] For aphakic children often uncooperative for biometry, formulas using aphakic refraction have been formulated.[29,30] These formulae, namely, Hug's and Khan's formulas were compared with biometry-based formulas also for secondary intraocular lens implantation.[31] Although these methods can give you a fair idea of the IOL power to be implanted; they are advantageous only in a setting where obtaining biometry is difficult.

Since all IOLCF have been regarded to give suboptimal accuracy, no clear-cut guidelines have been laid so far. It is fair to say that any formula used will give accurate results in 45%–50% of the patients only. It may be justifiable to continue using an appropriate combination of two single constant formulas and choosing the lowest power in children. Of course, the error should be expected with any new generation formula.[32] SRK/T and Holladay seem to be the most popular IOLCF so far used successfully in pediatric eyes.

Age and IOL power calculation formula

The variability in refractive outcomes after various IOLCF is particularly obvious in children younger than 2 years of age. Many studies have tested the accuracy of different IOLCF in a wide age group of children from less than 2 years to 8 years[10] and even up to 18 years.[7,9] One of these studies[10] used the SRK/T formula in all eyes less than 2 years as a standard guideline and hence the other formulae were clinically never tested in this age group. The acceptance of IOL implantation in less than 2 years has gradually increased and these young children need the most precise IOL power due to the largest anticipated myopic shift. These eyes undergo a rapid elongation of the eye.[11,33-35] Hence, the prediction errors have been reported to be maximum in this age group that has the smallest axial lengths.[15,18] The different axial lengths and corneal curvatures make the predictability difficult and inaccurate. The operative technique with vitrectomy does not seem to affect the refractive outcome.[9] Studies show that there is a trend toward larger prediction errors in axial lengths less than 22 mm in youngest children[7,36] Most of these studies were underpowered to separately look for the results of different formulae in children less than 2 years of age. Kekunnaya *et al*.[11] studied the predictability of desired postoperative refraction in children less than 2 years. They used SRK-II, SRK/T, Holladay 1, and Hoffer Q in 128 eyes of 84 children and found the SRK II to show the minimum predicted error (2.27 ± 1.69 D) with an accuracy of 50%. This error is also very large in clinical terms while considering postoperative amblyopia. Within the age group of 2 years; however, age was found not to influence the absolute prediction error with any formulae.[11] The accuracy of Hoffer Q in this age group was conflicting between the two studies.[9,12] As hypothesized by Kekunnaya *et al*.,[11] the surgical factor used in the Hoffer Q formula may be difficult to compute in these small eyes compounded by the inaccuracy of effective lens position. In another study with a relatively small sample size, where eight formulas were studied, it was seen that in patients younger than 2 years old or with AL ≤21 mm, SRK/T formulas were relatively accurate, whereas Barrett and Haigis formulas were better in patients older than 2 or with AL >21 mm.[36] They found out that the mean absolute prediction errors were similar using third-generation and fourth-generation formulas. Again the A constant used in all of these studies is derived from adults. In a recent study, a significant negative correlation between the age of the patient and predictive error of the SRK/T formula was found.[37] Overall, all IOL power calculation formulae tend to be variable in children, especially in children <2 years, with AL <19 mm and K readings >46.5 D.[36] In addition, age at the time of surgery significantly contributes to the refractive surprise using all formulas.[38] SRK/T and Holladay I formulas give better results in children aged less than 2 years.[39]

Lacunae

A lot of studies analyzing the accuracy of IOLCF have been retrospective with small numbers. Studies describing the use of the latest fourth-generation formulae in pediatric eyes are lacking. Barrett Universal II formula as a reasonable and reliable option in a single study has been reported.[40] Different surgeons and their different techniques could affect the predicted error post-cataract surgery and many comparisons in the studies were not randomized and were merely a consecutive series of patients.[10,11] Now that even smaller children are undergoing

IOL implantation, the prediction errors are increasing we are in a dire need of an IOL power calculation formula for children.

Conclusion

The increased ambiguity of IOL power calculation in children warrants the need for precise measurements and age-appropriate IOLCF. The current IOL power calculation formulae are largely originated from studies in adults and hence not perfect in children. There is presently no consensus on the best IOL formulae in children. The presently available formulas may give an error of more than 0.5 D in half of the pediatric patients. The accuracy of the advanced theoretical formulae in pediatric cataract surgery is also low. There is a need for the formulation of a separate IOL power calculation formula specifically designed for children. Till the time we have such customized formulae; a combination of any two modern formulae can be used.

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Conflicts of interest

There are no conflicts of interest.

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