The placement of an intraocular lens (IOL) in children and infants undergoing cataract surgery is gaining wider acceptance. With improved surgical equipment and techniques, the acceptable age for IOL implantation is becoming progressively younger. However calculation and selection of an exact intraocular lens (IOL) power for the eye of a child which is in a process of growth presents varied challenges. The implantation of an IOL with a fixed power in an eye that is still growing makes it difficult to chose an accurate IOL power that best benefits the child’s eye. The younger the child, the more difficult is the problem.

This is a challenging task for any ophthalmologist but probably more so in the our settings due to the lack of instrumentation in the operating-room like hand held keratometers and the A-scan ultrasound which increases the difficulty of calculating the IOL power in pediatric cataract surgery. Even with the availability of these instruments in the operating room, small and developing eyes of children possess unique challenges when calculating an IOL power. Also the formulas that we use in these cases were primarily designed for adult eyes, hence their extrapolation in paediatric eyes can be disastrous.

IOL implantation after cataract surgery in children >1 years of age is now widely accepted, although the implantation of IOLs during infancy is still controversial. In these scenarios, it is important to have optimal approach for determining IOL power in children and infants. As implanting an IOL at the calculated emmetropic power in children risks significant myopia/ refractive surprise at ocular maturity. For each case, the IOL power needs to be customized based on many characteristics including the age at which surgery is planned, unilateral or bilateral, whether amblyopia is present and likely compliance with glasses and occlusion therapy in the post operative period.

Here in again, ophthalmologist in our settings faces additional challenges. Many children present late and have dense amblyopia. In addition, parents compliance to amblyopia therapy and required regular follow-up may be poor. Thus, apart from calculation, selecting an IOL power and its implantation and its after effects are much more challenging to the ophthalmologist in the our setting compared to the west.

How to proceed

Before implanting an IOL in a child we need to be aware of physiological development of a normal, aphakic and a pseudophakic eye in children and their visual needs. We should know if a refractive shift is anticipated, and if so what is its nature and magnitude and at what age is it seen. Also we should be aware of target refraction that should be sought following the IOL implant.

Normal eye development

Maximal ocular growth occurs in the first few years of life with the changes as enumerated below. The normal newborn eye has a mean axial length (AL) ranging from 16.6 to 17.0 mm and a mean keratometric power of 51.2 diopters (D). It reaches an appx mean adult value of 23.6 mm at appx 15 years of age. As the child’s eye develops, the refractive changes seen are primarily due to the growth in the AL. More than 50% of this change in AL occurs before 1 year of age and the maximum axial growth occurs during the first 2 years of life. O’Brien and Clark demonstrated a mean AL of 15.38 + 0.25 mm in preterm infants of 33 weeks. AL increased at a rate of appx 0.18 mm/wk until 40 weeks then slowed down to 0.15 mm/week until the age of 3 months. The mean AL of infants at 3 months was 18.23mm. The growth rate then slows...
down even further again to an appx mean adult value of 23.6 mm at 15 years of age.\textsuperscript{3,4,5}

The change in mean keratometric values occurs primarily within the first 6 months of life. The corneal curvature decreases from an average power of 51.2 D at birth to a mean of 43.5 D (adult value), as the AL increases from an average of 16.8 mm at birth to 23.6 mm in adulthood.

Due to above mentioned changes, during the first year of life, lens and total eye power decreases by more than 10 D but there after it decreases only 3-4 D from the age of 2yrs to 10 years of age when it stabilizes.\textsuperscript{6}

**Refractive shift after surgery**

In pseudophakic eyes, the implanted IOL power does not change as in aphakia also it is static. If the AL grows normally as in an unoperated child, increasing myopia or reduction in hypermetropia would be expected. Axial growth after cataract surgery can be due to normal eye growth as in hypermetropia would be expected. Axial growth after and after it decreases only 3-4 D from the age of 2yrs to 10 years of age when it stabilizes.\textsuperscript{6}

McClatchey and Parks followed a series of aphakic children into adulthood and found that there was a decrease in the hypermetropic error which followed a logarithmical regression curve 7 and was very similar to that predicted from Gordonand Donzis’s study data on phakic children.\textsuperscript{7,8} They also calculated the long-term effects of pseudophakia on refraction in aphakic eyes on long-term follow-up and predicted an amount of 6.6 D mean myopic shift over a mean follow-up of 11 years.

Most of the children below 2 years at the time of the cataract surgery with or without IOL implantation have a significantly greater than predicted myopic shift and a greater variance in the refractive change than those older than 2 years at the time of surgery. Vanathi et al noted a mean myopic shift of 7.35 D in 12 children (mean age 6.7 years) post-uniocular cataract surgery followed for a mean of 7.8 years.\textsuperscript{9} In a study of 52 eyes in 42 patients aged 12 months to 18 years undergoing cataract surgery with IOL implantation, Crouch reported a mean myopic shift of 3.66 D in children operated on at the age of 3-4 years, 2.03 D in children operated on at the age of 7-8 years, 1.88 D in children operated on at the age of 9-10 years, 0.97 D in children operated on at the age of 11-14 years and 0.38 D in children operated on at the age of 15-18 years (Table 1).

<table>
<thead>
<tr>
<th>AGE</th>
<th>Plager et al</th>
<th>Crouch et al</th>
<th>Wilson et al</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 yr</td>
<td>6.22 D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3 yrs</td>
<td>4.6 D</td>
<td>3.66 D</td>
<td></td>
</tr>
<tr>
<td>3-4 yrs</td>
<td>2.68 D</td>
<td>2.03 D</td>
<td></td>
</tr>
<tr>
<td>6-7 yrs</td>
<td>1.25 D</td>
<td></td>
<td>1.88 D</td>
</tr>
<tr>
<td>7-8 yrs</td>
<td></td>
<td></td>
<td>0.61 D</td>
</tr>
<tr>
<td>9-10 yrs</td>
<td></td>
<td></td>
<td>0.97 D</td>
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<tr>
<td>11-14 yrs</td>
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<td></td>
<td>0.38 D</td>
</tr>
<tr>
<td>15-18 yrs</td>
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</tbody>
</table>

**Residual refractive error**

It is very difficult to decide about what residual refractive error to be left after surgery in infants and children. Literature search also remains ambiguous in this question. Some surgeons are recently targeting emmetropia after surgery at all ages beyond infancy to counteract amblyopia, however most aim for hypermetropia up to 5 years of age when the consensus opinion is towards emmetropia.

Some surgeons have been known to choose adult IOL power in children younger than 2 years. This action is on the premise that with expected growth and the myopic shift, the child will have emmetropia and good vision in adulthood. However this strategy results in significant hypermetropia in the later years, a condition that need to be corrected. Near vision is very severely affected because the pseudophakic eye does not accommodate, and hence even mild hypermetropia may cause severe amblyopia in case of anisometropia.

Few authors recommend emmetropia postoperatively after IOL implantation in children < 2yrs of age especially in unilateral cases. This helps in easier amblyopia management in early postoperative period especially in patients with poor compliance and follow up. With later ocular growth, the resulting refractive shift towards myopia will require the use of a contact lens or a refractive surgery to correct the residual refractive error and minimize the resultant aniseikonia in such cases.

Some recommendations are therefore children between 2 and 4 years to have IOL implanted in a way to obtain a refraction equal to that of the fellow eye and then do a reduction in the IOL power by 2D to allow for myopic refractive shift. It is also suggested that children elder than 4 years of age be implanted IOLs with powers to match the spherical equivalent of the fellow eye. For older children, it is recommended to aim for emmetropia, and then adjusted according to the other eye to avoid anisometropia greater than 3D.
Initial residual hypermetropia has the advantage that with the axial growth of the eye, the hypermetropia will reduce and the adult refraction will be closer to emmetropia. However, this advantage must be balanced with the fact that the uncorrected hypermetropia in children may cause exacerbation of amblyopia. To avoid this problem, some surgeons prefer to aim for emmetropia in the immediate post operative period. It helps in the battle for preventing late myopia will be more and more apparent as the child’s eyes continue to grow. Thus, a better solution may be to find a compromise between these two extremes.

Enyedi et al recommended a postoperative refractive goal of +6 for a 1-year-old, +5 for a 2-year-old, +4 for a 3-year-old, +3 for a 4-year-old, +2 for a 5-year-old, +1 for a 6-year-old, plano for a 7-year-old and -1 to -2 for an 8-year-old and older.

In Wilson’s survey of ASCRS and JAAPOS members in 2001, there was wide variation in the aimed postoperative refraction for infants at 6 months of age, ranging from emmetropia to high hypermetropia (approx 7D), with most aiming for moderate hypermetropia (>3D to <7D). For infants at 12 months of age, most surgeons aimed for moderate or mild >0D to <3D) hypermetropia. At 2 years of age there was a consensus to aim for mild hyperopia or emmetropia. This is consistent with the findings of Plager et al who postulated that a shift toward decreasing hyperopia i.e myopic shift will occur at a decreasing rate throughout childhood and, hence, gives children a hypermetropic refractive error. The magnitude of the planned hyperopia increases with decreasing age and is modified by the AL and refractive error of the fellow eye.

In the Infant Aphakia Treatment Study, the target refractive error after IOL implantation is 8D for infants 4-6 weeks of age and 6D for infants 6 weeks to 6 months of age. There is no study that demonstrates a visual advantage of one approach over the other.

Biometry in children

In addition to problems already enumerated, the measurements of AL and keratometry in children are difficult to measure and less reproducible, accurate and predictable than for adults. Measurements of AL and keratometry in OPDs and office are very difficult and practically impossible in most young children and infants. Biometry is usually done under anesthesia in a small child who is unable to cooperate with precise fixation and centration (Figure 1a,b).

A-scan ultrasound biometry is the conventional method for measurement of AL in all age groups. It can be performed using either traditional applanation or immersion techniques. There may be measurement error with applanation technique in recorded AL. It is important to make sure that the tip does not indent the cornea in applanation technique. It has been seen that the AL measurements made with this technique were, on the average, 0.28 mm less than measurements made using an immersion technique.
With the immersion technique, the probe does not come into direct contact with the cornea, a coupling fluid between the cornea and probe prevents inadvertent corneal indentation. When the probe is properly aligned with the optical axis of the eye the sound beam is perpendicular to the retina, the retinal spike is displayed as a straight, well defined steeply rising spike. When the probe is not properly aligned, the ultrasound beam is not perpendicular to the retinal surface and the retinal spike is displayed as poorly defined slow-rising spike.

We preferentially use the immersion technique in paediatric patients. Repeated measurements are taken until three equal measurements are obtained with sharp well defined retinal spikes. In addition to the problems enumerated above, in pediatric patients, AL measurement is frequently done in the operating room under anesthesia where a trained person may not be available.

The most appropriate ultrasound velocity for AL measurement is different at different ALs. Most machines employ a single average ultrasound velocity. For example, in a patient with axial myopia of 28.00 mm, AL is best measured at an average velocity of 1,550 m/sec, while in a patient with axial hypermetropia of 19.00 mm, AL is best measured at an average velocity of 1,560 m/sec. The human eye primarily comprises of aqueous and vitreous, of which both have an ultrasound velocity of 1,532 m/sec. Cornea and the lens have different ultrasound velocities. If the AL is measured at an average ultrasound velocity of 1,532 m/sec, a corrected axial length factor (CALF) of 0.32 mm is added to the measured AL to obtain the exact AL. This method is more accurate than using an average ultrasound velocity. In aphakia, an ultrasound velocity of 1532 m/sec is recommended.

Error in axial length (AL) measurement causes the most optically significant refractive errors in IOL power calculation and is appx 2.5 D per mm of error, which is very significant. This error increases to 3.5 D/mm in very short eyes (appx 20 mm). Thus, it is crucial that we take every possible step to minimize error in AL measurement.

Mittelviefhaus et al in their study concluded that due to lack of fixation in children who have keratometry under general anesthesia, inaccurate keratometry readings may be measured. For keratometry measurement, we avoid using a speculum and measure with a hand held Nidek AutoKeratometer. Measurements should be taken as soon as possible after induction of anesthesia to avoid the problems associated with corneal dryness. Balanced salt solution should be instilled on to the cornea to maintain a smooth corneal surface for accurate readings. We need only refractive power measurement with an auto keratometer, hence the problem of inaccurate axis measurement has got no bearing in these cases.

Partial coherence interferometry (PCI) has been recently used extensively in cooperative children. This technique relies on using a laser to measure the echo delay and intensity of infrared light reflected back from tissue interfaces. Advantages of PCI over conventional ultrasound techniques include high reproducibility, contact-free measurement, and observer independence of the measurements. Now a days ray tracing in a I-Trace is also being used for IOL power calculation in cooperative children.

**Intraocular Lens Power Calculation**

Once the plan has been made to do a cataract surgery and implant an IOL in the child. The desired postoperative refractive goal is determined according to the factors elaborated above. Next issue is to decide which power calculation formula should be used to reach that refractive goal. A number of formulas can be used to predict the IOL power needed to achieve the desired refractive goal. Primarily the formulas used in children for IOL lens power calculation have been largely derived from studies in adults. These intraocular lens power calculation formulas fall into two major categories; empirically determined regression formulas and theoretical formulas.

The regression formulas, such as the Sanders-Retzlaff-Kraff (SRK) formula, are based on analysis of a large samples of postoperative results in adults. The formula does not work well for unusually long (>25 mm) or short (<22.5 mm) eyes. The formula generally undercorrects short eyes and overcorrects eyes with long ALs, because it attempts a linear fit to a hyperbolic relationship. Hence these are notoriously very unreliable for small paediatric eyes.

The first-generation theoretical formulas assume that the IOL will be at a constant position or postoperative anterior chamber depth (ACD) will be similar in all eyes, regardless of their AL. Since the measured postoperative ACD was found in various studies to be directly proportional to the AL of the eye (longer eyes had larger ACDs), these formulas were found to be less accurate for long or short eyes. Several second-generation theoretical formulas have emerged, such as the Hoffer Q formula, that have replaced the constant ACD with one that included a correction for AL of the specific eye.

In adults, the Holladay formula is considered to be most accurate for eyes with an axial length between 22 and 26 mm. The Hoffer Q formula is considered to be most accurate for short eyes (<22mm) and the SRK/T formula is considered optimal for long eyes (>26mm).

In recent work by Eibschitz et al, an analytical comparison of predicted implant power using keratometry values up to 55D and axial length values as short as 16 mm was performed for two different refractive goals using the SRK II, SRK/T, Holladay I, Hoffer Q, and Haigis equations. Significant differences in intraocular lens power prediction were found among the Hoffer Q, Holladay-I, and SRK formulas.
II formulas in the pediatric range of axial length and keratometry values. The Holladay-I and Haigis formulas were found to be similar in their IOL prediction. The SRK/T was comparable to the Holladay I and Haigis formulas but still differed in the high keratometry values.19

When determining individual ACD constants in the Hoffer Q formula for short, medium, and long eyes, the results in the short eye (<22.0 mm) series are less accurate using the personalized pACD derived from the 36 short eyes examined than when using the pACD derived from the entire 450 eye series. The same is true for the long eye (>24.5 mm) series. This illustrates that developing a personalized ACD for AL subgroups at the extremes is of no value for the Hoffer Q formula and actually makes the results clinically less accurate in short eyes. A similar analysis performed for the Holladay and SRK/T formulas in short eyes showed no statistically significant benefit to a sub group of shorter long ALs using personalized SF or A-constant compared with using the overall 450 eye personalized pSF or A constant.

Although no formula has been proven to have an advantage, it is preferable to use the theoretical formulas (e.g., SRK-T, Holladay I and Holladay II, Hoffer I and II, Hoffer Q and Haigis) because they are generally more accurate for small eyes, and in the pediatric studies they appear to be slightly more accurate overall.20

**Author’s recommendations**

A one stop solution cannot be found for a complex problem of IOL power selection for paediatric patients. All of us have to formulate our own guidelines based on above mentioned facts and studies. Following is the protocol we follow at our centre which is working well for us. We take the final decision about the IOL based on following factors-

- **Whether to implant an IOL or not** - We donot routinely implant IOLs below 1yr of age in bilateral disease. In infants with unilateral cataract we aim for IOL implantation in all cases. However in some cases where AL<19mm, we may have to implant an IOL in the sulcus and in extreme cases <17mm AL, sometimes we have to leave the child aphakic also.

- **Age at the time of cataract surgery** - When an IOL is implanted in infancy, marked axial growth must be expected over the first 1 to 2 years after surgery. Therefore, IOLs implanted in infancy are usually selected to produce a 20% or more undercorrection. The closer to birth, the more marked this undercorrection will need to be. In children between 1-2 yrs we undercorrect by 10%. Beyond 2 yrs we leave the child emmetropic.

- **Status of the fellow eye** - More hypermetropia can be left when the surgery will be done bilaterally since non-compliance with glasses is less amblyogenic in these children. In an eye with monocular cataract, if the fellow eye is pseudophakic – it is important to look for refractive status in the fellow eye. Attempts should be made to minimize the anisokonia in the eyes with unilateral surgery.

- **Visual acuity** - Presence of dense amblyopia may influence towards a decision to have less hypermetropia (or even emmetropia) in an effort to help recovery vision by using the occlusion therapy and minimizing the need for glasses. In this instance, late myopia is acceptable. Most of the studies show that it will be difficult to treat dense amblyopia. Myopia can probably be more easily handled with contact lenses or refractive surgery later in life.

- **Expected compliance of child/family to glasses/contact lens/occlusion therapy** - If poor compliance is expected – it is better to leave the least possible refractive error, otherwise dense amblyopia may result.

- **IOL power** - In general, the smaller is the AL, higher is the IOL power and more is the undercorrection needed. For example, at age 1 month, if one child has an emmetropic power of 50 D and another child at same age has an emmetropic power of 40 D, the first child will necessitate a higher residual refraction. In other words, we may use approximate expected refraction in the first child as +10 D, while in second child we would use +8 D. On an average following is the undercorrection applied age wise:

  - 0-6 Months +7.5
  - 6 Mon-1 yr +5
  - 1-2 years +2.5
  - >2 years emmetropia

- **Implantation in-the-bag/ sulcus** - If a decision regarding the site of fixation needs to be changed after entering an eye and before IOL implantation – an appropriate adjustment is needed to be made. A plus-power IOL that is more anterior in the eye will have a greater refractive effect than if it were relatively posterior. Sulcus fixation of IOL produces a relative myopic shift from the estimated refraction. The IOL intended for capsular bag placement should be decreased by 0.75 D to 1.00 D (depending on the IOL power) when planned to be placed in the ciliary sulcus.

- **Secondary IOL Implantation** - keratometry reading errors have been known to occur after wearing RGP contact lenses which can persist up to 4 wks. Since the effects of RGP contact lens wear on corneal curvature and resultant IOL calculations is variable and unpredictable, it is important that IOL calculations be made at least 4 weeks after discontinuation of contact lens wear.
Table 2: The mean predicted refraction, observed refraction and prediction error between SRK II and Pediatric IOL Calculator

<table>
<thead>
<tr>
<th>Observed refraction (Spherical Equivalent)</th>
<th>SRK II (n = 16)</th>
<th>Pediatric IOL Calculator (n = 15)</th>
<th>* p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Predicted Refraction (Diopter, SD)</td>
<td>-0.06 (1.17)</td>
<td>1.19 (2.35)</td>
<td></td>
</tr>
<tr>
<td>Mean Observed Refraction (Diopter, SD)</td>
<td>-0.84 (1.31)</td>
<td>0.10 (1.74)</td>
<td></td>
</tr>
<tr>
<td>Mean Prediction Error (Diopter, SD)</td>
<td>1.03 (0.69)</td>
<td>1.14 (1.19)</td>
<td>0.74</td>
</tr>
</tbody>
</table>

* Independent-Samples T Test
p value < 0.05 (significant)

Table 3: Accuracy of predictability between SRK II and Pediatric IOL Calculator

<table>
<thead>
<tr>
<th>Observed refraction</th>
<th>SRK II (n = 16)</th>
<th>Pediatric IOL Calculator (n = 15)</th>
<th>* p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ ± 2.0 Diopter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accurate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0 D to ± 0.5 D</td>
<td>3 (18.75%)</td>
<td>7 (46.67%)</td>
<td>0.097</td>
</tr>
<tr>
<td>Inaccurate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; ± 0.5 D to ± 1.0 D</td>
<td>7 (43.75%)</td>
<td>0 (0.00%)</td>
<td>7 (22.58%)</td>
</tr>
<tr>
<td>&gt; ± 1.0 D to ± 2.0 D</td>
<td>4 (25.00%)</td>
<td>5 (33.33%)</td>
<td>9 (29.03%)</td>
</tr>
<tr>
<td>&gt; ± 2.0 Diopter</td>
<td>2 (12.50%)</td>
<td>3 (20.00%)</td>
<td>5 (16.13%)</td>
</tr>
</tbody>
</table>

* Pearson chi-square test
p < 0.05 (significant)

Parent’s refractive error - it is also important to ask about high refractive error in parents. It has been noted that if both parents are myopic, 30% to 40% of their children become myopic, whereas if only one of the parents is myopic, 20% to 25% of their offspring will become myopic. If neither of the parents is myopic, fewer than 10% of their children will become myopic. Keeping these genetic factors in mind and anticipating more eye growth in these cases, these children may be left with more hypermetropia than stated earlier.

The Pediatric IOL Calculator - It can be used for IOL power calculation in both primary and secondary IOL implantation (Figure 2). It needs the patients age, A constant of the intended IOL to be implanted, AL and K values. Desired post operative refraction can also be entered to get the optimum IOL power value (Table 2&3). The pediatric IOL calculator can be downloaded from the AAPOS website: http://www.aapos.org/proinfo/downloads.html.

Conclusion

Despite all our efforts and safeguards in IOL selection, it is not uncommon to see refractive surprises in children undergoing cataract surgery and IOL implantation. Besides these, several other factors (e.g., gender, race, etc.) have been reported to affect growth of the normal eye, and may also influence eye growth after cataract surgery.

Refractive growth and shifts after IOL implantation in infants and children cannot be predicted accurately due to large standard deviation and current IOL formulas vary in their predictive outcomes. If the target refraction goal is emmetropia, ambylopia treatment will be easier but may result in myopia later in life. If the target refraction goal is hypermetropia, ambylopia treatment may be more difficult but emmetropia later in life is more likely. Although placement of an IOL in children has gained universal acceptance and placement of an IOL in infants is gaining favor among many ophthalmologists, there remains no IOL power calculation formula derived primarily on the basis of specific peculiarities of the child’s eye or the studies comparing outcomes from IOL implantation in children. With the trend leaning towards implanting IOLs in infants with shorter ALs, there certainly will be a greater need to understand the applicability and differences between the
various formulas at the lower ends of AL and keratometry values.

Using currently available formulas and fine tuning the A-constant and surgeon factor may reduce postoperative refractive surprises, but unlike adults, volumes of surgeries are not there with most Ophthalmologists and with a wide range of AL and K values rendering adjustment of A-constants and surgeon factors very difficult, the one stop solution is unlikely in near future. Any modern IOL formula can be used on children but more error should be expected. Using immersion A-scan instead of contact and repeating K-readings to make sure they are reproducible may be a way to reduce errors. In children, given the need for highly accurate biometry, astigmatism control, and no refractive growth, caution should be used in considering the use of multifocal IOLs in infants and children.

Surgeons, especially who implant IOLs in infants and young children must be prepared for a wide fluctuation in the long-term myopic shift. Both the amount of the myopic shift and the variance in this shift are likely to be greatest in children having surgery in the first few years of life. Anticipation of this refractive phenomenon and appropriate correction or compensation will help achieve better functional outcomes of these young eyes undergoing cataract surgery. We must also remember that an IOL implanted in a child’s eye must stay there for many years, ie his whole life time. Long-term outcomes will certainly remain unsure for years to come till a less ambiguous solution is found. Long-term follow up and evaluation of outcomes of refractive error in these eyes will help us to develop formulas specially-suited for IOL power calculation for childhood cataract.

References