Techniques in pediatric refractive surgery

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Abstract:

Pediatric refractive surgery treats refractive errors and their associated comorbidities such as amblyopia and strabismus in special needs children intolerant of spectacles or contact lenses. Children with neurobehavioral disorders undergoing refractive surgery have improvements in visual acuity, communication, socialization, motor skills, adaptive behaviors, visual perception, and cognitive function. Contrary to adults, amblyopia is frequently an indication for refractive surgery in special needs children. Pediatric refractive surgery techniques modify ametropia at the corneal, anterior chamber, posterior chamber, and lens planes. This article will discuss the most common modalities used today in pediatric refractive surgery, including laser keratorefractive surgery, phakic intraocular lenses, and refractive lens exchange. Practical pearls are discussed for the implementation of pediatric refractive surgery, reviewing preoperative diagnostics, surgical techniques, and postoperative care.

Keywords:

Amblyopia, ametropia, pediatric refractive surgery, special needs

Introduction

Children with special needs are currently benefiting from the field of refractive surgery, frequently in ways which are more life-changing than spectacle-independence. Refractive surgery has generally been a science of modifying refractive error in adult patients for the purpose of improving uncorrected visual acuity (UCVA). In pediatric ophthalmology, refractive surgery is not only treating refractive errors but also their associated comorbidities such as amblyopia and strabismus in special needs children intolerant of spectacles or contact lenses. Such children are physically incapable of proper spectacle-wear or are agitated by wearing spectacles on their faces even in the presence of disabling refractive errors which cause them to live in visual isolation. More concerning is the development of amblyopia which may result in permanent vision loss if the ametropia is not corrected before maturation of the visual system.[1]

Correction of ametropia can occur at multiple planes: spectacle, contact lens, corneal, anterior chamber, posterior chamber, and lens. Refractive surgery involves modification of the last four planes in this list when the first two options are not feasible. The need for ametropic correction among children is common, but there is a subpopulation of children who have poor spectacle compliance which can be defined as wearing spectacles for 25% or less of waking time. Spectacles are frequently dislodged particularly in children with poor head control, or they may develop a habit of viewing around the spectacle frames. Spectacle noncompliance arises for a variety of reasons including neurobehavioral disorders, asthenopia, high power lens distortions, prismatic effects, narrowed field of view, social stigma, aniseikonia, anisovergence, craniofacial or ear abnormalities. The most common neurobehavioral disorders are cerebral palsy, autism, Angelman syndrome, Down syndrome, seizure disorders, idiopathic developmental delay, 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.[2-4]

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Many studies have shown dramatic improvements in UCVA in children undergoing refractive surgery with low rates of complications.[3,5-13] 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.[14] Refractive surgery is highly valued by parents of children with large refractive errors and spectacle noncompliance, and bilateral laser-assisted subepithelial keratectomy for these children ranked among the most cost-effective procedures in ophthalmology.[15]

Adapting Refractive Surgery to Pediatrics

The preoperative evaluation of the pediatric patient before 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 examinations, 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 from other family members or social services during the postoperative period. Discussion should also include the possibility 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 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 is the reason for undergoing refractive surgery. The 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.[2,16-18]

The presence of amblyopia which may be a contraindication to refractive surgery for an adult is frequently an indication for refractive surgery in the pediatric patient who requires a sharp, focused image on the retina for the amblyopia to improve.[19-22] In addition to strabismus and amblyopia, common comorbidities with high ametropia also include optic neuropathies, tauopathies, and nystagmus. The presence of these comorbidities does not mean that the ametropia is not important and does not warrant correction.[3] Rather, visual function should be optimized to the maximum potential of the child, sometimes requiring both eye muscle and refractive surgery.

When possible, preoperative biometric evaluation is performed in the clinic. However, children, particularly those with neurobehavioral disorders or gross motor deficits, are unable to remain stationary and fixate for diagnostic imaging such as corneal topography or intraocular lens (IOL) biometry. In this case, an examination under anesthesia (EUA) is required, and biometry is obtained with ultrasound for the measurement of axial length, aqueous depth (AQD), and lens thickness. Central corneal thickness is measured with handheld pachymetry and horizontal white-to-white (WTW) with industrial-grade digital calipers with precision to the hundredth of a millimeter [Figure 1].

The EUA provides an opportunity for a complete examination of all ocular structures because many of these children can

Figure 1: This shows the necessary equipment for an exam under anesthesia for pediatric refractive surgery. Beginning from left to right, the image shows an ultrasound unit with A-scan, B-scan, and ultrasound biomicroscopy, topical anesthetic drop, tape to close the eyelids to prevent corneal dehydration, mydriatic drops including a cycloplegic agent, hand-held slit lamp, hand-held autorefractor keratometer, contact tonometry and pachymetry devices, digital calipers, gonioscopy lens, normal saline for hydrating the corneal surface, cotton tips for performing limbal rub to accelerate mydriasis, immersion lens for A-scan, scleral depressor, eyelid speculum, retinoscope with lens racks, and binocular indirect ophthalmoscope with indirect viewing lens

be difficult to thoroughly examine in the clinic. Children undergoing refractive surgery have at least one full EUA 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, keratoectasia, corneal dystrophies, uveitis, and uncontrolled glaucoma. The absence of sufficient support structures for phakic IOL (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 examination to evaluate for risk factors for retinal detachment, such as lattice degeneration which may benefit from prophylactic laser barrier retinopexy before refractive surgery. At the completion of the EUA with cycloplegic refraction and biometric data in hand, one can decide on the best refractive surgery option for the patient and discuss this with the parents. The AQD and magnitude of ametropia frequently drive the decision-making, because pIOLs have minimum AQD requirements. Children can have a wide range of AQD, and those with a history of prematurity and in particular retinopathy of prematurity tend to have reduced AQD.[23,24] 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 implantable collamer lens (ICL) implantation.

Laser Keratorefractive Surgery

The excimer laser uses a 193-nm argon fluoride beam, which allows for precise reshaping of the corneal surface down to the submicron range, especially with the use of modern scanning lasers.[25] This powerful tool allows for the correction of myopia, hyperopia, and astigmatism using photorefractive keratectomy (PRK) and anterior corneal opacities using phototherapeutic keratectomy. Although there have been successful reports of pediatric LASIK,[11,16-18] it is preferable in the author's opinion to use PRK 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 PRK may have less long-term risk of ectasia and when properly performed leaves the eye appearing as though a procedure was never done, even with close examination at the slit lamp.[26,27]

In addition to the general preoperative assessment discussed previously, evaluating for keratoectasia is important since such a condition would be a contraindication to PRK. Patients are asked about chronic eye rubbing and atopy which are risk factors for keratoconus.[28] Children with Down syndrome are at greater risk for developing keratoconus, and corneal ablation in these patients should be approached with caution.[29]

Although older children may be able to undergo corneal ablation awake,[30] most children require brief general anesthesia in the operating room.[3,6,8-10,19,31-33] 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. Another advantage of PRK over LASIK is that it does not require the additional setup of a femtosecond laser or microkeratome in an already crowded operating room. For general anesthesia, patients are premedicated with nasal midazolam if needed. Standard induction is performed with a sevoflurane, oxygen, and nitrous gas mixture. A laryngeal mask airway is placed, and the flexible extension tube is oriented toward the feet so as not to obstruct the laser [Figure 2].

Positioning of the patient becomes critical since the patient is unconscious. The iris plane should be parallel to 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 morphine is 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 PRK to be performed in patients with nystagmus or other conditions with fixation impersistence.

A conservative residual stromal bed of 400 μ is set as a limit in children similar to that in adults.[34] After ablation, the stromal bed is treated with mitomycin-C to reduce corneal haze.[35] A bandage contact lens is placed, and the patient is started on topical tobramycin and dexamethasone 0.3%/0.1%, fluorometholone 0.1%, ketorolac 0.4%, and preservative-free artificial tears four times per day. Goggles are then placed over the eyes to prevent the child from dislodging the contact lenses. If the contact lenses are repeatedly dislodged, then an antibiotic and steroid ointment can be used as an alternative until the cornea re-epithelializes. 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

Figure 2: This shows the author positioning the patient underneath the excimer laser. The flexible extension tube of the laryngeal mask airway allows for the laser beam and pupil tracking system to be unobstructed. The patient's iris plane is parallel to the floor, and the patient's head is in line with his body

haze. On postoperative day 6, the corneal epithelium should be healed, and the bandage contact lens can be removed. Then, the patient is continued only on topical fluorometholone 0.1% two times per day 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 can be obtained using Teller acuity cards and spatial-sweep visually-evoked potentials.[36] However, when visual acuity cannot be obtained, particularly in severely delayed children, the patient's cycloplegic refraction and visual behavior become the indicators of successful treatment.

Long-term, there is evidence of refractive regression in children, especially with higher degrees of corneal ablation.[19,32,37,38] This practically limits the amount of treatment at the primary ablation to −10 D of myopia and +5 D of hyperopia. The treatment of high degrees of astigmatism, in particular when combined with hyperopic ablations, seems to create even greater refractive regression.[38] Regression leads to under-correction of the refractive error overtime, which sometimes requires retreatment if the patient has sufficient corneal thickness.

Wavefront and topography-guided treatments are currently available to children able to perform preoperative biometry. As the preoperative diagnostic equipment becomes more facile for use in children and examinations under anesthesia, customized ablations will become available to a broader population of children. However, a drawback of these customized ablations is that they remove more corneal tissue than traditional ablations.

Phakic Intraocular Lens

The two pIOLs which have most widely been implanted in children are the Visian 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 the iris, while the Artisan lens clips onto the anterior surface of the iris. pIOLs 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.[9,12,13,22,39-41] However, the feasibility of pIOLs is limited by the need for sufficient AQD, the anteroposterior distance from the apex of the corneal endothelium to the anterior lens capsule. The ICL requires an AQD of 3.0 mm, and the Artisan lens requires 3.2 mm. In children who tend to have smaller eyes than adults, the AQD plays an important role in choosing a refractive surgery option. Implantation of a pIOL in the setting of insufficient AQD can result in angle-closure glaucoma, accelerated corneal endothelial cell loss, subclinical inflammation, pigmentary dispersion, and cataractogenesis.[42] In addition, the ICL requires a horizontal WTW of 10.7–13.1 mm. This is why it is critical for the pediatric refractive surgeon to perform multiple checks of the patient's AQD, WTW, and corneal endothelial health before implantation to avoid long-term complications.

The ICL can correct myopia from −3.0 to −16.0 D. There is also a toric ICL to correct the cylinder from 1.0 to 4.0 D at the spectacle plane. It is a single-piece lens with overall length ranging from 12.1–13.7 mm. Different sizes are used due to anatomical variation in iridociliary sulcus diameter, which can be directly measured with ultrasound biomicroscopy, or 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.[43,44]

The implantation of the toric lens on the correct astigmatic axis is performed by first marking the horizontal meridian of the eye after the patient is under general anesthesia since preoperative toric marking is usually not possible in special needs children. Once the horizontal meridian has been marked, microscope alignment software can be used to capture the horizontal meridian and provide a visual overlay of the axis of astigmatism for the surgeon [Figure 3].

The use of intracameral moxifloxacin and a dexamethasone ophthalmic insert placed in the punctum at the end of surgery has removed the need for postoperative drops for ICL implantation in children. Furthermore, the introduction of the EVO ICL with three central holes through the ICL has eliminated the need for a peripheral iridotomy at the time of surgery. This has been highly advantageous for children who tend to have more inflammation and scarring postoperatively and thus are at greater risk for closure of a peripheral iridotomy.[12] Finally, intraoperative optical coherence tomography allows for the assessment of appropriate ICL vaulting over the crystalline lens and checking that the iridocorneal angle is not closed after ICL implantation [Figure 4].

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, the average shift of spherical refractive error was +0.59 D, which was nonsignificant. Endothelial cell

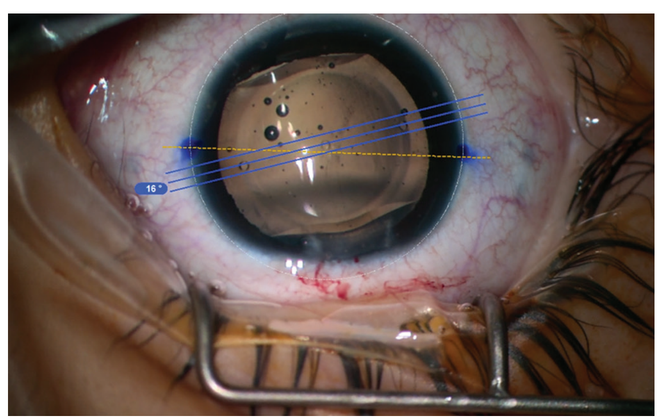

Figure 3: The axis of the toric implantable collamer lens is aligned using microscope alignment software

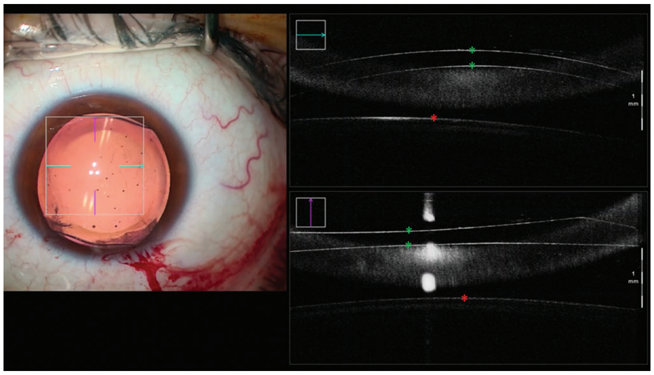

Figure 4: Intraoperative optical coherence tomography allows for the assessment of appropriate vaulting of the implantable collamer lens (ICL) over the crystalline lens, as well as iridocorneal angle viewing to check for angle closure. The green asterisks mark the anterior and posterior surfaces of the ICL. The red asterisks mark the anterior surface of the crystalline lens

density had an average 1% decline in 10 eyes able to undergo measurement. Other recommendations by the authors for adapting ICL surgery for special needs children include the administration of intravenous 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.[12] This author utilizes a dose of 10 mg/kg intravenous acetazolamide, 4-0 silk for the bridle suture, and 9-0 vicryl for closing corneal incisions.

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 1.0–7.5 D of cylinder. Currently, in the USA, only the myopic lens has been approved and is available in powers −5.0 to −20.0 D. The Artisan lens is made from polymethyl methacrylate and comes in optic sizes of 5.0 mm and 6.0 mm 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.[45,46]

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. The average age at surgery was 9.9 years, and the 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 were required to return to the operating room in the days following surgery because of iridotomy closure causing a 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.[39]

Refractive Lens Exchange

RLE is a procedure in which lensectomy of the crystalline lens with simultaneous implantation of an artificial 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.[47] However, in children, who can have an amplitude of accommodation >16.0 D,[48,49] the loss of accommodation is a major drawback to consider before removing the crystalline lens. RLE/CLE is used when other options are not possible due to insufficient space for a pIOL or too high of a refractive error.

An exam under anesthesia is performed weeks to months before the planned procedure 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 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.[50,51]

Lensectomy is performed in the manner of standard pediatric cataract surgery. If IOL implantation is required, the author prefers to create a manual anterior and posterior continuous curvilinear capsulorhexis followed by bicapsular capture of a three-piece hydrophobic acrylic IOL [Figure 5]. With this technique, the IOL is immediately centered and stabilized by the capsular bag, avoiding IOL sundowning or rotation. The anterior and posterior capsular leaflets are in apposition together anterior to the IOL optic, preventing the migration of lens epithelial cells posterior to the optic and significantly reducing posterior opacification. Anterior vitrectomy is not required, because the lens epithelial cells are effectively sealed off from the anterior vitreous face, and a bicameral eye is maintained. This technique also 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.[52]

In a study of unilateral lens extraction for high anisometropic myopia in a pediatric population, 86% of eyes were corrected

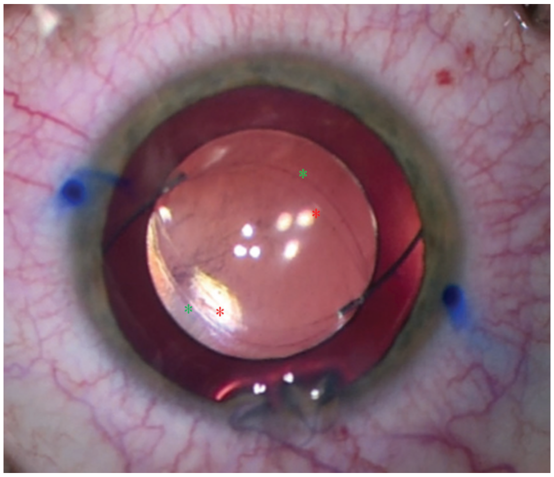

Figure 5: In bicapsular capture, the optic of the three-piece intraocular lens has been captured through the anterior (green asterisks) and posterior (red asterisks) capsular openings, while the haptics reside in the iridociliary sulcus

to within ±3 D of goal refraction. Myopia correction averaged 17.3 D, and myopic regression averaged 0.43 D per year.[53] In another study of CLE and RLE 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.[37]

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 8.1% to 0.37%.[54,55] 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.[37,53]

Conclusion

These techniques in pediatric refractive surgery can be combined for the treatment of higher magnitude refractive errors in a method known as bioptics. Bioptics is already being used in pediatric patients and involves a combination of keratorefractive and pIOL/IOL procedures to customize refractive error treatment. In general, the available techniques in pediatric refractive surgery are expanding at a rapid pace. Mastering these techniques will require the pediatric refractive surgeon to stay up-to-date on developments in refractive surgery and pediatric eye anatomy and physiology.

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Conflicts of interest

There are no conflicts of interest.

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