Pediatric Refractive Surgery

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The field of refractive surgery has historically been a science of modifying refractive error in adult patients for the purpose of improving uncorrected visual acuity (UCVA). More recently within pediatric ophthalmology, refractive surgery has emerged as a beneficial tool to address refractive errors and their associated comorbidities such as amblyopia and strabismus in special needs children intolerant of spectacles or contact lenses. Like any technology, the indications for use continue to evolve and expand as the safety, ease, and efficacy of the procedures are repeatedly demonstrated. At present, these procedures are mostly reserved for children with neurobehavioral disorders. Such children are physically incapable of properly wearing spectacles or are perturbed by the stimulation of wearing spectacles on their face even in the presence of disabling refractive errors which cause them to live in a world of blur. Contact lenses can be considered for a minority of these patients but require highly motivated and vigilant caretakers to ensure regular contact lens hygiene and prevent complications. This is usually impractical for such children who have multiple systemic comorbidities which are time-consuming for the caretaker to manage, or their behavioral disorder precludes cooperation with contact lens placement and removal.

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The field of pediatrics in general is a risk-averse field, as it should be, because treatments are applied to children who lack the ability for autonomous medical decision-making. Therefore, new technologies within pediatric ophthalmology must undergo great scrutiny before achieving widespread acceptance. This chapter will provide an overview of the past, present, and future developments within the exciting and burgeoning field of pediatric refractive surgery.

4.1 Classification and History of Pediatric Refractive Surgery

Correction of ametropia can occur at multiple planes: spectacle, contact lens, corneal, anterior chamber, posterior chamber, and lens. Pediatric refractive surgery involves modification of the last four planes in this list when the first two options are not feasible.

The earliest reported cases of pediatric refractive surgery include clear lens excision with resultant aphakia for high myopia dating back to the late nineteenth century. This procedure involved dissection of the crystalline lens, allowing the liberated lens material to swell within the anterior chamber, and then removing the intumescent lens material via needling. Treated patients included children as young as 8-years old [1].

Angle-supported anterior chamber phakic IOLs (pIOLs) were first implanted in the 1950s, again to correct myopia [2]. Also, during this time, the iris-enclavated IOL was initially used for the correction of aphakia after intracapsular cataract extraction. In 1986, the first iris-enclavated IOL implantation for myopic correction of a phakic eye was performed [3]. The first published report of iris-enclavated IOL implantation in pediatric patients as young as 12-years old was published in 1998 [4]. Posterior chamber pIOL implantation began in the 1980s with the introduction of a silicone pIOL with a “mushroom” configuration. This lens had an optic which projected anteriorly through the pupil and haptics behind the iris [5]. Technological advancements eventually lead to the development of two new posterior chamber pIOLs: the implantable collamer lens (ICL) by STAAR Surgical and the phakic refractive lens (PRL) by Carl Zeiss Meditec. The earliest published report of implantation of posterior chamber pIOLs in children was in 1999 utilizing the ICL. This study included four children ranging from ages 3 to 16-years old with a mean refractive error of −12.8 D [6].

Over 8.5 million people in the United States underwent keratorefractive surgery from 1995 to 2010 and by 2015 over 13 million LASIK procedures had been performed in the United States [7]. The earliest published report of excimer laser photorefractive keratectomy in pediatric patients was in 1995. This was a small case series of 9 patients ranging from ages 10- to 15-years old with refractive errors from −17.75 D to +8.25 D [8]. Since that time, many reports of successful excimer laser corneal surgery in children have been published in the literature with low rates of complications [9–20]. The largest study reported outcomes in 405 ametropic children with 96% of myopic and 91% of hyperopic eyes corrected to within ±1 D of their target value. Of eyes treated with intraoperative mitomycin-C, 91% had no corneal haze, and no child with postoperative haze lost best-corrected visual acuity (BCVA). The retreatment rate was 1.5% of treated eyes [10].

4.2 The Need for Pediatric Refractive Surgery

Myopia is a growing epidemic and the most common visually significant refractive error, with a rising prevalence of 25–40% in Western countries [21, 22]. In the United States, the prevalence of myopia doubled in a 30-year period ending in 2004, and pathologic myopia (over 8.0 D) rose eightfold [23]. There are over 80 million reported myopic children worldwide, and myopia is among the five conditions that have been identified as immediate priorities by the World Health Organization (WHO) in its Global Initiative for the Elimination of Avoidable Blindness [24]. Myopia of prematurity has become an increasingly recognized entity and according to WHO, every year an estimated 15 million babies are born preterm (before 37 completed weeks of gestation), and this number is rising [25].

Naturally occurring astigmatism is common with a prevalence of 14.9% in children using a cutoff value >0.5 D. Children in South-East Asia have the lowest prevalence at 9.8%, while children in the Americas have the highest at 27.2% [26]. The degree of astigmatism is higher in premature infants and has an inverse relationship with birth weight and gestational age [27, 28]. Astigmatism has been shown to reduce visual acuity by 0.31 logMAR per diopter of myopic astigmatism and 0.23 logMAR per diopter of hyperopic astigmatism [29]. That is equivalent to reducing the visual acuity from 20/20 to 20/40 for 1.0 D of uncorrected myopic astigmatism and from 20/20 to 20/35 for 1.0 D of uncorrected hyperopic astigmatism.

Hyperopia has a bimodal distribution with the majority of full-term infants exhibiting physiologic hyperopia between 0.25 D and 4.00 D. Prevalence of hyperopia $\geq$ +2.0 D decreases as age increases down to 1% at age 15 with an average prevalence of about 5% in children of all ages [26, 30–32]. Prevalence then rises again in adulthood affecting about 10% of the population age 40 and above [22]. Anisometropic hyperopia and astigmatism tend to be more amblyogenic than myopia [18]. Uncorrected high hyperopia is also associated with accommodative esotropia or exotropia [33].

Although there is a significant need for ametropic correction among children, there is a subpopulation of children who cannot tolerate correction at the spectacle or contact lens planes. These children have poor spectacle compliance which can be defined as wearing glasses for 25% or less of their waking time. Spectacles are also frequently dislodged particularly in children with poor head control, or children may develop a habit of viewing around the spectacle frames. Spectacle noncompliance arises for a variety of reasons including high power lens distortions, prismatic effects, narrowed field of view, social stigma, aniseikonia, anisovergence, asthenopia, neurobehavioral disorders, craniofacial, or ear abnormalities. The most common neurobehavioral disorders are cerebral palsy, autism, Down syndrome, Angelman syndrome, seizure disorders, idiopathic developmental delay/mental retardation, and progressive childhood encephalopathies. Uncorrected ametropia exacerbates the neurobehavioral disorder giving rise to visual autism which is described as heightened social isolation due to living in a cocoon of blur. Contact lenses are usually even more problematic in this group of patients. They can be expensive, difficult to insert and remove in children, increase the risk of corneal infection, and are frequently lost [18, 19, 34].

Many studies have shown dramatic improvements in uncorrected visual acuity in children undergoing refractive surgery with low rates of complications. A multitude of other benefits for children with neurobehavioral disorders undergoing refractive surgery are improvements in communication, socialization, motor skills, adaptive behaviors, visual perception, and cognitive function [35]. Refractive surgery is highly valued by parents of children with large refractive errors and spectacle noncompliance, and bilateral LASEK for these children ranked among the most cost-effective procedures in ophthalmology [36].

4.3 Unique Aspects of Refractive Surgery for the Pediatric Patient

The preoperative evaluation of the pediatric patient prior to refractive surgery has unique differences from the adult patient, but also similarities including a full ocular history and examination, motility assessment, cycloplegic refraction (manifest usually obtained in adults but difficult to obtain in children), and ocular biometry.

The history should include the reason for the child's aversion to spectacles and the lack of feasibility of contact lenses. It is important to know if a child with a neurobehavioral disorder has a sensory aversion to objects near their face. This is a common aversion within this group of patients and can make tasks such as wearing spectacles, haircuts, dental exams, or even wearing a hat challenging. If such a sensory aversion exists, then parents need to be informed about the challenges of postoperative management which will arise due to the need for eye drops, eye shields, and multiple examinations of the eyes. This gives parents time to arrange for assistance by other family members or social services during the postoperative period. Discussion should also include the possible use of arm restraints so that the child does not cause self-inflicted trauma to the surgical site. Arm restraints should be used sparingly when the parent cannot be with the child so as to avoid persistent elbow stiffness. Other less restrictive methods to protect the surgical site include distraction, repositioning, swaddling, and pain management.

The patient's target refraction is determined by considering the current cycloplegic refraction and the patient's age. Unlike in adults for whom emmetropia is the usual target, younger children need a more hyperopic target to account for the eye growth and myopic shift that will occur over the ensuing years. The practice of targeting a hyperopic refraction in pediatric refractive surgery is similar to that in pediatric cataract surgery but with the advantage of preserved lens accommodation depending upon the method of refractive surgery. The caveat however is that spectacle compliance will not be possible postoperatively, since this was the reason for undergoing refractive surgery. Evaluation of ocular motility and alignment is a regular practice for pediatric ophthalmologists and plays a role in the assessment for refractive surgery as well. For example, multiple studies have demonstrated effective treatment of accommodative esotropia with the use of refractive surgery to correct the hyperopia [34, 37–39]. In contrast to this, one must also consider the loss of correction of small heterotropias by the prismatic effects of spectacles if the patient undergoes refractive surgery. In general, hyperopic lenses provide a partial prismatic correction of any horizontal or vertical tropia, because the base of the prism is always pointing in the appropriate direction as long as the optical centers of the lenses are correctly placed.

The presence of amblyopia which may be a contraindication to refractive surgery for an adult is frequently an indication of refractive surgery in the pediatric patient who requires a sharp, focused image on the retina for the amblyopia to improve [11, 13, 14, 40]. In addition to strabismus and amblyopia, common comorbidities with high ametropia also include optic neuropathies, foveopathies, and nystagmus. The presence of these comorbidities does not mean that the ametropia is not important and does not warrant correction [18]. Rather, the visual function should be optimized to the maximum potential of the child, sometimes requiring both refractive and eye muscle surgery.

When possible, preoperative biometric evaluation is performed in the clinic. However, children, particularly those with neurobehavioral disorders or cerebral palsy, are unable to remain stationary and fixate on diagnostic imaging such as specular microscopy or IOL biometry. In this case, an examination under anesthesia (EUA) is required, and biometry is obtained with ultrasound for measurement of axial length, anterior chamber depth (ACD), and lens thickness. Central corneal thickness is measured with a handheld pachymeter and horizontal white-to-white (WTW) with industrial-grade digital calipers with precision to the hundredth of a millimeter. The EUA also provides an opportunity for a complete exam of all ocular structures, because many of these children can be difficult to thoroughly examine in the clinic. Children undergoing refractive surgery have at least two full EUAs and two cycloplegic refractions before finally undergoing surgery. During the EUA, the eyes should be evaluated for contraindications to keratorefractive surgery, such as severe dry eye, exposure keratopathy, ocular surface cicatrization, keratoectasias, corneal dystrophies, uveitis, and uncontrolled glaucoma. The absence of sufficient support structures for pIOL implantation or refractive lens exchange (RLE), such as ectopia lentis or a hypoplastic iris, should be noted. The posterior segment is examined with a 360° scleral depressed exam to evaluate for risk factors for retinal detachment such as lattice degeneration which may benefit from prophylactic laser barrier retinopexy prior to refractive surgery. At the completion of the EUA with cycloplegic refraction and biometric data in hand, one can decide upon the best refractive surgery option for the patient and discuss this with the parents. The ACD and magnitude of ametropia frequently drive the decision-making, because pIOLs have minimum ACD requirements (Fig. 4.1). Children can have a wide range of ACD, and those with a history of prematurity and in particular retinopathy of prematurity tend to have reduced ACD [27, 41]. Other factors to consider include adequate corneal thickness for excimer laser ablation and sufficient horizontal WTW, which serves as a proxy to iridociliary sulcus diameter, for ICL implantation.

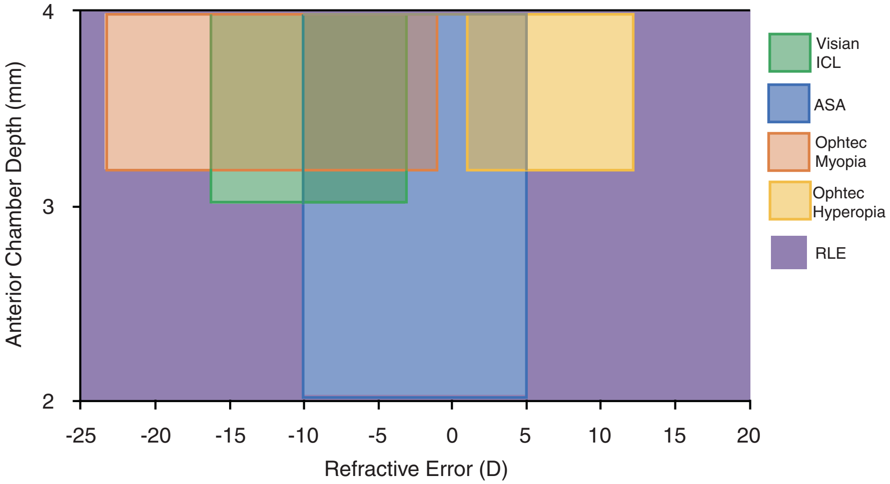

Fig. 4.1 This chart shows the available refractive surgery options based on the sphere of the refractive error on the *X*-axis and anterior chamber depth on the *Y*-axis. The Visian ICL (green) comes in powers from −3.00 D to −16.00 D. The ICL requires an anterior chamber depth (ACD) of at least 3.0 mm and a horizontal white-to-white (WTW) diameter between 10.7 and 13.1 mm. Advanced surface ablation (blue) can reliably correct refractive errors from −10.00 D to +5.00 D without an ACD limitation. The Ophtec myopia lens (orange) and hyperopia lens (yellow) are available in powers from −1.00 D to −23.5 D for myopia and + 1.0 D to +12.0 D for hyperopia, respectively. The Ophtec lenses require an ACD of at least 3.2 mm. Refractive lens exchange (purple) can correct very large refractive errors beyond the limits of the previous options or when there is insufficient ACD

4.4 Excimer Laser

Excimer lasers allow for precise reshaping of the corneal surface down to the submicron range, especially with the use of modern scanning lasers [42]. This powerful tool allows for the correction of myopia, hyperopia, and astigmatism (Fig. 4.2) using advanced surface ablation (ASA) and anterior corneal opacities using phototherapeutic keratectomy. ASA is a broad term covering photorefractive keratectomy (PRK), LASEK, and Epi-LASEK, which are methods to reshape the corneal stroma without the creation of a stromal flap as performed in LASIK. Although there have been successful reports of pediatric LASIK [20, 37–39], it is preferable in the author's opinion to use ASA in children. This is because children are at greater risk for traumatic flap dislocation which can be visually devastating to the eye. Other advantages for children are that ASA may have a lower long-term risk of ectasia and when properly performed leaves the eye appearing as though a procedure was never done, even with a close examination at the slit lamp [43, 44].

In addition to the general preoperative evaluation discussed previously, evaluating for keratoectasia is important since such a condition would be a contraindication to ASA. Patients are asked about chronic eye rubbing and atopy which are risk factors for keratoconus [45]. Children with Down syndrome are at greater risk for developing keratoconus, and ASA in these patients should be approached with caution or avoided [46].

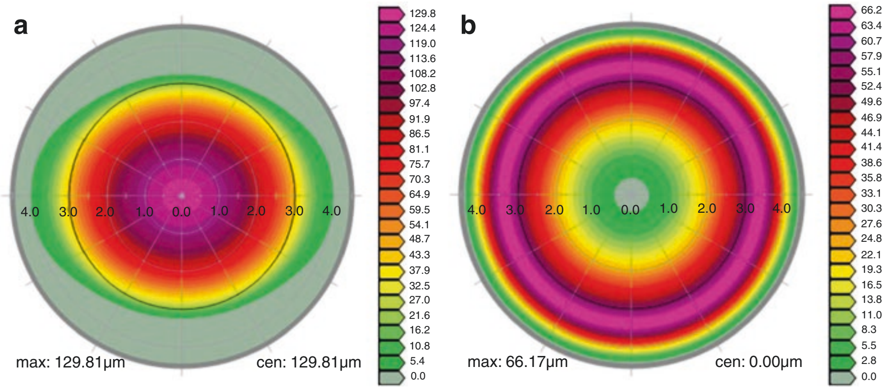

Fig. 4.2 Wavefront-optimized ablation profiles for a compound myopic astigmatism treatment (**a**) and simple hyperopic treatment (**b**) in two separate pediatric patients. Color-coding toward the pink side of the spectrum indicates greater ablation depth (values in microns), while the green side indicates less ablation depth. The numbers arranged horizontally across the ablation profile indicate optical zones of the cornea in millimeters. The numbers at the bottom of the profile indicate maximum and central ablation depth. The patient in (**a**) had refraction of −8.25 + 2.25 × 90 with a correction of −9.25 + 2.25 × 90 for a target of +1.00 D. Notice there is more ablation in the center of the cornea with less ablation in the periphery in order to flatten the central cornea for a myopic correction. Also notice that the ablation profile is ovalized in order to create steepening along the horizontal meridian to correct for astigmatism. The patient in (**b**) had a refraction of +5.00 with a correction of +4.00 for a target of +1.00 D. Notice that the highest amount of ablation is between the 3.0 and 4.0 mm optical zones with no ablation in the center in order to steepen the central cornea for a hyperopic correction. The ablation profile is spherical, because there is no astigmatic correction

Although older children may be able to undergo corneal ablation awake in the clinic [12], most children require brief general anesthesia in the operating room [9–11, 16–18, 47–49]. Excimer lasers are large machines and in operating rooms where space is limited, an organized and efficient setup is critical for performing this procedure safely and with rapid turnover (Fig. 4.3). Another advantage of ASA over LASIK is that it does not require the additional set up of a femtosecond laser or microkeratome in usually an already crowded operating room. For general anesthesia, patients are premedicated with nasal midazolam if needed. Standard induction is performed with sevoflurane, oxygen, and nitrous gas mixture. A laryngeal mask airway is placed, and the extension tube is oriented toward the feet so as not to obstruct the laser. Positioning of the patient becomes critical, since the patient is unconscious. The iris plane should be parallel with the floor. The head and neck should be vertically aligned beneath the laser, so that treatment of astigmatism will be on the correct axis. Propofol supplementation is provided as needed, and intravenous morphine or ketorolac are given at the end of the procedure to help with initial postoperative pain. Elbow restraints can be placed before emergence from anesthesia. General anesthesia also allows for ASA to be performed in patients with nystagmus or other conditions with fixation impersistence.

The procedure itself follows the same steps as adult ASA. A conservative residual stromal bed of 400 microns is set as a limit in children similar to that in adults

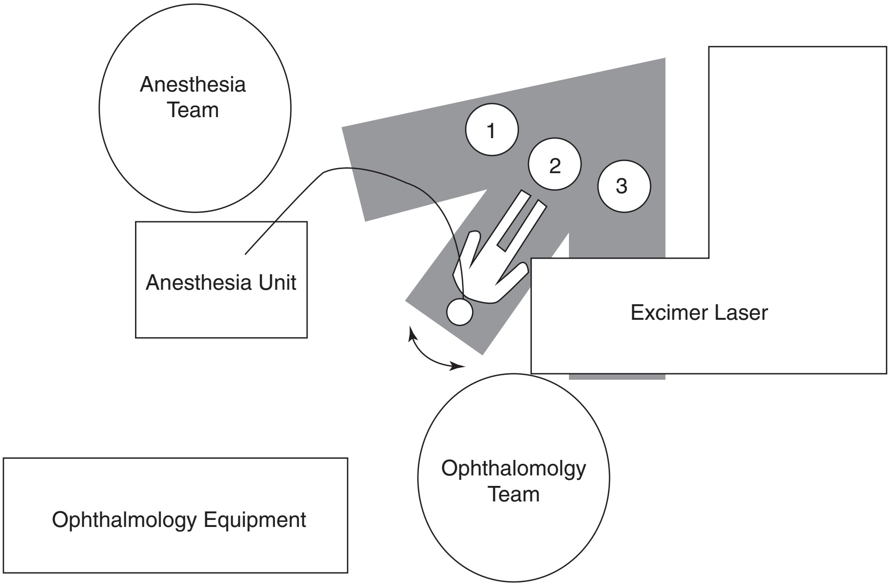

Fig. 4.3 Operating room layout for photorefractive keratectomy (PRK) under general anesthesia. The swiveling patient bed (grey) can rotate the patient to position 1 for induction and emergence from anesthesia, position 2 for exam under anesthesia by the ophthalmology team, and position 3 for excimer laser treatment. The ventilatory tubing should have sufficient length for the full excursion of the patient to position 3. The laryngeal mask airway should be oriented toward the patient's feet once exiting the mouth in order to avoid interference with the eye-tracking system of the excimer laser

[50]. After ablation, the stromal bed is treated with mitomycin-C to reduce corneal haze [51]. A bandage contact lens is placed, and the patient is started on topical tobradex, fluorometholone, and ketorolac. Goggles are then placed over the eyes. Patients are seen on postoperative day 1 to ensure the bandage contact lens is still in place and to review postoperative instructions. Vitamin C supplementation is encouraged to further reduce the risk of postoperative corneal haze. On postoperative day 5, the corneal epithelium should be healed, and the bandage contact lens can be removed. Then the patient is continued only on fluorometholone for 6 months. The postoperative refraction is checked at the 1-month visit and at subsequent visits to determine the effectiveness of treatment and regression. Visual acuity is not always obtainable, particularly in delayed children, and therefore the patient's cycloplegic refraction, visual behavior, and pattern visual evoked potential become the indicators of successful treatment.

Long-term, there is evidence of refractive regression in children, especially with higher degrees of corneal ablation [9, 11, 52, 53]. This practically limits the amount of treatment at the primary ablation to −10 D of myopia and +5 D of hyperopia (Fig. 4.1). Treatment of high degrees of astigmatism, in particular when combined with hyperopic ablations, seems to create even greater refractive regression [53]. Regression leads to under correction of the refractive error over time, which sometimes requires retreatment if the patient has sufficient corneal thickness.

4.5 Phakic Intraocular Lens (pIOL)

The two pIOLs which have most widely been implanted in children are the Visian implantable collamer lens (ICL) made by STAAR Surgical and the iris-enclavated Artisan lens made by Ophtec. The ICL is placed in the posterior chamber between the crystalline lens and iris, while the Artisan lens clips onto the anterior surface of the iris thus residing in the anterior chamber (Fig. 4.4). Phakic IOLs have shown excellent refractive outcomes in children with minimal regression, because they do not have the problem of tissue remodeling, which drives refractive regression after corneal ablation [6, 17, 40, 54–57]. However, the feasibility of pIOLs is limited by the need for sufficient anterior chamber depth (ACD). The ICL requires an ACD of 3.0 mm, and the Artisan lens requires 3.2 mm. In children who tend to have smaller eyes than adults, the ACD plays an important role in choosing a refractive surgery option (Fig. 4.1). Additionally, the ICL requires a horizontal white-to-white (WTW) of 10.7–13.1 mm. Implantation of a pIOL in the setting of insufficient ACD can result in angle-closure glaucoma, accelerated corneal endothelial cell loss, subclinical inflammation, pigmentary dispersion, and cataractogenesis [58]. This is why it is critical for the pediatric refractive surgeon to perform multiple checks of the patient's ACD, WTW, and corneal endothelial health prior to implantation to ensure that the appropriately sized ICL is used.

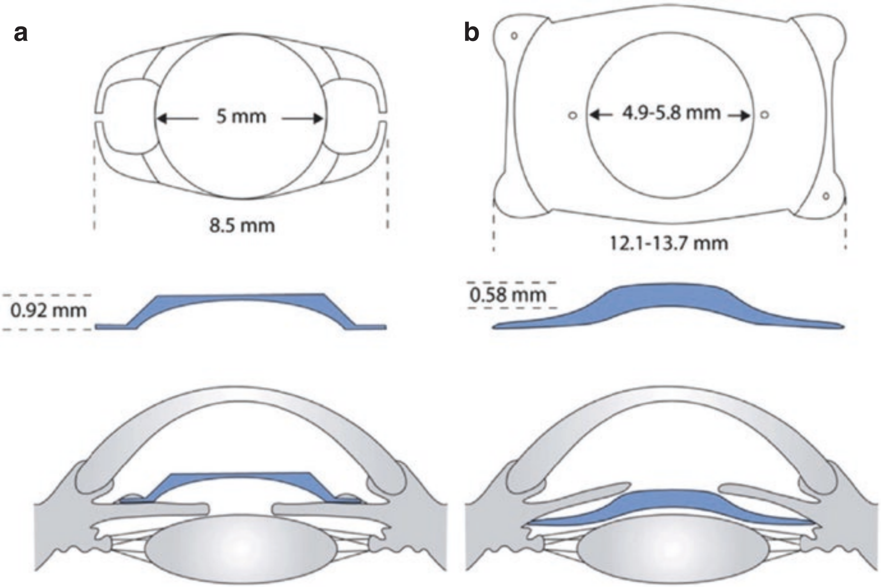

Fig. 4.4 Dimensions and anatomic position of the Ophtec-Artisan (**a**) and Visian ICL (**b**) phakic intraocular lens (pIOL) in the anterior segment. (Reprinted with permission from Faron N, Hoekel J, Tychsen L. Visual acuity, refractive error, and regression outcomes in 169 children with high myopia who were implanted with Ophtec-Artisan or Visian phakic IOLs. *J Am Assoc Pediatric Ophthalmol Strabismus*. 2021;25:27.e1–27.e8)

The ICL can correct myopia from −3.0 to −16.0 D. There is also a toric ICL (TICL) used for the correction of cylinder from 1.0 to 4.0 D at the spectacle plane. It is a single-piece lens with an overall length ranging from 12.1 to 13.7 mm. Different sizes are used due to anatomical variation in iridociliary sulcus diameter, which can be directly measured with ultrasound biomicroscopy, though in children the horizontal WTW is used as a proxy. All ICLs can be implanted through a 3.2 mm corneal incision. It is made from a copolymer of hydroxyethyl methacrylate and porcine-collagen and has nearly 100% transmittance of visible light, making it nearly imperceptible after implantation [59, 60].

In a 2016 study of 23 special needs children implanted with an ICL, 88% were corrected to within ±1.0 D of goal refraction. Eighty-five percent of children with a neurobehavioral disorder were reported to have enhanced visual awareness, attentiveness, or social interactions after ICL implantation. At an average of 9 months follow-up, average shift of spherical refractive error was +0.59 D, which was nonsignificant. Endothelial cell density had an average 1% decline in 10 eyes able to undergo measurement. Two children (8%) required an unplanned return to the operating room on the first postoperative day to relieve pupillary block caused by nonpatent iridotomy. The authors explain this occurred in the first two children implanted in their series who both had Nd:YAG laser iridotomies. Thereafter, laser iridotomy was abandoned in favor of scissor iridectomy at the time of ICL implantation. Afterward, no further complications were encountered. Other recommendations by the authors for adapting ICL surgery for special needs children include administration of IV acetazolamide during surgery to prevent postoperative ocular hypertension due to retained viscoelastic, use of a bridle suture to stabilize eye position while the patient is under general anesthesia, and closure of all corneal incisions with absorbable suture [54].

The Artisan lens can correct −1.0 to −23.5 D of myopia and +1.0 to +12.0 D of hyperopia. Toric lenses are also available correcting 1.0 to 7.5 D of cylinder. Currently, in the US, only the myopic lens has been approved and is available in powers −5.0 to −20.0 D. There is also an Artisan aphakia lens currently undergoing a multicenter clinical trial for patients aged 2–21-years old. Its power ranges from +10.0 to +30.0 D, and it requires a minimum ACD of 3.2 mm [61]. The Artisan lens is made from polymethyl methacrylate and comes in optic sizes of 5.0 mm and 6.0 mm in diameter. Typically, the 5.0 mm diameter optic is used in children, which requires a corneal incision of 5.2 mm for insertion. The overall length of the lens is 8.5 mm [62, 63]. De-enclavation of the Artisan lens from the iris can occur usually in the setting of trauma. Therefore, in the author's opinion, retropupillary fixation of the aphakic lens as sometimes performed in adults is not recommended in children.

The largest study of pIOL implantation in children evaluated 115 eyes implanted with the Artisan lens and 154 eyes implanted with the ICL. These children had a history of high myopia and spectacle-aversion. Average age at surgery was 9.9 years, and mean follow-up was 3.9 years. Spherical correction averaged 12.3 D, and 92% of eyes were corrected to within ±0.5 D of goal refraction. There were significant gains in uncorrected distance visual acuity, corrected distance visual acuity, and binocular fusion. The reason for postoperative improvement in corrected distance visual acuity is due to the relative image magnification achieved after reducing the amount of myopic lens power needed at the spectacle plane. Of the 169 children in the study, 81% were noted to have enhanced visual awareness, attentiveness, or social interactions. Of the eyes implanted with the Artisan lens, 8% required surgical repositioning/re-enclavation for traumatic dislocation. Three percent of the children implanted with either pIOL required return to the operating room in the days following surgery because of iridotomy closure causing pupillary block. The authors note the two major advantages of pIOL implantation for high myopia in this study were the marked low rate of refractive regression and no removal of corneal tissue, both of which are considerable drawbacks of excimer laser ablation for high levels of refractive error [55].

4.6 Refractive Lens Exchange (RLE)

RLE is a procedure in which lensectomy of the natural, crystalline lens with simultaneous implantation of an artificial intraocular lens (IOL) is performed for the treatment of refractive error. In eyes with a long axial length and/or steep keratometry values, aphakia may yield the desired refractive target. In this case, lensectomy without IOL implantation is performed, and the procedure is called clear lens extraction (CLE). These procedures are usually a secondary option in pediatric refractive surgery, because they result in loss of accommodation. Typically, in adults, RLE is performed around the age of presbyopia onset, so the loss of accommodation has minimal significance [64]. However, in children, who can have an amplitude of accommodation greater than 16.0 D [65, 66], the loss of accommodation is a major drawback to consider before removing the natural lens. RLE/CLE is used when other options are not possible due to insufficient space for a pIOL or too large of a refractive error for ASA or a pIOL (Fig. 4.1).

An exam under anesthesia is performed a few months before the planned procedure in order to obtain accurate biometry and perform a thorough scleral depressed exam of the peripheral retina. If there are risk factors for retinal detachment, such as axial length exceeding 29 mm, lattice degeneration, or asymptomatic retinal tears, then a barrier diode laser may be prophylactically applied. However, the use of barrier diode laser for retinal detachment prophylaxis is debated [67, 68]. Standard lensectomy with posterior capsulectomy and anterior vitrectomy is performed as in the manner of pediatric cataract surgery. The primary posterior capsulectomy and anterior vitrectomy are important to prevent posterior capsule or anterior hyaloid opacification, which can have an incidence as high as 50% [52]. Families should also be informed that the capsulectomy may need to be repeated in the future. Older children who can cooperate with an Nd:YAG capsulotomy in clinic may have the posterior capsule left intact at the time of surgery but should be closely monitored for the development of posterior capsule opacification.

If an IOL needs to be implanted to achieve the refractive target, then consider implantation of an acrylic, foldable 3-piece IOL in the iridociliary sulcus with posterior optic capture. This allows for implantation through a small incision with excellent long-term centration of the lens and facilitates future IOL exchange if needed. Multifocal lenses may be beneficial to counteract the loss of accommodation for older children outside of the amblyogenic age. These children should have normal pupillary movement and the ability to maintain stable centration of the multifocal IOL [69].

In a study of unilateral lens extraction for high anisometropic myopia in a pediatric population, 86% of eyes were corrected within ±3 D of goal refraction. Myopia correction averaged 17.3 D, and myopic regression averaged 0.43 D per year [70]. In another study of clear lens extraction and refractive lens exchange for high bilateral myopia in children with neurobehavioral disorders, 81% were corrected to within ±2 D of goal refraction. Uncorrected acuity improved an average of 2 log units in all 26 eyes, with commensurate gains in behavior and environmental visual interaction in 88% of children. Myopic regression averaged 0.16 D per year. Focal retinal detachment occurred in one eye with a history of cicatricial retinopathy of prematurity and trauma and was successfully repaired but resulted in loss of visual acuity [52].

The most vision-threatening complication of RLE is retinal detachment because unlike other refractive surgery options, the procedure necessitates surgery within the vitreous chamber. Myopic eyes are at higher risk of retinal detachment, and lens extraction increases this risk. In adults, the reported incidence of retinal detachment after RLE ranges from 0.37% to 8.1% [71, 72]. In the two pediatric studies mentioned above, the authors estimate the incidence to be about 3% at an average follow-up of 4.5 years [52, 70]. It is prudent to note that other serious complications may only appear after prolonged follow-up.

4.7 Future Technologies

Pediatric refractive surgery is a rapidly advancing field with new technologies continually emerging in the areas of preoperative evaluation, treatment interventions, and postoperative care.

Iris anatomy and limbal vessel registration obtained during preoperative biometry create a map of the ocular surface which can then be overlayed onto the surgeon’s view in the microscope. The axis of astigmatism can then be precisely treated without the confounding effect of globe cyclotorsion when the patient is in the supine position. For children who can cooperate with preoperative biometry, this will greatly assist in the treatment of astigmatism, because children usually cannot tolerate preoperative toric marking. Intraoperative anterior segment optical coherence tomography allows for a very accurate evaluation of pIOL position and vaulting. This is critical for ensuring long-term anterior segment health in children.

In the realm of keratorefractive surgery, treatment of higher order aberrations is becoming increasingly important in improving contrast sensitivity along with visual acuity. Advancements in this area include wavefront-optimized, wavefront-guided, and topography-guided treatments. Wavefront-optimized treatments are already being applied to pediatric patients. Wavefront and topography-guided treatments will be more available to pediatric patients as the preoperative diagnostic equipment becomes more facile for use in children and for exams under anesthesia. A drawback of these customized ablations is that they remove more corneal tissue than traditional ablations. Bioptics is another methodology already being used in pediatrics and involves a combination of keratorefractive and pIOL/IOL procedures to customize refractive error treatment. Small incision lenticule extraction (SMILE) provides an advantage in pediatric patients in that there is minimal disruption of corneal epithelium while still reshaping corneal stroma. This may reduce the risk of infection and would effectively remove the need for postoperative bandage contact lens management as currently performed with PRK. Surgical management of astigmatism, particularly hyperopic astigmatism, is currently a challenge in pediatric refractive surgery. The use of femtosecond laser nonpenetrating limbal relaxing incisions appears promising in children because the treatments are highly precise and should result in minimal pain, postoperative recovery time, and infection risk as there is no epithelial incision. These limbal relaxing incisions also do not remove a significant amount of tissue and are repeatable.

Phakic IOLs with a central opening will obviate the need for a peripheral iridotomy at the time of surgery. This will be safer for children who tend to have more inflammation and scarring postoperatively and thus are at greater risk for closure of the iridotomy.

In postoperative management of children, simplicity is key. Combination drops which mix antibiotic, steroid, and NSAID can help reduce the eyedrop burden on caregivers of children with neurobehavioral disorders. In a similar approach, punctal steroid implants and intracameral antibiotic given at the end of surgery may abolish the need for postoperative drop regimens altogether.

As the safety of these procedures improves and repeatedly manifests itself, the indications for pediatric refractive surgery will expand, like any medical technology. The surgeon's enthusiasm for achieving better results with cutting-edge technology must be continually tempered by the concern for the long-term visual health of young patients. Pediatric refractive surgery can make meaningful and lasting impacts in the lives of children when surgeons combine the knowledge and skills of refractive surgery and pediatric ophthalmology.

Key Points

1. Pediatric refractive surgery addresses refractive errors and their associated comorbidities such as amblyopia and strabismus in special needs children intolerant of spectacles or contact lenses.
2. Contrary to adults, amblyopia is frequently an indication for pediatric refractive surgery.
3. Pediatric refractive surgery involves modification of ametropia at the corneal, anterior chamber, posterior chamber, and lens planes.
4. The most common modalities used for pediatric refractive surgery today are advanced surface ablation, phakic intraocular lenses, and refractive lens exchange.
5. Children with neurobehavioral disorders undergoing refractive surgery have improvements in visual acuity, communication, socialization, motor skills, adaptive behaviors, visual perception, and cognitive function.

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