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Update on pediatric cataract surgery

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ABSTRACT

Cataracts in infants and children are comparatively rare, but they remain an important cause of potentially lifelong visual impairment, largely because of associated deprivation amblyopia. This is particularly seen in children missed by screening programs and thus presenting late for treatment. However, advances in diagnosis, surgical techniques and amblyopia management have improved the prognosis for most children seen with this condition. This comprehensive review focuses on all aspects of the care required to optimize outcomes. It covers modern genetic investigations, performed to precisely determine underlying cataract etiology, and discusses the use of outcome-based evidence to guide the timing of surgical intervention. The paper also outlines the options available to clinicians for post-operative refractive error correction and compares indications, risks and benefits for the use of contact lenses, spectacles and intraocular lenses (IOL). The challenge of choosing the most appropriate dioptric power of IOL to implant into a growing eye is discussed, as is consideration of types of IOLs that can be considered and the surgical techniques needed. Evidence-based approaches to the clinical management of amblyopia, glaucoma and visual axis opacification, the three most common complications seen following pediatric cataract surgery, are reviewed. Two specific conditions associated with pediatric cataract are discussed in detail–persistent fetal vasculature and ocular trauma. Strategies for assessment, management and surgical treatment of these conditions are reviewed.

Introduction

Cataract surgery in children differs from adult cataract surgery as it is being performed during a period of ocular and visual development. There are unique problems associated with pediatric cataract surgery such as: amblyopia, glaucoma and ongoing ocular growth. After infancy, most pediatric cataract surgeries include primary intraocular lens implantation, but an expected myopic shift over time needs to be a part of the long-term planning. Bilateral pediatric cataracts are often associated with systemic disorders, and many have an underlying genetic etiology.

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Diagnostic and genomic investigations are thus required to determine the specific cause and enable medical interventions/treatments where appropriate. For some metabolic and multi-system disorders these treatments may be life- changing.

Pediatric cataract surgery differs technically from adult cataract surgery utilizing specialized surgical skills and instruments. For example, the greater elasticity of ocular tissues in infants requires modifications of techniques. Finally, contact lenses are important in the visual rehabilitation of aphakic infants, whereas aphakic contact lenses are rarely used in adults. Ophthalmologists need to maintain the specific surgical skills required, despite the low incidence of pediatric cataracts, and long-term follow up is needed by a clinical team able to accurately update optical correction and manage amblyopia and glaucoma. In this review an international panel of experts discuss current approaches to the diagnosis and management of pediatric cataracts.

Diagnosis and investigations

The prevalence of congenital and pediatric cataract varies between countries. It is estimated to be between 2.2 and 13.6 per 10,000 live births but is influenced by the efficacy of national screening programs, immunization policies, and population genetics.[1] Early diagnosis, and surgery underpin good visual outcomes.[2,3] However, not all affected children need surgical intervention. Dense infantile cataracts require urgent surgery. However, partial, lamellar or developmental cataracts can often be managed conservatively.[4] If left untreated a dense nuclear cataract can cause irreversible deprivation amblyopia, accompanied by the other features of sensory deprivation such as nystagmus and strabismus.[5] Prompt referral of affected infants is thus paramount.

Screening

In most developed countries neonates are offered newborn and infant screening examinations.[3,4] The aim is to detect pupillary red reflex abnormalities and thus identify infants with cataracts. Risk factors for cataracts should be noted, including family history of childhood cataracts, a history of prematurity or maternal infections, particularly rubella or cytomegalovirus. This is especially important in communities with low immunization uptake. A British study found that less than 50 % of children under age 3 years, requiring cataract surgery, were referred before 9 weeks of age.[6] The authors concluded that the newborn eye examination has poor sensitivity when performed by a non-ophthalmologist using an ophthalmoscope. The same group is validating screening using a digital camera with an infrared light.[6]

Genetic testing

Congenital cataract is a clinical sign and not a precise diagnosis. It can be linked to many systemic, chromosomal and genetic disorders. Determining the underlying etiology is often challenging. Traditional investigative pathways have poor diagnostic yeild.[7] However, a careful history, in combination with a thorough examination of the child and family remains essential, looking for both ocular and systemic features. Determination of the onset of cataract formation (and/or any other ocular symptoms) can provide important clues about etiology. Later onset cataracts may have a metabolic cause or be associated with lens structural defects such as posterior lenticonus. Non-ocular abnormalities should prompt pediatric referral for medical investigations alongside appropriate genetic testing.[3,4]

Unilateral congenital cataracts are usually sporadic and often associated with persistent hyperplastic vasculature (PFV) abnormalities. However, most bilateral pediatric cataracts in the developed world have a genetic etiology and over 100 genes have been found to be associated with cataract formation.[8] The largest subgroup is non-syndromic and linked to mutations in genes coding for major lens structural proteins such as the crystallin, connexin and intermediate filament proteins. They are mostly autosomal dominant in inheritance although congenital cataracts with recessive and X-linked inheritance patterns occur.[8] Examinations of parents, siblings and other relatives can thus be informative and provide useful phenotypic information.

A smaller but significant proportion of children with bilateral cataracts have an underlying systemic or metabolic disorder (Fig. 1).[9] In these children biochemical, microbiological and immunological investigations remain important. However, the clinical utility of these tests, when used indiscriminately, is poor.[7] Their use should be guided by clinical findings, both ocular and systemic, and ordered in combination with genetic testing. The introduction and validation of high throughput next generation DNA sequencing (NGS) has shown that genomic investigation can efficiently identify a small but significant group of children with cataract and associated metabolic and systemic disorders. Previously these children would have been diagnosed when older.[7,8] Trio (both parents and affected individual) whole genome sequencing (WGS) has been shown to better identify pathogenic de novo genetic mutations, enabling more accurate counselling, and in turn assist targeted screening of siblings and family members.[10] Genetic investigation, used with clinical phenotyping, and a multidisciplinary team approach to variant interpretation, has also improved diagnosis in children with bilateral cataract.[7–9,11,12] It has increased identification of systemic associations, and led to the identification of novel pathogenic genes, enabling establishment of important genotype–phenotype correlations. This diagnostic pipeline is now routine practice in many clinics (Fig. 2).

Timing of pediatric cataract surgery

Determining the optimum time for surgery can be a significant challenge in pediatric cataract management. Factors which need to be taken into consideration when considering timing of pediatric cataract surgery include:

- Patient age. Dense cataracts present throughout the critical period of visual development and can cause profound deprivation amblyopia.[13] Early removal ameliorates this disruption to visual development.
- Cataract density and morphology. Dense infantile cataracts usually need early surgery. Mild or partial cataracts may be treated conservatively with regular follow-up to monitor progression. The goal with partial cataracts is to maintain youth lens accommodation unless the cataract is visually significant enough to justify the presbyopia that follows cataract removal.
- Patient factors. A systemic disorder, associated or co-existent with the cataracts, may require stabilization before administration of anesthesia. Other specific factors such as adherence to amblyopia management, school exams and other life events may influence the timing of surgery.

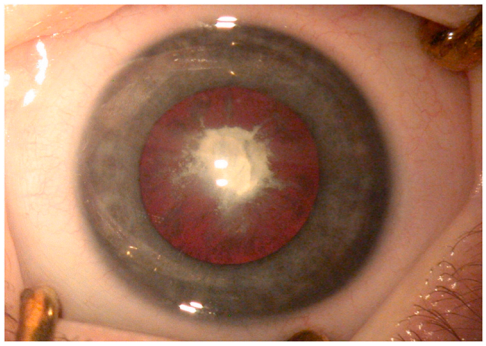

Fig. 1. A dense irregular cataract in a child with Lowe syndrome.

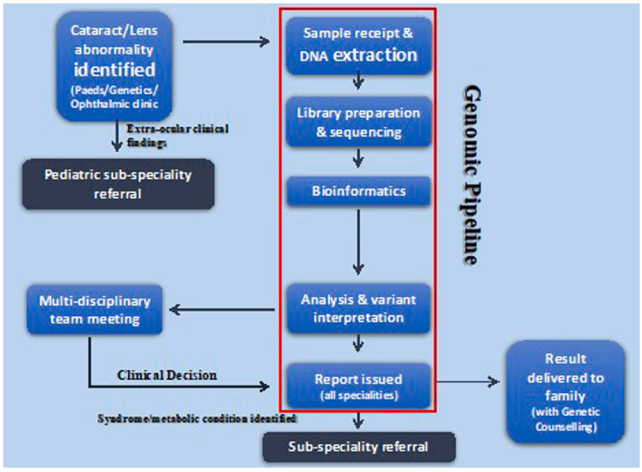

Fig. 2. Flow diagram for the genetic investigative pathway for a child with bilateral congenital cataracts.

- Ocular factors. Patients with co-existent glaucoma and cataract, for example in aniridia or Lowe syndrome, may need glaucoma surgery first. Patients at high risk of retinal detachment, for instance Stickler syndrome, may require prior or simultaneous prophylactic retinal cryotherapy or laser.

Age at surgery is the most important factor affecting visual outcome in dense congenital cataracts. Optimal outcomes require early diagnosis and referral, so that timely management can be undertaken. When congenital cataract is identified shortly after birth, the timing of surgery requires balancing the risk of stimulus deprivation amblyopia and sensory nystagmus, with the risks of secondary glaucoma and general anesthesia.[13] Better visual outcomes are achieved with surgery within the first 3 months of life.[14–16] Early surgery lowers strabismus rates and nystagmus.[5,17] The IoLunder2 study found that each additional month of age at cataract surgery within the first three months of life was associated with a progressively worse visual outcome.[14] However, early surgery must be balanced against the risk of secondary glaucoma. The risk of this common and serious complication increases with lower age at time of surgery.[18–22] The Infant Aphakia Treatment Study (IATS) and Toddler Aphakia and Pseudophakia Treatment Study demonstrated that every increased month of age at the time of surgery reduced this risk.[23,24]

The optimum timing for surgery for an infant with dense bilateral congenital cataracts, balancing glaucoma risk with visual outcome, appears to be between 6 and 10 weeks of age.[4] If an infant with dense cataracts presents late, surgery should still be performed promptly, with the family advised of the more guarded visual prognosis.

Timing of cataract surgery in premature neonates is less clear. These children begin their visual development earlier but have an anatomically immature eye. Many surgeons currently use corrected gestational age (weeks from term) to determine timing for cataract surgery in premature infants.[25] Detection of congenital cataracts in preterm infants may be delayed which may affect surgical timing.[26]

Unilateral congenital cataract

Children with unilateral dense congenital cataract typically exhibit worse outcomes in the affected eye due to deprivation amblyopia. Visual outcomes are dependent both on early surgery and compliance with occlusion therapy.[13,14,27,28] Birch and Stager reported a marked decline in acuity outcomes in those unilateral cases undergoing surgery after approximately 6 weeks.[29] A Swedish study of 54 children with unilateral congenital cataract, 65 % of whom had surgery before 6 weeks corrected age, found that more children with surgery before 6 weeks achieved VA of 1.0 LogMAR or better, than those operated later.[16] Optimum timing for dense unilateral cataract surgery thus appears to be between 6 and 8 weeks of age.[4,15]

Timing of surgery in older children

Clinical judgement is required to determine the best time for intervention in children with less severe cataracts. A need for surgery may be suggested by changes in visual behavior, deterioration in VA, or onset of sensory strabismus or nystagmus. Examination may reveal cataract progression, and, or deterioration of the view to the retina. Reduction in contrast sensitivity or symptoms of glare may also prompt intervention.[30] In some situations, it may be unclear if a decline in vision is due to amblyopia or the cataract and in such cases a trial of occlusion therapy of the sound eye may help confirm the underlying cause of reduced vision in the eye with a cataract.

Immediate vs delayed sequential bilateral cataract surgery in children

Immediate sequential bilateral cataract surgery (ISBCS) is increasingly popular amongst adult cataract surgeons as it offers quicker visual rehabilitation[31] without evidence of increased risk of intra- and post-operative complications when compared to delayed sequential bilateral cataract surgery (DSBCS).[32,33] In children where the cohort of patients is far smaller, analysis of outcomes is more challenging, and confounded by variables such as whether a child is left aphakic or pseudophakic, age, amblyopia management and compliance.

Concerns remain about the potential for bilateral sight-threatening complications following ISBCS, such as endophthalmitis or toxic anterior segment syndrome (TASS). To date, there are no reported cases of bilateral endophthalmitis in children after cataract surgery. Common practices to minimize this risk is to treat each eye as a separate procedure, re-scrubbing and re-gowning, use of separate sterile drapes, separate sets of sterile instruments, and separate batches/lots of disposable products. However, there are four reported cases of bilateral endophthalmitis following ISBCS in adults,[34–37] There is consensus that more rigorous procedures to avoid cross-contamination could have prevented these cases.[38] There is one reported case of TASS following unilateral pediatric cataract,[39] attributed to inadequate rinsing of surgical equipment and contamination with glutaraldehyde, but to the authors' knowledge no cases of bilateral TASS following pediatric cataract surgery have been reported. Most surgeons leave infants aphakic following cataract surgery due to increased rates of further surgical intervention required following IOL implantation.[40] In this group, ISBCS is commonly performed but DSBCS remains standard practice for those having an IOL implanted, due to concerns about post-operative (including refractive) complications.

General anesthetic risk is a particular concern in infants, as younger age is associated with increased risk of anesthetic complications[41,42] but timely surgery is critical to minimize amblyopia. Children undergoing ISBCS have significantly reduced total anesthesia time compared to DSBCS despite comparable total procedure times between the two groups.[43] Others have found no significant difference in total procedure times between ISBCS and DSBCS groups, although total time in the operating room was reduced in ISBCS patients.[44] Alongside a reduction in total time of anesthesia, ISBCS requires only one general anesthetic, minimizing the risk of anesthesia-related complications.[41].

ISBCS has been shown to be significantly more cost-effective than DSBCS in Canada[45] and the USA,[46] with savings more than $2300 USD per patient with the largest share of savings coming from the hospital portion of the patients' fees ($1855 vs $303 from the physician portion),[46] Additional cost savings occur from a societal ($3776 CAD) and a health system ($2200 CAD) perspective.[44]

We believe there now exists sufficient evidence to support ISBCS in selected pediatric cases, if stringent risk management procedures are

followed.

Optical correction

Aphakic contact lens management

Contact lenses are an excellent option for refractive correction of aphakia following pediatric cataract surgery, particularly in infants. They offer the benefits of improving visual outcomes, treatment compliance in the setting of high refractive error, and overall quality of life in children.[40,47,48] They correct anisometropia, prevent aniseikonia, and may be a convenient therapeutic option for amblyopia co-management amongst eye care practitioners (ECPs).[49]

IATS randomized 114 infants with unilateral congenital cataract, to either IOL or contact lens correction of aphakia. Children who wore contact lenses for a greater proportion of waking hours during the entire study period tended to have better VA at age 4.5 years, even after accounting for adherence to patching therapy.[50] It has been suggested that contact lenses offer a better overall quality of life for children than spectacles.[51]

Wear and replacement schedules vary depending on the contact lens design and material. Many soft and rigid gas-permeable (RGP) lenses are daily wear; worn during the daytime and disinfected overnight in a multipurpose disinfection solution. Contact lenses may be daily disposable (considered a single-use device), or replaced biweekly, monthly, quarterly or annually. Contact lenses may also be approved for extended wear, defined as available for overnight or continuous wear ranging from one to six nights or up to 30 days.

Microbial keratitis

Like all therapeutic options, contact lens wear has risks, especially if there is misuse. This can include lack of proper disinfection, poor handling and care of the contact lenses or their solutions and/or accessories, such as contact lens cases. Microbial keratitis (MK) is the most serious potential adverse event related to contact lens wear and can cause permanent vision impairment.[52] Fortunately this is rare amongst children [53]

Contact lens management involves an initial evaluation of visual needs, refractive error, anterior segment features, typically using refraction, topography and/or keratometry, and biomicroscopy. Once a lens is designed, refractive error can again be assessed with the potential of implementing near vision correction, especially in infants. Insertion and removal training, and lens disinfection is imperative, as well as instruction on maintenance of good ocular hygiene and long-term health. Once a contact lens prescription is finalized, the appropriate follow-up schedule will depend on patient age and the expected rate of growth and corneal flattening. Infants are typically evaluated every three months, as they typically undergo rapid refractive and corneal flattening in the first year of life. Average corneal curvature flattens from approximately 48D at full term birth, to 44D at the age of 18 months.[54] This stabilization in both corneal curvature and refractive error results in the need for less contact lens parameter and prescription changes. Thus those 18 months of age and older may be seen every 4–6 months for contact lens assessment. By two to three years of age, corneal diameter size reaches average adult size of approximately 11.7 mm.[55] At this time, more contact lens types based on lens diameter become available for use that are appropriate for the treatment of children and aphakia (Table 1). Ultimately, selection of the contact lens type best suiting co-management goals and ocular anatomy, while considering patient and family needs, results in the best success rate for both visual effectiveness and safety outcomes.

In summary contact lenses are an excellent option for correction of both unilateral and bilateral aphakia following pediatric cataract surgery.[56] Good compliance with follow up is important and enables optimization of contact lens performance, and provision of alterations in contact lens modality, design, and power as necessary.

Table 1
Contact lens types available for aphakia treatment.

Contact Lens Type	Pros	Cons
Soft	• Available in daily disposable modality • Daily or extended wear • Available in higher oxygen permeable materials • Ease of patient access, commercially available with prescription	• Limited to + /−20D spherical correction • Larger lens diameter may not allow for insertion for infants and those small apertures
Custom Soft	• Daily or extended wear • Available in powers up to + /−35D • Customizable diameter, easier to apply and remove for smaller apertures	• Available in lower oxygen permeable materials • Require ECP custom ordering through manufacturer
Corneal RGPs	• Daily or extended wear • Available in powers up to + /−30D • Customizable diameter, easier to apply and remove for smaller apertures • Available in higher oxygen permeable materials • Indicated for irregular corneal conditions	• Increased lens awareness, especially for unilateral wearers • More frequent contact lens parameter changes required for infants as cornea flattens • Require ECP custom ordering through manufacturer
Hybrid	• Available in higher oxygen permeable materials • Combine RGP optics with the comfort of a soft contact lens • Indicated for irregular corneal conditions	• Available in daily wear only • Limited to + /−20D spherical correction • Larger lens diameter and need to be filled with non-preserved saline solution creates leads to more challenging lens handling, recommended for older children and those with caretaker assistance for lens handling • Require ECP custom ordering through manufacturer
Scleral	• Available in powers up to + /−30D • Available in higher oxygen permeable materials • Design vaults over cornea, limiting corneal-lens interaction • Indicated for irregular corneal conditions	• Larger lens diameter and need to be filled with non-preserved saline solution creates, more challenging lens handling, recommended for older children and those with caretaker assistance for lens handling • Require ECP custom ordering through manufacturer

Spectacle correction

Aphakic refractive error needs to be corrected as soon as possible to facilitate visual rehabilitation. This can be achieved with either aphakic glasses or contact lenses.[55,57,58] Contact lenses are the most widely accepted means of optical correction of aphakia during infancy.[59] However, there can be difficulties associated with their use. It is therefore important to also consider glasses as a means of optical correction even if a child successfully wears contact lenses, as having a backup pair of glasses is imperative. These can be worn when contact lens wear may not be possible. Thus, if glasses are prescribed concurrently, there will be no disruption to optical correction. This is particularly important during amblyopia treatment.

Glasses should be prescribed as soon as possible after cataract surgery. Temporary + 20D glasses can be issued safely on the day of surgery. The prescription can then be refined after an accurate refraction. This may be once sutures have dissolved (or been removed) and the eye has settled down fully from the surgery. Glasses can also be used whilst waiting for a contact lens fitting. In infants with aphakia, glasses are prescribed with a 2.0 D over-correction to provide a near point correction as babies tend to be interested only in their immediate

environment.[60] After the age of two years, bifocal lenses can be prescribed with a distance correction and a near add of + 3D.[61]

Aphakic glasses magnify the perceived image, giving better measured VA than contact lenses. Therefore, children with bilateral aphakia whose best corrected VA is 6/18 (20/60) or worse, often cope better with glasses than with contact lenses in school.[60] However, in children with unilateral aphakia, the high degree of anisometropia causes a large difference in retinal image size between the two eyes (aniseikonia) due to the magnification from the position of the aphakic lens. This poses an additional barrier to binocular vision and further contributes to amblyogenesis.[62]

Accurate assessment of the refractive status is critical for visual rehabilitation. Retinoscopy is considered the gold standard, but automatic refractometry can also be an option. In children with a large angle strabismus, media opacities, irregular corneal surfaces, pupillary abnormalities, albinism and/or nystagmus, retinoscopy becomes more difficult.[63,64] A vergence formula has also therefore been developed which may provide a simple and reliable calculation of the refractive status of aphakic eyes.[65]

$$F_e = \frac{1.336/L\text{-}K}{1 + 0.012(1.336/L\text{-}K)}$$

Fe = estimated refractive value (spherical equivalent value) of aphakic glasses (D, diopters)

L = axial length (m).

K = average keratometry value (D, diopters)

1.336 is the aqueous index of refraction

0.012 is the back vertex distance (m, meters)

In infants and children with pseudophakia, glasses are typically prescribed by the one-month post-operative visit if any of the following conditions exist: > 1D hyperopia, > 3D myopia, or astigmatism of more than 1.5D. At any age, if there is uncorrected astigmatism when wearing contact lens(es), this can be corrected through glasses worn over the contact lens(es). However, some practitioners suggest that astigmatism need not be corrected in infants as it frequently improves or disappears in the first two years.[60]

In children with unilateral aphakia, it is important to remember to also correct any refractive error in their phakic eye. In the IATS study, the phakic eye was corrected with spectacles if any of the following conditions were evident: > 5D hyperopia, > 5D myopia, > 1.5D astigmatism, or accommodative esotropia.[61]

For infants who have been left aphakic following cataract surgery, and when contact lens wear isn't always possible, the provision of accurate, well-fitting spectacles is of the utmost importance for visual and facial development. A poorly fitting pair of glasses for a young infant, whose facial anatomy has soft cartilage, can cause discomfort, permanent visual harm or even disfigurement.

There are numerous challenges when dispensing spectacles to newborns and infants with aphakia: the weight of high plus powered lenses, movement of the glasses in children unable to support their neck, as well as cosmetic and psychological effects. If the glasses are not stable, a small change in the vertex distance, pantoscopic tilt, or alignment of the pupil with the optical center of the lenses can dramatically alter the optical correction. Further, full aperture lenses are unlikely to be available in the high prescriptions required. Instead, lenticular lenses should be dispensed – either single vision or bifocals, depending on the age and ability of the patient. These will help to keep the spectacle weight and lens thickness to a minimum but, may create a ring scotoma, a "jack in the box" effect (when objects suddenly appear in and out of a patient's field of view) and optical aberrations. (Table 2)

High plus lenses cause spectacle magnification and reduce the field of view. In some cases, this can be beneficial with the spectacles acting as a low vision aid, increasing the magnification factor and improving VA. Constant monitoring of the spectacles is required to ensure the best fit, especially for newborns and infants whose head width and head circumference change rapidly. Fig. 3

Intraocular Lenses

The implantation of IOLs in children provides a partial continuous optical correction for aphakia. While the benefits associated with IOL

Fig. 3. Infant with bilateral aphakia wearing a Tomato Baby frame and 1.6 index lenticular lenses from Optimum Coatings.

Table 2
Guidelines for dispensing pediatric aphakic spectacles.

- A frame is dispensed that has dimensions suitable for an infant's unique facial measurements.
- Use a frame with approximately the same depth as the lenticular bowl size.
- Take monocular pupil distance and vertical heights wherever possible.
- The higher the prescription, the smaller the bowl size of the lenticular lens.
- Order surfaced lenses for optimum cosmetic effect.
- Avoid decentering the lenses (match the frame box center distance with patient pupillary distance).
- Pupils should be positioned on or just above the horizontal center line of the frame.
- Plastic frames help to hide and support the lenses.
- Fit the glasses with as small a vertex distance as possible. This will maximize field of view, reduce spectacle magnification and retinal image size, and reduce optical aberrations.
- Always include a UV filter.
- Anti-reflection coatings reduce surface lens reflection and improve light transmission.
- Bifocals should be set much higher for children than for adults to ensure use – ideally at the lower pupil margin. There must be adequate depth in the frame so that there is enough room for the reading area and at least 10 mm of clear-distance vision at the top. Inset and segment drop should be measured as they will likely be smaller than adult measurements.
- Always manage expectations with regard to the thickness of the lenses and the time taken to manufacture the glasses. Expert communication will ensure everything goes as smoothly as possible post-surgery.

implantation, such as a reduced reliance on external optical aids, are evident, the adoption of this procedure in children has progressed at a slower pace compared to the adult population.

Contraindications

During the initial adoption period of IOLs in children, the emphasis was on the establishment of the indications for pediatric IOL implantation. Currently most toddlers and older children undergoing cataract surgery have primary IOL implantation. Consequently, the focus is now on contraindications to primary IOL implantation. Most contraindications should be considered relative: children with severe lens subluxation, uveitis induced by juvenile idiopathic arthritis, aniridia, Peter's anomaly, or other ocular conditions associated with severe comorbidities, particularly those lacking capsular support, represent relative contraindication for IOL implantation. Children with unilateral cataracts are more likely to receive IOL implantation than those with bilateral cataracts. Similarly, children with developmental delay may be more likely to be offered primary IOL implantation because of potential compliance issues with optical correction. The implantation of IOLs is not recommended for children under six months of age if infant appropriate contact lenses are available.[66] Where infant contact lenses are unavailable or impractical, primary IOL implantation may be considered, if feasible, but in conjunction with full informed consent regarding risks and benefit.

Primary posterior capsulotomy

Primary posterior capsulotomy (PPC) is routinely performed during pediatric cataract surgeries to prevent posterior capsule opacification (PCO), which manifests more rapidly and frequently in children than in adults. Visual axis opacification (VAO) occurs much more quickly in young children and is virtually unavoidable if the posterior capsule is preserved. As a general guideline, primary posterior capsulectomy and vitrectomy are standard practices in children under the age of five years. For children aged 5–8 years, posterior capsulotomy may be performed without the need for vitrectomy. Posterior optic capture can be utilized to prevent cellular proliferation from reaching the intact vitreous face. In children older than eight years, it is often acceptable to leave the posterior capsule intact. However, even in children older than 8, posterior capsulectomy and vitrectomy are advisable when there is a dense posterior capsular plaque, a pre-existing posterior capsule defect, or if poor cooperation is expected with an office based YAG laser capsulotomy, unavailability of Nd:YAG under anesthesia or uncertain follow-up.

Type of IOL

The type of IOL chosen for pediatric cataract surgery is critical due to the unique anatomical and physiological characteristics of children's eyes. PCO is one of the most prevalent complications after pediatric cataract surgery, so an IOL that minimizes its incidence is more frequently utilized in children. Single-piece hydrophobic acrylic lenses are commonly used in children. Three-piece acrylic IOLs have a posterior angulation designed to reduce pupillary capture when placed in the ciliary sulcus. These lenses are suitable for either sulcus fixation or in-the-bag positioning. They may inhibit PCO because of this posterior vaulting when placed in the capsular bag. Single-piece hydrophobic acrylic IOLs are not typically placed in the ciliary sulcus because they can cause inflammation, bleeding, iris chafing with pigment dispersion, and increases in intraocular pressure (IOP). However Sharon and colleagues[67] recently reported that single-piece hydrophilic IOLs can be placed in the ciliary sulcus in an adult population and are non-inferior to three-piece hydrophobic IOLs in the ciliary sulcus. A group of cataract surgeons in Europe use a technique known as "bag in the lens" to implant an IOL in matching (5 mm) anterior and posterior capsulorhexes. The IOL has a circumferential groove between two flanges that prevents lens epithelial cell (LEC) migration.[68] This IOL is not widely available.

IOL placement

In-the-bag IOL placement is regarded as the gold standard when anatomically feasible. Ciliary sulcus placement may be used for cases with insufficient capsular support. Indications for ciliary sulcus IOL placement include a ruptured or absent posterior capsule, inadequate capsular support, or the presence of dense posterior capsule plaque requiring large posterior capsulectomy. Optic capture through the anterior and posterior capsulorhexis (bi-capsular capture) can be attempted to achieve improved centration and stability. IOL exchange is much easier with a sulcus IOL than with a bag-fixated IOL.

Secondary IOL implantation

Secondary IOL implantation is generally recommended when traditional spectacle or contact lens correction of aphakia proves ineffective. Additionally, many parents electively opt for secondary IOL implantation for their aphakic children once eye growth begins to slow after the age of four years. The most favorable position for the secondary IOL is within the reopened capsular bag. Nevertheless, if the capsular leaflets are sealed together with no reproliferated cortex, ciliary sulcus fixation is the preferable alternative. In-the-bag fixation is achieved more consistently in eyes that are primarily aphakic from early infancy. These eyes are more likely to develop a dense Soemmerring ring.[69] The Soemmerring ring lens cortex fills the equator of the capsular bag, thereby preventing the anterior and posterior capsule remnants from sealing together and closing the capsular bag remnant. Removing the contents of the Soemmerring ring facilitates more predictable in-the-bag secondary IOL placement.

Toric and multifocal IOLs (Premium IOLs)

Premium IOLs are commonly used in adults after cataract surgery. These IOLs have toric, multifocal, trifocal, or extended depth of focus (EDOF) designs built in. Precision is required when selecting the power of the IOL being implanteed since refractive surprises reduce the effectiveness of these technologies. Toric IOLs may be considered for older children; however, their use is less prevalent than in adults. Children who can cooperate for the necessary detailed preoperative assessment may be considered if their eyes exhibit substantial, regular corneal astigmatism (e.g., $\geq$1.5 diopters). Generally, children under the age of five are not considered. More frequent follow-up appointments are required, particularly during the early postoperative period. Examination after full dilation should be performed to assess IOL position. Rotational stability is important as any rotation exceeding 10° diminishes the efficacy of astigmatic correction. Detecting rotation at an earlier stage and intervening promptly can significantly enhance outcomes. Vasavada and colleagues have reported outcomes of toric IOL implantation in children over five years of age.[69] Multifocal and EDOF IOLs are not often recommended for children.[70] An unstable refraction due to ongoing eye growth makes the optical effect of multifocal optics less effective.[71,72] Multifocal and EDOF IOLs have been used in children, but reports lack long term follow-up. The inevitable myopic shift reduces the effectiveness of these IOLs and creates a situation where multiple images are present yet none of them are on the retina. For this reason, the implantation of multifocal and EDOF IOLs is usually reserved for when eye growth has ended. Eye growth in the second decade of life has been studied and documented to continue through at least age 20 years and is quite variable.

Newer monofocal IOLs that are referred to as "monofocal plus" IOLs have been shown to have improved intermediate vision and a better defocus curve, compared to standard monofocal IOLs. These IOLs do not

cause dysphotopsia and do not become less effective after a myopic shift from eye growth. Since initial hyperopia is often aimed for in children after IOL implantation, the improved defocus curve allows for better VA even when the hyperopic corrected spectacles are not being worn.

Choosing an IOL power

The long-term goals of choosing an IOL power in children undergoing pediatric cataract surgery are good vision and adult emmetropia. We have no data to recommend an optimal IOL power for both vision and refraction at the time of surgery. However, an understanding of the growth of the eye can help guide the surgeon's choice.

Eyes grow throughout childhood in a semi-logarithmic pattern (Fig. 4).[73] The refractive error of an aphakic eye (at the IOL plane) vs. log of adjusted age (age + 0.6 yr) is a straight line. The slope of this line is the "rate of refractive growth" (RRG3) and can be used to predict future refractions.[74]

$$RRG3 = \frac{IOL_2 - IOL_1}{\log(age_2 + 0.6yr) - \log(age_1 + 0.6yr)}$$

where IOL_1 is IOL power for emmetropia at age_1 (the younger age), etc.

IOL formulas' prediction errors are worse in children compared to adults,[75] leading to the oft-stated assertion that an IOL formula is needed that is specifically made for children's eyes. Studies do not consistently show that any modern IOL formula is substantially better than the others (Table 3).

The results of IOL calculation in young children are already close to the theoretic minimum absolute predictive error (unpublished calculations, SKM), indicating that adult-based formulas are satisfactory.[76] Instead, the large prediction errors may be because preoperative biometry and postoperative refractions are less accurate in children. In addition, small measurement errors have a greater effect on the outcome. More importantly, the variance in the growth of the eye is large and tends to overwhelm any initial errors. Oke et al. demonstrated that errors in initial biometry and IOL calculation could account for only 12 % of the variation in refraction at age 10 years.[77] For these reasons, we do not think that a lack of a pediatric-specific IOL formula is detrimental to power selection or long-term outcomes. Similarly, developments in prediction of axial length or keratometry such as from Lottelli et al. are unlikely to improve IOL selection.[78]

Ultimately, the choice of IOL power is made for a goal postoperative refraction. Some have advocated for initial emmetropia in unilateral cases.[79] Most authors prefer moderate initial hyperopia in young children or even using an adult-power IOL that the child's eye can grow into.[80]

We think that the surgeon should account for the future myopic shift with growth of the eye, the refraction of the opposite eye, the age of the patient, and the planned refractive and amblyopia management. A reasonable approach for a goal postoperative refraction is a moderate amount of initial hyperopia in young children according to age (Table 4), with a likely outcome of moderate myopia in adulthood. This can be guided by examining the likely future refraction range throughout childhood.[81]

Cataracts requiring specialized techniques

Persistent fetal vasculature (PFV)

PFV is a frequent cause of unilateral congenital cataract. It is important to recognize these abnormalities since adverse events are more common in eyes with PFV following cataract surgery.[82]

Clinical findings

PFV has protean manifestations and is classified as anterior, posterior or mixed (Table 5).[83] Anterior manifestations may include any combination of persistent pupillary membranes, persistent iridohyaloid vessels with radial iris vessel and iris anomalies, variable cataract ranging from a Mittendorf dot to total cataract, and posterior lens capsule fibrovascular plaque, typically with elongation of ciliary processes. It is often associated with microphthalmia, microcornea, steepening of the cornea and, occasionally limbal abnormalities, posterior embryotoxon and corneal opacity from iridocorneal adhesions or kerato-lenticular touch.[84] Occasionally there may be lens subluxation, microspherophakia[85], platyphakia[86] and atypical colobomas.[87] Intra-lenticular or epicapsular blood vessels may bleed causing rapid progression of cataract. Progressive angle-closure with ocular hypertension or glaucoma arises from anterior traction of the lens-iris diaphragm or from swelling of the lens. Posterior manifestations include posterior hyaloid remnants varying from a thin, avascular remnant within Cloquet's canal (minimal fetal vascular remnants (MFVR)), to a thick fibrovascular stalk with patent vasculature with or without tractional detachment of the retina. Traction may consist of mild epiretinal folds to extensive falciform retinal folds, congenital non-attachment of the retina, and retinal dysplasia. Other posterior segment anomalies such as foveal traction, foveal hypoplasia, uveoretinal coloboma may also be present, [10]. There may also be anomalies of the optic disc head, such as Bergmeister papilla, peripapillary staphyloma, disc hypoplasia or dysplasia such as morning-glory disc anomaly.

PFV is typically sporadic and unilateral in otherwise well, term-born infants [88] and may be suspected by the presence of any abnormal

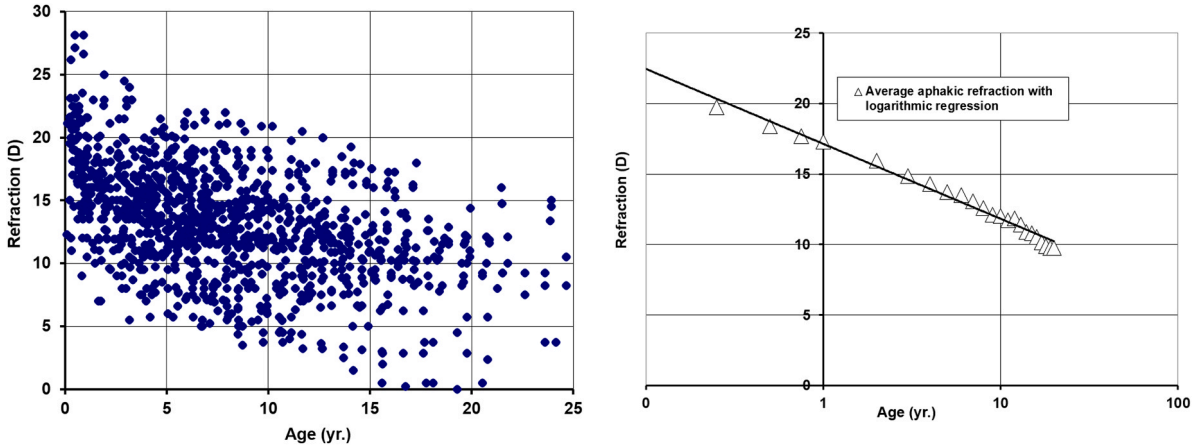

Fig. 4. a. Plot of refractive error versus age for 281 aphakic eyes.[73] Reprinted with permission from SLACK Inc. b. The same eyes' refractions averaged and converted to a semilogarithmic curve, with slope equal to "rate of refractive growth".

Table 3
Median absolute prediction error for recent studies of IOL formula accuracy in pediatric patients.

Ref.	SRK II	SRK-T	Hoffer Q	Holladay 1	Holladay 2	Haigis	Barrett U II	Notes
[77]	2.2	1.3	2.1	1.2	1.4			
[160]	0.83	0.75	0.83	0.88	1.00	0.74	0.89	*1
[78]		0.67	0.56	0.58	0.53			
[161]	0.90	0.71	0.61	0.64				*2

* 1: greater scatter in APE for eyes before age 3 yr. of age.
* 2 biometry done in office resulted in better APE than when done under anesthesia.

Table 4
Expected future refractions at age 3, 10 and 20 years for typical eyes made pseudophakic in childhood, with an initial postoperative hyperopia according to age.

Age at surgery (yr)	Refractions at various ages (D)			
	Initial postop	**3 yr**	**10 yr**	**20 yr**
1	+ 5	*+ 1.2*	*−2.8*	*−5.1*
3	+ 3		*−0.6*	*−2.6*
10	+ 1			*−1.0*

* Predicted pseudophakic refractions are shown in italics
All predictions are based on "typical eyes" and are subject to the large variance in RRG3

vascular remnant on slit-lamp examination (Fig. 5). Subtle features may only become apparent during an examination under general anesthesia. Cataract morphology suggestive of PFV include posterior capsule plaque with vascular patch (salmon patch) with or without ciliary process elongation, posterior polar cataract, posterior lenticonus and membranous cataract.[86] Posterior segment involvement should be assessed either by indirect ophthalmoscopy or, if no view is possible, by B-scan ultrasound (US). A hyaloid stalk or tractional detachment of the retina can be associated. US-Doppler imaging may demonstrate blood flow within hyaloid remnants and reveals configuration of the PFV involvement into "I", "Y", "inverted Y" and "X" patterns. This influences surgical planning and prognosis.[89] PFV may be mistaken for retinoblastoma and B-scan ultrasound helps distinguish the two conditions.

The decision to operate on PFV-related cataract is largely governed by two factors: prognosis for visual rehabilitation and presence of, or potential for, secondary angle closure glaucoma. Age at presentation may be a significant prognostic consideration, although delayed surgery may not be as critical to final outcome depending on the severity of the condition[14]. Significant posterior segment involvement such as tractional retinal detachment typically limits outcome and, in these cases, if there is no risk of secondary angle closure glaucoma, surgery may not be justified. Similarly, surgery may be avoided in mild cases of PFV with a limited, off-axis opacity or in MFVR'S that do not obscure the pupil aperture.[15] Alternatively, severe anterior traction with shallow or flat anterior chamber may require urgent lensectomy to avoid secondary angle closure glaucoma.

Which surgical approach to adopt, via a limbal or pars plana entry, is debatable. However, abnormal anatomy with anteriorly dragged retina or other adherent structures in this region may render a greater risk of inducing a retinal detachment through pars plana approach[16]. Where there is 360 degree of anterior retinal extension there is a high risk of adverse outcome including phthisis bulbi.[17]

In mild PFV associated cataract, a standard limbal approach lensectomy is usually straight forward. Lensectomy for more severe PFV

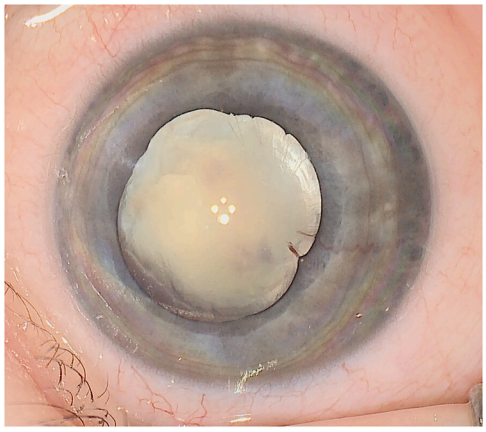

Fig. 5. A dense cataract in an eye with persistent fetal vasculature (there is a retrolenticular plaque and iridohyaloid vessels).

Table 5
Clinical characteristics of eyes with persistent fetal vasculature undergoing surgery.

Author	**Year**	**No. of eyes**	**Mean / median age at surgery / presentation (Mo. ± SD)**	**anterior PFV only (%)**	**posterior PFV only (%)**	**mixed PFV (%)**
Dass & Trese[23]	1999	27	16.4 ± 42.2	2 (7.4)	10 (37.0)	15 (55.6)
Alexandrakis et al.[24]	2000	30	16	2 (6.7)	2 (6.7)	26 (86.7)
Anteby et al.[12]	2002	89	14.4 ± 22.8	29 (32.5)	28 (31.4)	30 (33.7)
Sisk et al. [25]	2010	70	3.83	26 (37.1)	7 (10)	37 (52.9)
Morrison et al. (IATS)[1]	2011	18	2	NR	0	NR
Vasavada et al.[26]	2012	33	6.30 ± 5.16	33 (100)	0	0
Tartarella et al.[27]	2013	38	14	9.4 (out of total of 58 eyes)	11.3 (out of total of 58 eyes)	79.2 (out of total of 58 eyes)
Kuhli-Hattenbach et al. [28]	2016	19	5.47 ± 3.47	16 (84.2)	0	3 (15.8)
Solebo et al. **unilateral**[12]	2016	46	2.25	22 (47.8)	0	23 (50)
Solebo et al. **bilateral**[12]	2016	12	4.75	6 (50)	0	6 (50)
Karacorlu et al.[29]	2018	44	3	5 (11)	5 (11)	34 (78)
Bata B et al.[16]	2019	58	2.1 ± 1.5	NR	0	NR
Khurana et al.[7]	2021	20	14 ± 13.37	6 (30)	0	14 (70)
Chen et al. [30]	2024	539	36.7 ± 45.4	539	0	0
Haider et al.[31]	2024	64	2 (aphakic); 29 (pseudophakic)	46 (72)	0	18 (28)

requires additional considerations. A fibrovascular-posterior capsular (FV-PC) with anterior lens traction, shallow or flat anterior chamber (AC), usually requires high viscosity, cohesive viscoelastic to reform the AC and protect the corneal endothelium. Iridohyaloid remnants or persistent membranes adhering to the anterior lens capsule require careful viscodissection. If an anterior continuous curvilinear capsulorrhexis is not possible, vitrector-assisted capsulotomy followed by lens aspiration may be preferred. Capsule staining with trypan blue, though helpful, can worsen the surgeon's view in long-standing lens-corneal touch with corneal opacity due to corneal endothelial staining.[90] Use of a portable femtosecond laser device to create anterior and posterior capsulotomies has been described.[91]

Patent blood vessels running within the FV-PC complex may require intra-ocular diathermy before FV-PC opening. A thick, extensive/total FV-PC complex can exert significant traction on an anteriorly inserted retina. Opening can be achieved with a narrow gauge microvitrectomy blade combined with microgauge intra-ocular scissors as the vitrector alone is insufficient. A combination of both vitrector and intra-ocular scissors may be required to avoid excessive traction on the FV-PC complex which risks intra-operative retinal detachment. Where there is severe elongation of ciliary processes, intraocular scissors can detach the capsular bag from the ciliary processes which appear to insert directly into the capsule. Radial, wedge-shaped incisions into peripheral capsule followed by complete removal disrupts circumferential traction.[92] Care must be taken to avoid cutting ciliary processes. Visual outcomes tend to be worse with elongated ciliary processes.[93]

Diathermy of the distal end of a patent vascularized hyaloid stalk is advisable prior to truncation during removal of the posterior capsule and anterior vitrectomy, with care taken to avoid exerting traction on the retina posteriorly. A pars plana micro-endoscopic approach may assist with this[7]. The Fugo plasma blade™ enables simultaneous cauterization and cutting of the posterior capsule and hyaloid stalk.[94] A peripheral iridotomy prevents pupil block and iris bombé from secondary pupillary membrane formation in aphakic eyes. IOL implantation is often not possible, except in milder PFV or cataract with MFVR's. Post-operative complications include hyphema, vitreous hemorrhage, pupil block, iris bombé, secondary angle closure glaucoma, corneal decompensation, peri-operative retinal detachment and post-operative hypotony. Later complications include glaucoma, VAO (particularly associated with primary IOL implantation[85]), chronic hypotony and phthisis.

Traumatic cataracts

Ocular trauma is common in children, particularly boys, due to outdoor play and lack of supervision. Common objects causing injury include sticks, pens, stones, scissors, fireworks, and rarely electric shock induced trauma (Fig. 6). Penetrating injuries predominate accounting for almost 75 % of cases.[95] Traumatic cataracts account for about 30 % of all childhood cataracts and are a leading cause of preventable visual disability in children.[96] These cases are often complex both because of the unique anatomical and physiological characteristics of immature eyes and the presence of associated ocular injuries. These can include corneal/conjunctival/lid lacerations, lens subluxation/dislocation iridodialysis, zonular dialysis, angle recession glaucoma, vitreous hemorrhage, and retinal damage (Fig. 7). Timely and skillful management is essential to prevent long-term visual impairment and amblyopia.

Traumatic cataract may form immediately or gradually after an injury. In blunt trauma, percussive damage via coup and contre-coup mechanisms often leads to rosette-shaped lens opacities. Penetrating injuries lead to localized opacification at the site and can progress to total cataract if fluid enters the lens if fluid enters the lens leading to osmotic damage. Zonular damage, lens subluxation, posterior capsular rupture, and intraocular foreign bodies (IOFB) are also common sequelae.[97]

Clinical evaluation must include a careful history and thorough examination usually under anesthesia particularly in younger and uncooperative children. Key components of evaluation include VA testing (age-appropriate), pupil reflex testing (for optic nerve damage), slit lamp examination and external examination to rule out any associated injuries, IOP measurement, gonioscopy, and indirect ophthalmoscopy. Additional investigations such as ultrasound biomicroscopy, OCT and B-scan ultrasonography are valuable in the assessment of deeper structures/retinal status and for detection of retained foreign bodies. A CT scan or orbital X-ray can help in IOFB localization; MRI is contraindicated unless any foreign body is confirmed to be non-metallic.

Preoperative counselling and informed consent is essential. Parents/guardians should be informed of the following. 1) Possibility of need for multiple surgeries; 2) Delayed or secondary IOL implantation; 3) Guarded visual prognosis; 4) Need for regular follow-ups and amblyopia therapy in younger children; and 5) Medico-legal documentation if appropriate.[97]

Surgical management

The surgical plan is dictated by multiple factors, especially the presence of coexistent injuries such as corneal laceration and iridodialysis. Surgery for uncomplicated traumatic cataract is ideally performed 3–4 weeks post-injury, allowing time for inflammation to subside. However, immediate intervention is needed for corneal/scleral lacerations, uncontrolled IOP or severe anterior chamber reaction.[98] General anesthesia is usually required in children. Surgery may be prolonged if there is a need for additional procedures such as vitrectomy or placement of an endocapsular ring. In children with open globe injuries, intravenous mannitol (1–2 g/kg over 30–60 min) may be given preoperatively, to reduce the vitreous volume. IOL power calculation is challenging when there is a coexisting corneal tear. The fellow eye can be used to estimate an approximate IOL power (unless there is a history of marked anisometropia). Placement of an endocapsular ring, iridodialysis repair, iris or scleral fixation of IOL may be considered on a case-to-case basis and appropriate instruments/equipment made

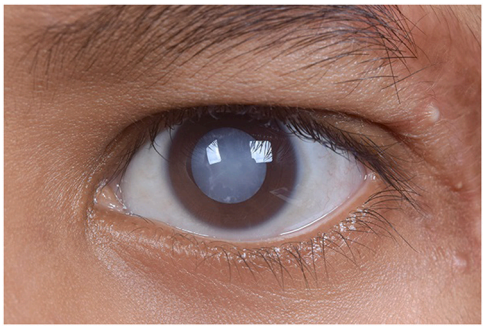

Fig. 6. Total cataract in a 9-year-old after electrical shock injury.

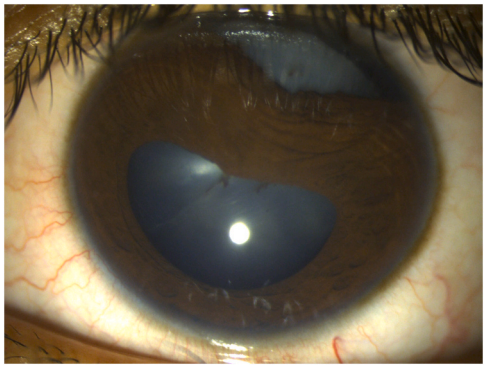

Fig. 7. Cataract and Irido dialysis in a 6-year-old with suspected blunt injury.

available.

Anterior and posterior lens capsule management in traumatic cataract cases is very challenging and unpredictable, especially in eyes with penetrating trauma. The anterior capsule may be ruptured and thus a standard capsulorhexis may not be possible (Fig. 8). Staining the capsule using 0.1 % Trypan blue dye assists in visualization and management. If there is only partial damage to the anterior capsule or a substantial band of anterior capsule can be preserved, it can be used to support an IOL.[99] A thick fibrosed capsule requires mechanical cutting with micro scissors or a vitrector-assisted rhexis. In-the-bag IOL placement is ideal when the capsular bag is intact (Fig. 9). Where integrity of the posterior lens capsule is uncertain following trauma, hydro dissection should be avoided. The nucleus and cortex are usually soft or fluffy and can be easily removed by irrigation and aspiration techniques. Rarely the nucleus may be hard requiring phacoemulsification.

Posterior capsule and anterior vitreous management is almost identical to non-traumatic cataracts (see above) except PCO formation is typically more rapid in children post trauma.[100] Primary posterior capsulectomy and vitrectomy should be considered for children having traumatic cataract even for older children Inadequate anterior vitrectomy may lead to risk of retinal tears/detachments in the late post-operative period. Any vitreous incarcerated in the wound, present in the subconjunctival space or the anterior chamber should be identified and cleared. Intra cameral triamcinolone can be used to identify the vitreous in the anterior chamber and is a useful tool to enable a thorough vitrectomy. Lens matter or uveal tissue may also be incarcerated along with vitreous in penetrating trauma and should also be excised either manually or with a vitrector. Irido dialysis repair when required can be performed simultaneously. It should be noted that the vitrector can inadvertently injure normal tissue such as intact lens capsule with injudicious use. If zonular dialysis is present a capsular tension ring or scleral fixation of the IOL may be necessary.[101] In-the-bag placement is ideal if the capsular bag is intact. Sulcus placement with optic capture is preferred if posterior capsule is ruptured.[102] The use of hydrophobic acrylic lenses is preferable, and it reduces inflammation and PCO risk. Iris, anterior capsule, posterior capsule and vitreous management during surgery; post operative medications play an important role in the long-term outcome.

In conclusion, management of pediatric trauma can be complex. Prognosis varies because of the variability of co-existent ocular injury and response to treatment. About 50–75 % of children may achieve 20/60 or better VA. Poor outcomes are associated with corneal scarring, posterior segment involvement, and delayed management.[103]

Complications

Amblyopia

Amblyopia is the most common adverse event occurring after pediatric cataract surgery. Using a kitten model, Hubel and Wiesel

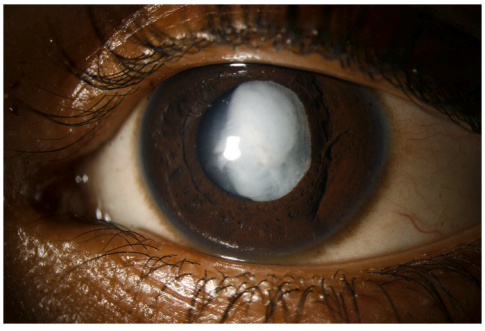

Fig. 8. Total cataract in a 10-year-old following blunt trauma and rupture of anterior lens capsule.

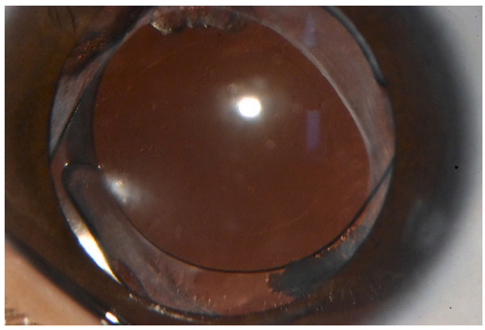

Fig. 9. A one-piece IOL in the capsular bag of a 12-year-old with mild zonular dialysis following blunt trauma.

demonstrated that suturing one or both eyelids closed for three months causes permanent changes in the architecture of the striate cortex.[104] After unilateral eyelid closure, neurons stop responding to visual stimuli to the deprived eye. Whereas in normal kittens 80 % of the neurons in the striate cortex respond to visual stimuli to both eyes, after suturing one eye closed, nearly 100 % of neurons only responded to visual stimuli from the unmanipulated eye. While these effects were partially reversed by opening the eyelid of the deprived eye and then suturing the fellow eye closed, many of the deficits were permanent.[105] After bilateral eyelid closure, many neurons in the striate cortex became unresponsive to any visual stimuli.

In human infants there is a four to eight weeks latent period when vision is believed to be subcortical. This latent period is followed by a critical period during which children are at risk of developing amblyopia. Performing cataract surgery during this latent period can prevent amblyopia from developing. Amblyopia is generally more severe in children with unilateral versus bilateral cataracts. Amblyopia is also more severe in children with dense cataracts.[106] Delaying bilateral congenital cataract surgery beyond ten weeks of age often results in the development of nystagmus further reducing the vision in these children.[107]

Amblyopia may also develop secondary to anisometropia and strabismus. Removing the lens from only one eye usually causes severe anisometropia that is very amblyogenic. Many children with cataracts also develop strabismus that causes amblyopia that is additive to the amblyopia resulting from anisometropia and deprivation.

Amblyopia can be minimized in children with cataracts by early cataract surgery, optically correcting refractive errors, and part-time patching of the fellow eye. In children with bilateral cataracts, the optical correction in the better-seeing eye can be manipulated to promote visual development in the weaker eye. For example, if the child is wearing aphakic contact lenses, the contact lens may be removed from the better seeing eye for several hours each day to treat the amblyopia in the worst-seeing eye. After unilateral congenital cataract surgery, part-time patching therapy of the fellow eye is critical. However, too much patching may impair the development of binocularity, whereas too little patching may result in poor vision in the aphakic/pseudophakic eye.[108,109] Consistent patching at nearly the same time each day has been shown to be associated with a better visual outcome.[109] Part-time patching of the fellow eye is particularly important during the first year of life after unilateral congenital cataract surgery. Beginning in the second year of life, patching can be gradually tapered and then discontinued by age 7 years (Fig. 10).[3] Patching regimens should be personalized for each child based on their visual acuity.[110] Visual acuity at age 4 years accurately predicts visual acuity at age 10 years in children with dense amblyopia (20/200 or worse), regardless of how much patching is performed after age 4 years.[111]

Amblyopia may involve visual deficits other than decreased visual acuity. Delaying congenital cataract surgery until later in childhood has been shown to result in impaired facial recognition that exceeds the

Fig. 10. Teenager who underwent a lensectomy in her left eye at age 6 weeks for persistent fetal vasculature. Postoperatively her aphakia was corrected with contact lenses. She was patched from age 7 weeks to 8 months, 1 h/day/month of life; 9–13 months, 6 h/day; 14 months-1½ years, 5 h/day; 2 ½ −3 years, 4 h/day; 3 years, 2 h/day; 4 years, 4 h/day every other day; 5–7 years, 4–5 h/day twice a week. Visual acuity is 20/20 in both eyes, she is orthotropic, and she has 40 s/arc of stereopsis.

deficits expected from decreased VA alone.[112] It has been postulated that the gradual restoration of vision in these children (e.g. a period of low visual resolution before he restoration of high visual resolution) may allow them to remodel their striate cortex in a manner that is more conducive to developing normal facial recognition.

Glaucoma following cataract surgery

Glaucoma following cataract surgery (GFCS), previously known as aphakic or pseudophakic glaucoma, is a subtype of secondary glaucoma based on the Childhood Glaucoma Research Network (CGRN) classification.[113] It is one of the most common complications of cataract surgery in children, with an incidence ranging from 6.0 % to 58.7 %.[24,114–122] Diagnosis may be made as early as a few months following surgery or decades later.[123] Recent 10-year data from the IATS showed that the risk of glaucoma continues to increase with duration of follow-up.[124]

Diagnostic criteria

The diagnostic criteria of GFCS and glaucoma suspect vary depending on the study. However, the most cited criteria were established by the IATS[125] and the CGRN[113] (Table 6). Elevated IOP was an essential criterion in the IATS, as opposed to the CGRN, where diagnosis could be made based on other signs of glaucoma without elevated IOP. Current knowledge suggests that glaucoma may develop and/or progress even with IOP within normal limits, favoring the CGRN criteria in most studies.

Risk factors

Risk factors for developing GFCS include younger age at time of surgery[22,114,126,127], aphakia[127], performing posterior capsulotomy[126], post-operative complications and need for re-interventions[126–129], and certain ocular anomalies[130,131] (e.g. microcornea, PFV, microphthalmia). While two meta-analyses reported a possible protective effect of IOL insertion, neither the IATS nor IOLu2 study found that inserting an IOL altered the risk of developing glaucoma.[22,124,127,132]

Pathophysiology

GFCS can be divided into two categories: closed-angle and open-angle. In the former, excessive post-operative inflammation can lead to anterior synechia formation and/or pupil block. Closed-angle GCFS is uncommon with modern surgical techniques and effective post-operative anti-inflammatory medications. The pathophysiology of open-angle GCFS remains poorly understood. Current hypotheses include a toxic interaction of the immature trabecular meshwork (TM) with LEC[133] or vitreous cells, leading to increased outflow resistance. Chronic trabeculitis and TM collapse[134] post-lensectomy may also play a role in the development of GCFS.

Table 6
Diagnostic criteria of glaucoma following cataract surgery (GFCS).

IATS	CGRN
Glaucoma	
IOP of > 21 mmHg with 1 or more of the following anatomical changes: – Corneal enlargement – Asymmetrical progressive myopic shift accompanied by enlargement of the corneal diameter and/or axial length – Increased optic nerve cupping, defined as an increase of 0.2 or more in the cup-to-disc ratio – Use of a surgical procedure for IOP control	– OP > 21 mm Hg – Visual field: reproducible visual field defect that is consistent with glaucomatous optic neuropathy with no other observable reason for the visual field defect – Axial length: progressive myopia or myopic shift with increased ocular dimensions that outpace normal growth – Cornea: findings that include Haab striae, corneal diameter > 11 mm in newborns, > 12 mm in children younger than 1 year, and > 13 mm in children older than 1 year – Optic nerve: progressive increase in cup-to-disc ratio, cup-to-disc asymmetry ≥ 0.2 when optic discs are of similar size, and focal rim thinning
Glaucoma suspect: at least 1 of the following	
– Two consecutive IOP measurements of > 21 mmHg on different dates after discontinuation of topical corticosteroids without any of the anatomical changes listed above – Use of glaucoma medication to control IOP without any of the anatomical changes listed above	– IOP: > 21 mm Hg on 2 separate dates – Visual fields: visual field defect indicating glaucoma – Axial length: increased axial length in the setting of normal IOP – Cornea: increased corneal diameter in the setting of normal IOP – Optic nerve: optic disc appearance indicating glaucoma

IATS: Infant Aphakia Treatment Study, CGRN: Childhood Glaucoma Research Network, IOP: intraocular pressure

Treatment

Treatment of GCFS usually begins with medications, first-line therapy being topical beta-blockers, carbonic anhydrase inhibitors and/or prostaglandin analogues. Systemic carbonic anhydrase inhibitors may also be used but require electrolyte and blood gas monitoring if used for prolonged periods. Alpha-agonists, such as brimonidine and apraclonidine, are to be used cautiously in the pediatric population. Side-effects can include respiratory depression, apnea and central nervous system depression. Brimonidine is contraindicated in children less than two years old and should also be used with caution in children less than six years old or weighing less than 20 kg.[120,135,136] Apraclonidine does not cross the blood-brain barrier as readily and may be safe in children older than 6 months.[137,138] If medications fail to control IOP and/or prevent progression of disease, surgical options include angle surgery, cyclophotocoagulation and tube shunt insertion.

Visual Axis opacification

VAO is a common complication of pediatric cataract surgery with or without IOL implantation.[139–141] It is a particular concern in pediatric eyes due to the higher mitotic activity of LECs and exaggerated inflammatory response to surgery seen in children. The prevention and treatment of VAO is thus a necessary consideration in all pediatric cataract surgeries. VAO occurs due to either proliferation of LECs across a patent posterior capsule (Fig. 11) or anterior vitreous face, or scar tissue formation across, or phimosis of, the pupil.

The repair potential of LECs is stimulated by surgery. They

proliferate and migrate towards the posterior capsule (or anterior vitreous face) resulting in opacification and changes to the remaining lens capsule including phimosis, Elschnig pearls, Soemmerring rings, and attempted lens regeneration.

Pupillary membranes are primarily caused by post-surgical anterior chamber inflammation caused by blood-aqueous barrier breakdown. The resulting inflammatory response leads to deposition of fibrin, collagen and other contractile proteins in and around the pupil causing opacity, tethering and/or constriction of the pupil margin.[142] The two forms of VAO are not completely distinct, as remaining LECs also undergo epithelial–mesenchymal trans differentiation into fibroblasts. These lay down collagen and contractile proteins leading to formation of fibrotic membranes and contraction of the posterior capsule and or pupil.[143]

Risk factors for VAO include; younger age, incomplete cortical clearance (more remaining LECs), inadequate management of the posterior capsule and anterior hyaloid face (providing a scaffold for VAO), inadequate postoperative anti-inflammatory medications and the use, type and positioning of an IOL (likely affecting both scaffolding for LEC proliferation, the inflammatory response and indirectly the extent of cortical clearance).[143] Additionally, the rate of VAO has been shown to be higher in eyes with associated ocular anomalies.[144]

Preventing VAO

Prevention of VAO starts with treating pre-existing risk factors such as uveitis, selecting the least invasive surgery balanced with factors such as visual outcomes and considering the timing of surgery (the younger the patient, the greater the risk of VAO).[4] As a general principle, minimally traumatic surgery reduces the risk of VAO following pediatric cataract surgery.[4] The use of low molecular weight heparins in the irrigating solution has been reported to reduce the inflammatory response following surgery but other studies have not shown any benefit from its use.[145]

It is well established that leaving the posterior capsule intact during cataract surgery in young infants, results in rapid onset, visually significant VAO in almost all cases.[146] Therefore, whether an IOL is to be used or the eye left aphakic, posterior capsulectomy is necessary in all children under the age of 5–7 yrs particularly where YAG laser capsulotomy may be unavailable or inappropriate due to, for example, developmental delay.[147]

When IOL implantation is performed under the age of 2 years, most studies find the rate of VAO requiring secondary surgery to be around 40 %,[4,144,148] typically more than double that of leaving the eye aphakic.[148] Accordingly, many surgeons do not implant IOLs of any type under the age of 2 years.[4] The extent of cortical clearance, size of posterior capsulectomy and extent of anterior vitrectomy have been linked to the rate of VAO. Lens capsule polishing has also been advocated to minimize the number of LECs and reduce VAO rates.[149] It has been suggested that posteriorly vaulted 3-piece acrylic IOLs are associated with lower rates of VAO.[150] Other surgical techniques may also reduce the rate of VAO primarily relating to the removal or blockade of scaffolding for LEC proliferation including optic capture[147,151,152] and the bag-in-the-lens technique.[153]

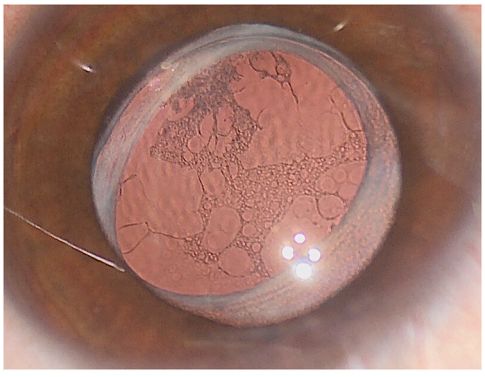

Fig. 11. Lens epithelial cell migration causing visual axis opacification in a child with an acrylic single piece IOL.

The postoperative management of children after cataract surgery has the aim of reducing inflammation, infection and pain. With regards to VAO, topical corticosteroids reduce the inflammatory response. Cycloplegics are used to avoid posterior synechiae and disrupt the scaffold for pupillary membranes.[69]

Once VAO has developed, treatment is necessary to restore visual potential. In less severe cases, Nd:YAG laser treatment is effective but in thicker or more cellular membranes, surgical treatment is necessary. Clinic-based YAG procedures are commonly performed in adults, but good compliance is needed and thus it is often inappropriate for younger children or those with developmental delay or significant behavioral issues. For these children, YAG can be performed under general anesthesia, but this requires either a modified technique using adult designed laser equipment (e.g. the lateral decubitus position)[154] or a specially designed supine YAG laser.

Treating VAO

When YAG laser treatment is not possible due to unavailability of equipment, patient characteristics, significant lens regrowth, or thick pupillary membrane formation surgical ‘anterior segment revision’ can be performed using a variety of techniques typically employing a small gauge vitrector + /- irrigator with either limbal or pars plana access. Like cataract surgery itself, maximum dilation of the pupil before surgery is used along with a minimally traumatic approach to clear the visual axis and remove fibrin scar tissue and lens cells in addition to elements of the posterior or anterior capsule. An anterior vitrectomy is often performed to remove scaffold for further lens regrowth in addition to adequate pupil dilation post-operatively.[155]

Conclusion

Despite recent advances in screening, diagnosis and surgical treatment, pediatric cataract remains a major global cause of visual impairment. Many affected children achieve good outcomes with modern surgical treatment. However, those individuals left with poor vision will require lifelong support. This has a significant impact, both on the affected individual, their family, and their community. It is thus imperative that diagnosis and treatment of pediatric cataract is optimized, and poor outcomes kept to a minimum. Dense congenital and infantile onset cataracts need urgent diagnosis and prompt surgical intervention in the first few weeks after birth, ideally by a sub-specialist team with the requisite experience, expertise and access to appropriate surgical, diagnostic and pediatric infrastructure. Traumatic cataract in children is often complex and multifaceted and similarly requires expert management. The use of modern genomic sequencing techniques has revealed that most bilateral pediatric cataracts in the developed world have a genetic etiology. This has altered the diagnostic and investigative approaches for many children, particularly those presenting with bilateral congenital cataracts. Investigations should be more specifically targeted and guided by clinical findings. However, it should be noted that cataract can be a clinical feature of many systemic and metabolic disorders. In some of these conditions, the course of the disease can be altered by early diagnosis followed by medical intervention/treatment. It is thus important that pediatric ophthalmologists, and other clinicians involved in the care of children with cataract, are aware of these associations and work collaboratively with pediatric and genetic colleagues, referring promptly where indicated.

Declaration of Competing Interests

The authors declare no conflict of interest.

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