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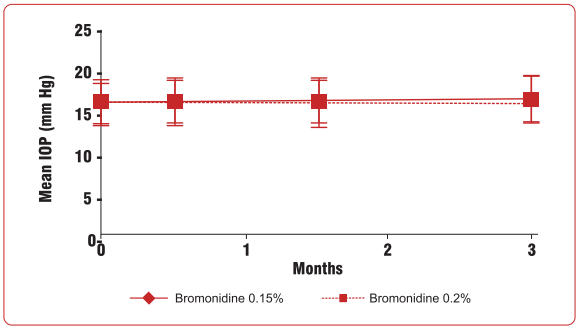

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Surgical Considerations in Children with Corneal Opacities and Cataracts

Alexander Foster, Anne Ko, Michael R. Banitt

Introduction

Corneal opacities in children have been classified as congenital versus acquired or as traumatic versus nontraumatic in nature. While these categories may offer some insight into prognosis, the evolution of corneal surgery beyond penetrating keratoplasty suggests that more attention should also be directed toward the anatomic location of the corneal pathology. In Peters anomaly, many congenital corneal opacities are typically treated with penetrating keratoplasty, while congenital hereditary endothelial dystrophy (CHED) can now be treated with endothelial keratoplasty. This chapter discusses surgical treatment options for pediatric corneal opacities, including penetrating, endothelial, and lamellar keratoplasties. Attention will also be given to Boston keratoprostheses (KPro), as well as to a less frequently reported procedure, optical iridectomy. The management of coincident glaucoma will also be discussed.

Indications and Timing of Corneal Transplantation

One of the rewards of caring for pediatric patients is the ability to limit or avoid lifelong visual disability. Since there is great variability in how pediatric corneal disorders are expressed, no two pediatric cornea cases are ever the same, which, in turn, makes it difficult to make blanket statements about whether, when, or which specific surgery is advisable.

Indications for pediatric keratoplasty vary by region. In North America, congenital corneal opacities and dystrophies are the most common [1]. Opacities that result from infectious keratitis, ulceration, and traumatic scar predominate in Asia and Africa [2, 3].

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Although the timing of surgical interventions has been studied, when best to operate remains unclear. Early interventions intended to minimize amblyopia may be associated with increased risks from general anesthesia and graft rejection. However, studies have not always demonstrated worse outcomes for surgery at a younger age [1]. Early surgery should be considered in cases of bilateral involvement, particularly when there are concerns about bilateral deprivational amblyopia.

Due to the heterogeneity of corneal opacities and varying study sizes and follow-up periods, it is difficult to make firm conclusions from the literature regarding the outcomes of penetrating keratoplasty in children related to age. A study from Lowe and co-workers of 765 grafts in individuals younger than 20 years of age revealed that the grafts of children 5 years of age and younger did worse than did those in the older age groups [4]. Grafts did best in the oldest subjects. However, adolescents aged 13 to 19 tended to undergo penetrating keratoplasty for keratoconus, which carries a more favorable prognosis (due to its limited clinical associations) than does, for instance, Peters anomaly. Dana and coauthors reported on over 160 grafts for which visual outcome was not affected by the timing of surgery [1]. And, finally, Low and colleagues studied 105 children for whom graft survival tended to improve in patients over 12 months of age [2], although the difference was not statistically significant. The effect of the patient's age and ideal timing of surgery on prognosis is not clear cut.

The ability of a patient's family to comply with treatment and follow-up should also inform decisions regarding the timing and type of surgery performed. Furthermore, as some corneal opacities present as part of a syndrome, the general health of a patient (and his/her ability to undergo serial examinations under anesthesia [EUA]) must be taken into consideration. Comorbidities, including developmental delay, can affect daily care and drop administration. The potential for self-inflicted trauma should also be considered, particularly if penetrating keratoplasty is to be performed.

The decision to perform a corneal transplant should be carefully considered, weighing various factors including the bilateral or unilateral nature of the disease, the density of the opacity(ies), intraocular pressure (IOP) control, anesthetic and surgical risks, and risks for early or delayed complications, including amblyopia. In general, we tend to be surgically less aggressive in children with unilateral opacities. Children with bilateral central opacities typically warrant early surgery. For example, a child with congenital hereditary endothelial dystrophy who undergoes bilateral endothelial keratoplasty can expect to do well. On the other hand, a child with a unilateral type 2 Peters anomaly presenting with no clear peripheral cornea and glaucoma would require a penetrating keratoplasty and glaucoma surgery with a more complicated postoperative course and a guarded visual prognosis. Preoperative discussions should include a reasonable estimation of visual potential, particularly in unilateral cases, as a well as a thorough discussion of medication and appointment regimens to be expected postoperatively.

Pediatric Penetrating Keratoplasty

At all stages, penetrating keratoplasty in a child is more challenging than when undertaken in an adult. Concomitant ocular abnormalities, such as anterior segment dysgenesis and glaucoma, are

common. Reduced scleral rigidity and positive posterior pressure can make surgery more difficult. Depending on the ability of the child to cooperate, routine postoperative evaluations and suture removal may not be able to be performed in a clinic setting and therefore require multiple serial EUAs. For patients who are unable to articulate complaints, parents may only become aware of problems after symptoms and findings become severe. Since the pediatric immune response is robust, children experience higher rates of allograft rejection compared to adults [1, 5]. Even when graft clarity is maintained, visual outcomes can be disappointing due to amblyopia. Despite these difficulties, the art of pediatric keratoplasty has evolved considerably.

Surgical Technique

The surgical technique for penetrating keratoplasty in pediatric populations is similar to adult surgery with a few notable exceptions. To reduce the risk of damage to the lens, pilocarpine can be administered preoperatively in cases where the iris is not adherent to the cornea. Placement of a Flieringa or McNeill-Goldman ring (Katena Products, Denville NJ, USA) can assist with reduced scleral rigidity, a characteristic of young eyes. Preoperative use of a Honan balloon or intravenous mannitol can mitigate positive posterior pressure that might otherwise cause the lens to come forward. Rather than oversizing grafts by 0.25–0.5 mm as we typically do in adults, larger grafts (oversized by 0.75–1.0 mm) can aid in securing the wound over the lens and iris. Larger grafts also offer the advantage of deepening the anterior chamber (AC) and limiting or preventing the formation of iridocorneal adhesions and glaucoma [6, 7].

For young children, host buttons are often punched to a diameter of 5–6 mm. Although these wounds can be closed with fewer sutures than in larger grafts, sutures loosen frequently and early in children, so we feel it is best to place roughly 16 interrupted sutures. The use of a running suture is discouraged due to the possibility of uneven wound healing and suture loosening.

Postoperative Management

Younger patients often require frequent EUAs to monitor graft health, IOP, and axial length. As the likelihood of graft rejection is higher in the first year after transplant, close follow-up will be necessary during this period [8]. Suture removal tends to occur earlier than it does in adults due to faster healing. Unlike in adults, all sutures should ultimately be removed to minimize the risk of suture-related infections. These children are often best managed by a team of specialists able to attend to amblyopia and patching as well as congenital and secondary glaucoma.

Outcomes

Pediatric corneal opacities are a heterogenous group of disorders, which makes it difficult to make firm statements about outcomes after penetrating keratoplasty. The prognosis after pediatric penetrating keratoplasty (PKP) depends on several factors, most important of which might be the presence of other ocular anomalies.

Table 1 summarizes selected series of pediatric PKP and highlights the heterogeneity of the patients and outcomes [1, 2, 4, 9-15]. Yang and coauthors found that corneal staphylomas and adhesions between the lens and cornea conferred a 7.93-fold increase in the rate of graft failure [5]. In reviewing the literature, Bhandari and coauthors noted a similar finding in Peters anomaly patients with the more severe, lens-involving form of Peters having significantly worse graft survival than type 1 patients, 14.2% compared to 87.5% [16]. Not surprisingly, several studies have indicated that concurrent surgical procedures, including lensectomy and vitrectomy, are also associated with poorer graft survival [11, 13, 16, 17]. A series reported by Low *et al.* also identified deep corneal neovascularization, active inflammation, preexisting glaucoma drainage device, and ocular surface disease as factors associated with poor graft survival [2].

Subsequent intraocular surgery, including cataract extraction with intraocular lens placement, has also been found to negatively affect graft survival [1]. In a study that involved 164 grafts, Dana and colleagues found that only 19% of 27 eyes that underwent repeat grafting remained clear. Of the six eyes that underwent a third graft, none maintained clarity, suggesting that prior grafting may be strongly associated with graft failure [1].

Age at the time of first surgery has been variably implicated as a prognostic factor [8, 10, 11, 15, 18]. With a mean age at first transplant of 42.4 months and 83% of children undergoing their first surgery after 12 months of age, Chang *et al.* noted graft failure rates at 1, 3, 5, and 10 years of 30%, 39%, 70%, and 77%, respectively [10]. They concluded that delaying PKP was not inferior to earlier surgery in children with Peters anomaly. Rao and coauthors determined that children with Peters anomaly younger than 6 months of age had a 2.2-fold higher risk of graft failure than did older children [8]. However, the poor outcomes in these studies may be less related to age at the time of surgery than to the underlying pathology.

While it is likely that delaying PKP increases the incidence and depth of deprivational amblyopia, a large study from Dana and associates found that amblyopia treatment (and not timing of surgery) was the only independently significant prognostic factor for postoperative visual improvement [1]. In a small study from Al-Rajhi and coauthors, children who presented with the delayed-onset form of CHED had better postoperative acuity and graft survival (92 vs 56.4%) than did those with the congenital form of CHED [19]. In one of the largest studies of PKP in children, Lowe *et al.* attributed the better outcomes attained by their adolescent patients to their primary indication for surgery, keratoconus [4]. None of their Peters anomaly patients saw 20/40 or better. The majority of these patients saw 20/240 or worse. For all other indications, a nearly equal number of children saw 20/120 or better (mostly with 20/40 or better vision) or 20/240 or worse. In the end, amblyopia was seen to have a major impact on visual outcome, affecting 8% of the total cohort with infants accounting for over 40% of the group.

Pediatric PKP and Glaucoma

It is common for glaucoma to develop or worsen after PKP due to synechial angle closure. The postoperative use of topical steroids can also play a role.

Table 1: Summary of selected studies of pediatric penetrating keratoplasty, demonstrating the varying indications and outcomes in such a heterogenic group of patients.

Series	Number of grafts	Indications for surgery	Age at time of surgery	Follow-up	Results and conclusions
Al-Ghamdi *et al*. [9]	165	78.8% congenital opacity (27% CHED), traumatic opacity 10.9%, acquired nontraumatic opacity 10.3%	Not documented	50 months for clear grafts, 6 months for failed grafts	44.2% of grafts remained clear, 55.8% failed. Graft survival, likelihood of ambulatory vision significantly higher in CHED than other indications. Worst prognosis was non-CHED congenital opacities
Chang *et al*. [10]	23	Peters anomaly	42.4 months	1–10 years	30% failure rate at 1 year, 39% at 3 years, 70% at 5 years, 77% 10 years. Mean final acuity in clear graft group was 1.883 LogMAR, failed graft group 2.767 LogMAR
Cowden [11]	66	33% congenital opacification, 30% corneal decompensation, 18.5% keratoconus, 18.5% failed grafts		1–10 years	32 clear grafts, 30 failed grafts, 4 enucleations. Acquired scars, corneal decompensation, older children had best prognosis. Perforations, active inflammation, or multiple abnormalities did worse
Dana *et al*. [1]	164	64% congenital opacities, 17% traumatic, 19% acquired nontraumatic	45.3 months	45 months	80% graft survival at 12 months, 67% at 24 months. When quantifiable, 33% had better than 20/200 vision. Vitrectomy/ lensectomy, regrafting associated with poor survival. Amblyopia treatment associated with better outcomes
Karadag *et al*. [12]	46	89.1% congenital opacity, 4.3% traumatic opacity, 6.5% acquired nontraumatic opacity	24.6 ± 39.9 months	36.4 ± 28.8 months	Mean graft survival time 45.2 ± 5.8 months (survival rate 75.7% at 1 year). 1-year graft survival was 51.9% and 90.7% with and without glaucoma, respectively. Concomitant vitrectomy was a poor prognostic factor. Age at surgery not associated with poorer survival
Low *et al*. [2]	105	22.9% corneal scar, 21.9% limbal dermoid, 15.2% anterior segment dysgenesis, 14.3% keratoconus	8.38 ± 5.63 years	34.6 ± 39.1 months	Penetrating keratoplasty survival was 92.8% at 1 year, 88.9% at 2–4 years, 80.9% 5–16 years. Deep corneal vascularization, preexisting glaucoma drainage implant, preexisting ocular surface disease associated with worse prognosis

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Lowe *et al*. [4]	765	Infant group: 44% Peters anomaly, 21% corneal deformity; 5–12-year age group: keratoconus 35%, scar or opacity 27%; adolescent group: keratoconus 86%			Graft survival 16 years postoperatively was 40% in infants compared to 70% in 5–12-year-old age group. 14 of 32 grafts done for Peters' anomaly failed. Graft survival reduced by history of failed graft, graft neovascularization, post-graft operative procedure, 1 or more rejection episodes. Best survival was seen in host-bed size 7.5–8.5 mm
Majander *et al*. [13]	42	Injury (27%), acquired nontraumatic opacity (23%), keratoconus (17%), corneal dystrophy (14%), congenital opacity (13%), aniridia (6%)	4.5 months to 16 years (median 12 years)		46% of grafts clear at 5 years. Simultaneous intraocular surgery at time of graft, corneal neovascularization, and regrafting were independent risk factors for failure. When none of these factors were present, survival was 84% at 5 years
Patel *et al*. [14]	65	Congenital (14%), acquired nontraumatic (66%), acquired traumatic (9%)	10.6 ± 4.3 years	1 year	82% survival at 1 year. Congenital indications had lower rates of survival and worse visual outcome
Stulting *et al*. [15]	152	Congenital (30%), acquired nontraumatic (20%), acquired traumatic (20%)	30 months in congenital group, 97 months for acquired nontraumatic, 98 months for acquired traumatic	30.1 months	Clarity rates at 1 year were 60% for congenital opacities, 70% for acquired traumatic opacities, and 73% for nontraumatic acquired opacities. Rates of 20/400 vision or better were 29%, 45%, and 67%, respectively. Preoperative corneal vascularization, persistent epithelial defects, and concomitant lensectomy/vitrectomy associated with poor survival

CHED congenital hereditary endothelial dystrophy

Glaucoma negatively affects graft survival in adults, and it appears that the same holds true in children. Huang *et al*. reported a 1-year graft survival rate of 32% in eyes with glaucoma compared to 70% in eyes without glaucoma [17]. Karadag and colleagues corroborated this finding in their series of 46 grafts in which 51.9% of patients with glaucoma had a clear graft at 1 year compared to 90% of patients with clear grafts in those without glaucoma [12]. The mechanism for this discrepancy is unclear. It is not solely attributable to endothelial failure secondary to raised IOP, as children with controlled glaucoma also had a higher likelihood of graft failure. In a series of 66 PKPs performed in 50 children, Cowden noted higher rates of failure in the setting of preoperative glaucoma. His recommendation that IOP be controlled prior to PKP [11] aligns with other studies that indicate that children who undergo combined procedures tend to have poorer long-term success rates.

Autorotational Penetrating Keratoplasty

For patients with smaller corneal opacities and 4–5 mm of clear peripheral cornea, a rotational graft fashioned from the patient's own cornea can be effective in producing a clear central visual axis. This technique is best employed in patients with static corneal scars whose opacities do not extend more than 10–20% (3–4 mm area of clear peripheral cornea present) of the corneal diameter beyond the corneal center [19]. Although fundamentally a PKP, autorotational grafts offer a large advantage over PKP in that there is little need for chronic, topical steroid use to suppress rejection. Therefore, autorotational grafts are most appropriate for patients at high risk for rejection. The aim of rotational autokeratoplasty is to achieve a clear central visual axis of approximately 3 mm, if possible, with rotation of the scar [20]. Those in resource-poor countries where there is scarce access to optical-grade corneal tissue may also benefit.

Children who undergo rotational grafts are at risk for suture-related problems and infections. These grafts seem to result in a significant increase in postoperative astigmatism when compared to traditional, centered, penetrating keratoplasty. Jonas and coauthors have suggested that planning for a clear central axis of 3–4 mm permits better postoperative acuity [20]. Patients with induced, irregular astigmatism will likely benefit postoperatively from rigid gas permeable contact lens wear, if tolerated. Consultations with pediatric ophthalmologists and optometrists are warranted with regard to irregular astigmatism, contact lens use, and amblyopia assessment and treatment in children.

Endothelial Keratoplasty

Endothelial keratoplasty is the procedure of choice for adults with endothelial dysfunction, but it has also been adapted to pediatric cases. Pediatric Descemet stripping endothelial keratoplasty (DSEK) was first reported in 2008 by Fernandez and Jeng and their colleagues [21, 22]. Since then, the indications for pediatric DSEK have expanded to include other causes of relatively isolated endothelial dysfunction, such as CHED, primary corneal graft failure, Descemet breaks caused by forceps delivery, and posterior polymorphous dystrophy (PPMD).

The advantages of DSEK over PKP are well documented and include early stabilization of refractive error (6 weeks versus 1 year for PKP) and a lower risk of traumatic wound dehiscence. For children in particular, DSEK requires fewer EUAs for suture removal (and fewer suture-related complications) as well as less induced astigmatism and, therefore, a reduced dependence on contact lenses.

Surgical Technique

In children, positive posterior pressure from the vitreous pushes the lens-iris diaphragm forward, further shallowing the AC of eyes that are usually small and often phakic. To mitigate the effect of posterior pressure, we employ many of the techniques discussed earlier with regard to pediatric PKP: use of a Honan balloon, administration of intravenous mannitol, and administration of pilocarpine (to protect the lens from inadvertent damage). In these cases, the cardinal sutures are often extremely difficult to place and care should be taken to observe for incarceration of iris within the wound.

In eyes with CHED, the view into the AC may be limited by severe edema. Removal of the epithelium often improves visualization. The application of topical glycerin may also be helpful.

The corneas of CHED patients are characterized by thickened Descemet membranes and few endothelial cells [23]. In these patients, Descemet membrane is firmly adherent to stroma and can be difficult to identify and remove. To avoid iatrogenic damage to the lens and iris, non-Descemet stripping endothelial keratoplasty (nDSEK) has been performed. Eliminating this step has not been shown to affect visual outcomes [24-26]. However, there is some indication that children who undergo nDSEK are subject to higher rates of postoperative graft dislocation [27]. Poor compliance with postoperative positioning may also have contributed to this finding.

Donor tissue can be inserted into the eye in a variety of ways. The method of tissue insertion must be compatible with a comparatively shallow AC in an eye that is often phakic. In pull-through techniques, where instruments reach across the eye, shifting incision sites to either side of the pupil can help to avoid reaching over the lens with instruments [23].

Poor cooperation with postoperative positioning is likely in young patients and may suggest a role for a larger air bubble with an inferior iridotomy. Postoperative assessments of graft adherence and IOP will also be difficult. Use of imaging to assess graft adherence may not be possible due to patient positioning and cooperation.

Outcomes

In the largest series of DSEK performed for CHED, Busin and coauthors showed visual outcomes that were superior to published results for PKP, with eight out of nine patients (88%) achieving visual acuities of 20/40 or better [23]. In a paired-eye analysis of five children with CHED [28], Ashar and colleagues directly compared DSEK to PKP. Despite the presence of residual anterior stromal haze in the corneas that underwent DSEK, the final visual acuities were comparable. The authors postulated that the haze was a result of differences in the ultrastructure of the stroma.

Advances in endothelial keratoplasty are promising. Gonnerman and colleagues have reported on the case of a 12-year-old boy who underwent Descemet membrane endothelial keratoplasty (DMEK) for corneal endothelial dysfunction secondary to Kearns-Sayre syndrome [29]. They observed an excellent anatomic result. The final visual acuity of 20/100 was achieved within 1 week after surgery and was thought to be limited by retinal dysfunction.

Endothelial Keratoplasty and Glaucoma

Glaucoma after endothelial keratoplasty can occur immediately after surgery as a result of pupillary block caused by a large air bubble. Alternatively, air that has travelled behind the iris can occlude the angle by pushing the iris forward. Both forms of air bubble-induced angle-closure glaucoma should be recognized early and treated promptly to minimize long-term effects.

Standard glaucoma surgeries can be performed in eyes that have undergone endothelial keratoplasty, namely, angle-based, trabeculectomy, and glaucoma drainage devices. If an angle-based surgery is planned, areas of iridocorneal adhesions and synechial angle closure should be mapped out, with careful consideration to the possible necessity of goniosynechialysis. Some types of iridocorneal adhesions after endothelial keratoplasty can be broken and the angle can be reopened, but frequently the anterior synechiae can reform again postoperatively, thereby undoing or negating any IOP reduction from the angle surgery. Glaucoma drainage devices can be performed before, concurrently, or after endothelial keratoplasty. In children who are pseudophakic, we prefer posterior chamber tube insertion to avoid ongoing damage to the corneal graft.

Lamellar Keratoplasty

Keratoconus is the most common indication for lamellar keratoplasty in the pediatric population. With a later age of onset, adolescents who undergo surgery are typically well outside of the amblyopic period. The limited nature of the disease also confers an excellent visual prognosis. If the stroma is successfully dissected from the Descemet membrane, surgery in this population should proceed as it does in an adult.

Keratoprosthesis

Keratoprosthesis surgery involves the implantation of an artificial cornea with a clear central visual zone. The Boston keratoprosthesis (KPro) is most commonly used. The 7.0 mm backplate version is approved for pediatric use.

Published indications for the KPro have included multiple graft failures, congenital glaucoma with corneal decompensation, keratitis-ichthyosiform-deafness syndrome, and congenital opacities [30]. In contrast to grafts, the KPro's rigid, clear optic allows for rapid visual improvement without concern for astigmatism, rejection, or tissue edema. However, the postoperative course can be challenging and fraught with unique complications. The most common of these are the formation of retroprosthetic membranes, which required surgical removal in 26% of children in

the largest published series to date with a mean follow-up of 9.7 months [30]. Crowding of the angle results in high incidence (up to 100% in some series) of glaucoma, which we prefer to proactively manage with Baerveldt glaucoma implants (Abbott Laboratories, Abbott Park IL, USA) [31]. Endophthalmitis with predictably devastating consequences has also been reported after pediatric keratoprosthesis [32]. The postoperative management of these patients has traditionally involved the use of a protective contact lens and prophylactic antibiotics. Although keratoprosthesis may have a role in the pediatric population, it should likely be considered as a last resort due to its significant complication profile. This view is supported by a more recent publication with a mean follow-up of 42 months where the authors recommended against the use of the KPro (type 1) in the pediatric population due to its significantly higher rate of complications, device failure, and worse visual outcomes than adults [33].

Optical Iridectomy

Optical iridectomy was first described in 1932 by Foster [34]. It is an alternative to penetrating keratoplasty in children who have a central corneal opacity with an adjacent clear area [34]. The goal of optical iridectomy, as with keratoplasty, is to provide a clear visual axis. It offers significant advantages over PKP, including no need for suture management and no risk from suture-related complications or rejection.

Optical iridectomy should be considered in cases of Peters anomaly, where central opacities are bordered by clear cornea and the lens is clear. From the experience of the authors, in Peters anomaly the peripheral clear areas of cornea can become slightly larger over weeks to years, especially if the IOP is normal range and the iris adhesions are swept from the posterior cornea (Figs. 1 and 2).

Surgical Technique

The site at which an optical iridectomy is made is important. Ideally the size of the peripheral clear zone will equal or surpass the diameter of a normal pupil (3 mm). Medial or temporal sites are preferred, as the upper eyelid tends to encroach on the superior quadrants.

A conjunctival peritomy is typically created in the area of the planned iridectomy so that a near limbal incision can be created. A relatively vertical, anteriorly placed (anterior surgical limbus) incision is constructed with the width of the incision being proportional to the size of the iridectomy desired. The verticality of the wound facilitates pulling of the iris up through the wound. Typically non-toothed forceps are used in a hand-over-hand technique to externalize the iris until the pupillary border is just outside of the wound. The iris is then excised with scissors as close as possible to the incision, as is done during trabeculectomy surgery. The AC is reformed using balanced salt solution. Making sure there are no iris fibers within the wound, the incision should be closed with a 10–0 nylon or polyglactin suture. Ophthalmic viscoelastic devices can be used but must be removed from the eye before concluding. It can be used during the procedure to stabilize the AC, especially if sweeping of the iridocorneal adhesions will be performed in an attempt to increase the clear peripheral cornea. Video 1 demonstrates optical iridectomy as

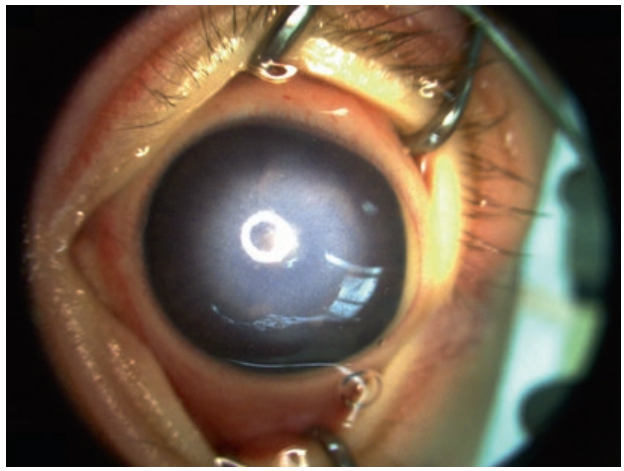

Fig. 1: Photo before surgery on 20-day-old infant with Peters anomaly and cloudy cornea. (Courtesy of Alana L. Grajewski, MD)

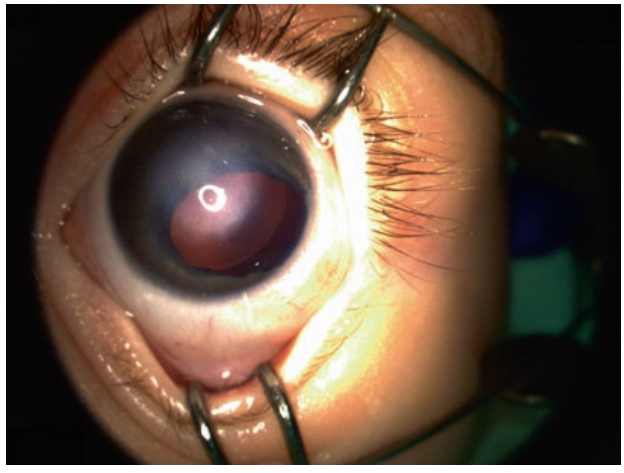

Fig. 2: Photo of the same patient after iridocorneal adhesions lysed, 360° trabeculotomy, and optical sector iridectomy. Notice the significant corneal clearing. (Courtesy of Alana L. Grajewski, MD)

described above. Video 2 shows a similar approach but combined with an ab externo 360° trabeculotomy, iridocorneal adhesion lysis, and temporal optical sector iridectomy, demonstrating a combined procedure.

Alternatively the procedure can be performed through smaller incisions accommodating an AC maintainer and a vitrector. The vitrectomy cutter is applied to the iris to create the iridectomy. Agarwal *et al.* described placing the vitrectomy cutter between the iris and lens with the cutter facing anteriorly to avoid cutting the lens [35].

Outcomes

In a series from Sundaresh and colleagues, 22 children with corneal opacities underwent optical iridectomy [36]. Preoperative acuity ranged from 6/60 to light perception. Postoperative best-corrected acuity was variable, ranging from 6/60 to 6/12, but improved in all but two patients.

Agarwal *et al.* published a series of 15 patients who underwent vitrectomy-facilitated iridectomy [35]. There were no intraoperative complications and no cases of cataract formation. The median best-corrected visual acuity improved from 1/60 to 6/24.

While less studied, optical iridectomy is an excellent option for children with corneal opacities. In good candidates, it offers visual results comparable to PKP with far fewer potential complications and easier postoperative care. It is unlikely to cause glaucoma, nor will it worsen preexisting glaucoma, as opposed to PKP, optical iridectomy has no suture related complications or concerns about rejection. Recovery is rapid and a clear visual axis is established much faster than after PKP, allowing retinoscopy and the initiation of amblyopia treatment soon after surgery.

If unsuccessful, an optical iridectomy does not preclude later PKP, if necessary. Since patients with type 2 Peters anomaly have a guarded prognosis with PKP, we prefer to attempt optical iridectomy if there is peripheral clear cornea. For these children, optical iridectomy also offers the advantage of potentially not having to disturb the central lens-cornea attachments.

Conclusion

Pediatric keratoplasty demands skill and postoperative vigilance. It can be humbling, yet immensely rewarding. The care of these patients is often complicated by glaucoma. Traditional penetrating keratoplasty in the pediatric population has given some ground to the same anatomically selective keratoplasty options being performed in adults. We believe that optical iridectomy should not be overlooked as an effective option with few potential complications for the treatment of children with corneal opacities.

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Laser/Light Application in Ophthalmology: Control of Intraocular Pressure

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Abstract

The term "glaucoma" refers to a group of disorders that share common phenotypes. There are over 20 different subtypes of glaucoma. The glaucomas are defined by a characteristic loss of retinal ganglion cell axons leading to a progressive optic neuropathy that is related to intraocular pressure (IOP). If untreated, glaucoma can cause visual disability and even blindness. Although elevated intraocular pressure (IOP) is no longer formally part of the definition, it is recognized as the major risk factor for progression of the disease.

Keywords: Glaucoma, Intraocular pressure, Laser applications, Laser iridotomy, Laser iridoplasty, Laser trabeculoplasty, Cyclophotocoagulation

- Glaucoma is a multifactorial optic neuropathy that results in progressive vision loss.
- The only treatable risk factor for glaucoma is intraocular pressure (IOP).
- Diagnosis of glaucoma requires measurement of IOP, assessment of vision loss by visual field testing, determination of corneal thickness, examination of the ocular fundus for signs of optic neuropathy such as cupping, and differentiation of open- and closed-angle glaucoma by gonioscopy.
- Treatment differs for closed-angle glaucoma (CAG) and open-angle glaucoma (OAG).
- Medications, laser procedures, minimally invasive glaucoma surgeries (MIGS) and incisional surgery are all critical to the management of glaucoma. The method of treating a particular patient depends on the severity as well as the type of glaucoma.

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- Laser iridotomy is the creation of a microscopic hole through the iris that serves as an alternate route of aqueous flow that bypasses the blockage at the pupil between the iris and the lens.
- Laser peripheral iridoplasty is a procedure that causes circumferential contraction of the iris away from the trabecular meshwork. Its main indication is CAG, specifically plateau iris syndrome, and is often attempted when laser iridotomy fails or is not indicated because the pathophysiology does not involve pupillary block.
- Laser trabeculoplasty is the application of laser to the trabecular meshwork with the intention of increasing aqueous outflow. Selective laser trabeculoplasty (SLT) is a technique that seems to be equally effective to argon laser trabeculoplasty (ALT). Advantages of SLT include a potential benefit from treatment following ALT, and theoretically its use for multiple treatments.
- Both ALT and SLT are effective first-line agents for primary open-angle glaucoma.
- Cyclophotocoagulation is the use of laser to destroy ciliary body tissue in order to decrease aqueous humor production and reduce intraocular pressure. Because of its higher rate of side effects and complications, it is usually reserved for glaucoma refractory to all other treatment options. There are four approaches to cyclophotocoagulation: contact transscleral, including transscleral cyclophotocoagulation and micropulse transscleral cyclophotocoagulation, noncontact transsceral, transpupillary, and endoscopic.
- There are a number of other applications for laser in glaucoma that are either adjuncts to or very similar to surgical procedures for glaucoma. These include laser sclerostomy, laser suture lysis, closure of cyclodialysis clefts, and goniophotocoagulation.

Introduction

- Glaucoma is a multifactorial optic neuropathy that is initially asymptomatic but can result in progressive visual field deficits.
- The prevalence of glaucoma increases with age, but can be seen at birth (i.e. congenital). Intraocular pressure (IOP) elevation is a major primary risk factor.
- The many types of glaucoma can be generally categorized into open-angle glaucoma (OAG) and closed-angle glaucoma (CAG).
- Diagnosis of glaucoma requires measurement of IOP and corneal thickness, optical coherence tomography of the retinal nerve fiber layer, ganglion cell analysis, assessment of vision loss by visual field testing, and examination of the ocular fundus for signs of optic neuropathy such as cupping, and differentiation of OAG and CAG by gonioscopy.
- The only clinically proven treatment for glaucoma is lowering the IOP. This can be accomplished with medications, laser surgery, and/or incisional surgery.
- Laser surgery has become increasingly popular as a treatment modality for glaucoma because the risks are favorable in comparison to incisional surgery. A number of lasers are used, the most common being argon, neodymium:yttrium-aluminum-garnet (Nd:YAG), and diode lasers.

Definition, Classification, and Epidemiology

The term "glaucoma" refers to a group of disorders that share common phenotypes. There are over 20 different subtypes of glaucoma. The glaucomas are defined by a characteristic loss of retinal ganglion cell axons leading to a progressive optic neuropathy that is related to intraocular pressure (IOP). If untreated, glaucoma can cause visual disability and even blindness. Although elevated intraocular pressure (IOP) is no longer formally part of the definition, it is recognized as the major risk factor, and only modifiable risk factor, for progression of the disease.

The subtypes of glaucoma are categorized into open-angle glaucoma (OAG) or closed-angle glaucoma (CAG). The "angle" refers to the iridocorneal (iris-cornea) junction at the periphery of the anterior chamber (Fig. 1). The angle is the site of drainage for aqueous humor. OAGs and CAGs are further subclassified into 'primary,' when the cause of the dysfunctional IOP is unknown, or 'secondary,' when the cause of the elevated IOP is the result of a known disease process. Furthermore, glaucomas are classified by their onset—acute or chronic. The most common form of glaucoma in the United States is primary open-angle glaucoma (POAG).

With approximately three million Americans affected by glaucoma it is the second leading cause of blindness in the United States. Although it affects people of all ages, it is six times more common in those over 60 years of age than those 40 years of age. Annual medical costs for glaucoma services to glaucomatous patients and glaucoma suspects totals over 2.86 billion dollars.

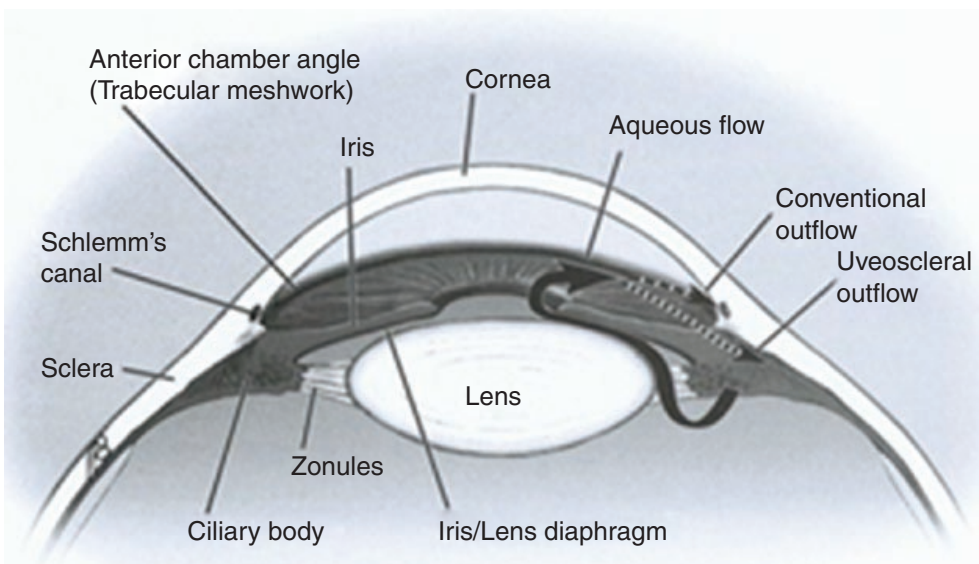


Fig. 1: Anterior segment anatomy and physiology.

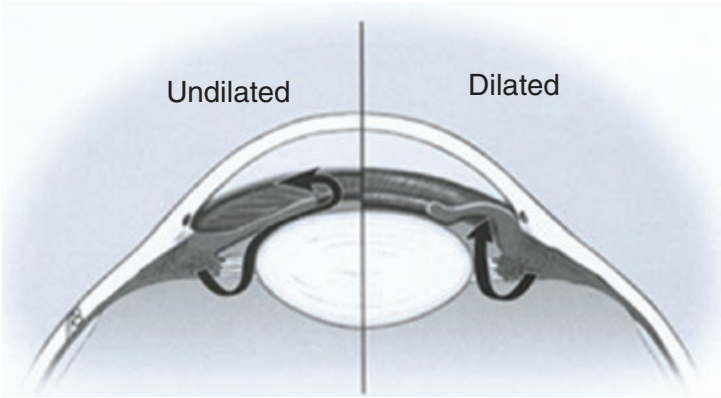


Fig. 2: Close-angle glaucoma due to pupillary block.

Aqueous Physiology and Pathophysiology

Aqueous humor is a clear fluid that circulates in the anterior chamber of the eye to provide nutrients and remove metabolic waste from the avascular structures of the eye—namely the lens, cornea, and trabecular meshwork. The balance of aqueous secretion and drainage determines the IOP. Aqueous humor is produced by the ciliary processes, which are located behind the iris, through active secretion, ultrafiltration, and diffusion. Aqueous circulates within the posterior chamber, travels through the pupil, and exits the eye through the angle via one of two pathways (Fig. 1): (1) the conventional pathway through the trabecular meshwork, canal of Schlemm, intrascleral channels, and then episcleral and conjunctival veins; or (2) the uveoscleral pathway, through the ciliary body face, choroidal vasculature, and vortex or scleral veins. The conventional pathway is responsible for the majority of outflow, especially in older adults. CAG results from physical obstruction of these drainage tissues by approximation of the iris and cornea (Fig. 2). OAG occurs when aqueous drainage is impaired by increased resistance to aqueous drainage that is intrinsic to the outflow pathways (Fig. 3). Although it is possible that overproduction of aqueous humor could lead to an elevated IOP, all studies have shown that the pathophysiology is poor aqueous drainage. The average IOP is approximately 16 mmHg (2 mmHg standard deviation). An elevated IOP is defined as a value that is 2SD above the average (i.e., >20 mmHg). There is a form of OAG, named "low-" or "normal-tension glaucoma," in which damage occurs within the average range (11–21 mmHg). Although IOP reduction is often effective treatment for this type of glaucoma, other etiologic factors such as vasospasm or ischemia are thought to have a larger role in the pathophysiology.

Symptoms

Vision loss from chronic glaucoma is usually painless and slowly progressive. Peripheral vision is usually affected first, and the deficits may be asymmetric. This results in delays in realization of vision loss.

Acute angle closure and a few secondary glaucomas present with symptoms, most commonly a painful red eye, blurred central vision, and rapid progression of visual loss. The presence of non-visually related symptoms are due to the rapid change in IOP causing immediate ischemic compromise of several ocular tissues—principally, the cornea and optic nerve.

Diagnosis

Diagnosis of glaucoma requires a complete history and ocular examination including measurement of IOP, determination of corneal thickness, assessment of the anterior chamber angle by gonioscopy, quantification of vision loss by visual field testing, and examination of the ocular fundus for signs of optic neuropathy such as cupping (Fig. 4). Gonioscopy is examination of the

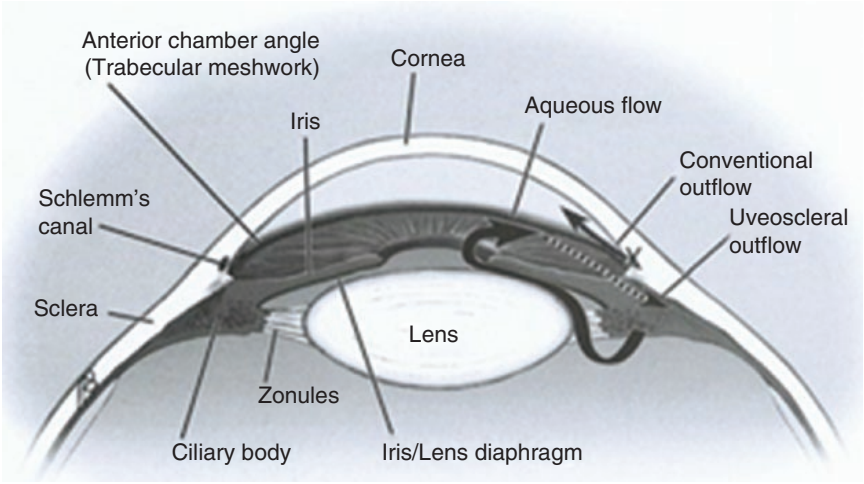


Fig. 3: Open-angle glaucoma.

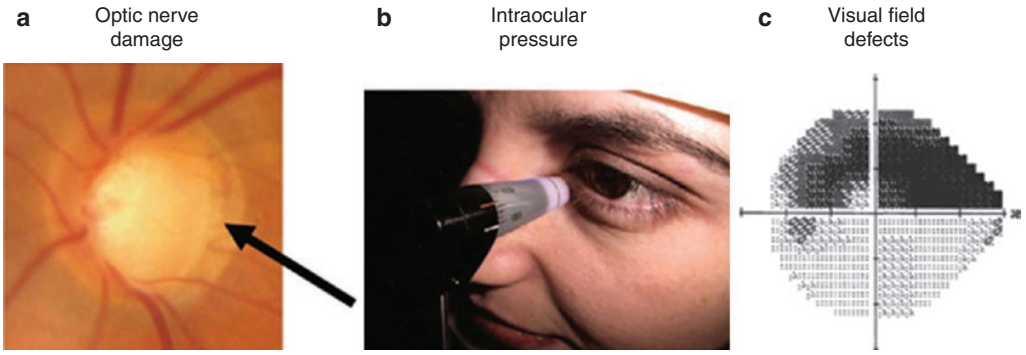


Fig. 4: Clinical triad of glaucoma, (**a**) optic nerve damage, (**b**) intraocular pressure, (**c**) visual field defects.

iridocorneal angle with a slit-lamp and contact lens containing mirrors to visualize the angle. Measurement of an elevated IOP identifies a significant risk-factor but is neither necessary nor sufficient for the diagnosis of glaucoma. Visual field defects and optic nerve defects characteristic of glaucoma are strong support for the diagnosis but other causes of optic neuropathy such as optic neuritis need to be excluded.

Treatment

To date, lowering IOP is the only clinically proven treatment for the glaucomas. Glaucoma suspects may also be treated depending on the presence of high risk characteristics and the individual risk aversion of the patient. The treatment approach differs between CAG and OAG. CAG treatment requires laser or incisional surgery to bypass the mechanical blockage. OAG can be treated with topical medications, laser, and/or incisional surgery. Topical medication may decrease aqueous production or increase aqueous drainage. Laser trabeculoplasty attempts to enhance the drainage function of the trabecular meshwork. Laser peripheral iridotomy creates a secondary pathway to allow aqueous to bypass a potential blockage; in doing so, equalization of the pressure gradient between the spaces anterior and posterior to the iris often allows the angle to deepen. Laser iridoplasty directly alters the angle anatomy by moving the iris away from the drainage structures. Glaucoma refractory to the above treatments may require cyclodestructive procedures to destroy the ciliary body and decrease aqueous production. Incisional operations such as trabeculectomy and glaucoma drainage implant devices create a new pathway to drain aqueous from the anterior chamber to the subconjunctival space.

General Comments Regarding Lasers in Glaucoma

Many lasers are used in glaucoma management. Their use has increased because their less invasive nature and generally lower rates of complications appeal to surgeons. The most commonly used lasers are argon diode and neodymium:yttrium-aluminum-garnet (Nd:YAG). The argon laser (488–514 nm) has a thermal effect on tissues, which either results in coagulation or vaporization depending upon the power settings used. The diode laser (810 nm) also has a photocoagulative effect. The Nd:YAG laser (1064 nm) has a coagulative effect when used in a continuous-wave mode. The short-pulsed q-switched Nd:YAG has a photodisruptive effect on tissues, which has an explosive effect. Other lasers have a photoablative effect that results in excision of tissue without any damage to the adjacent tissue. Photoablation has more applications for the cornea, but is also used in glaucoma. Besides the type of effect observed on tissues, different lasers may be used because they specifically target a certain type of tissue or because they have a desirable depth of penetration.

Laser Iridotomy

Iridotomy is the creation of a microscopic hole through the iris that provides an alternate route for aqueous to enter the anterior chamber (Fig. 5). Laser iridotomy is preferred over surgical

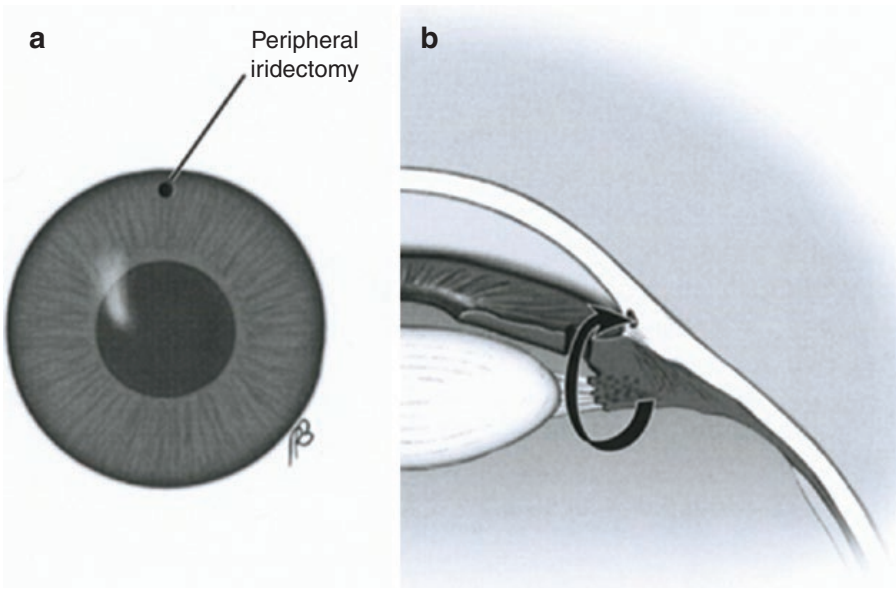


Fig. 5: Laser peripheral iridotomy, (**a**) shows clinical appearance of an iridotomy at the 12 o'clock position of the iris; (**b**) shows a secondary pathway to allow aqueous to bypass a potential blockage.

iridotomy because it is safer, equally effective, and preferred by patients; however, surgical iridectomy serves as second-line treatment if laser iridotomy is unable to be performed (e.g. a patient who is unable to maintain position in the laser). The popularity of this established technological advancement is evidenced by utilization statistics. Although the total number of laser iridotomies and surgical iridectomies has increased in proportion to the aging population, the ratio of laser iridotomies to surgical iridectomies performed has increased from 15:1 in 1995 to 52:1 in 2004. The procedure is treatment for all forms of CAG that involve pupillary block. Patients with easily occludable angles may also require the procedure.

Indications and Contraindications

Indications

- Closed-angle glaucoma with pupillary block
- Narrow angles with signs of glaucoma
- Narrow angles with positive provocative tests

Contraindications

- Opacified cornea
- Uncooperative patient who is unable to maintain position for the procedure

The primary indication for laser iridotomy is to relieve pupillary block that may progress to acute angle closure glaucoma or CAG. Mechanistically, pupillary block is caused by an

increased resistance to aqueous flow through the pupil because of anatomic obstruction of the pupil by the lens or another anterior or posterior structure. Increased resistance leads to a pressure differential between the anterior and posterior chambers, which results in anterior bowing of the peripheral iris over the trabecular meshwork. Laser iridotomy is indicated if pupillary block has caused angle-closure or is in imminent threat of causing angle-closure. Angle-closure glaucoma may be acute, intermittent, or chronic; and all are indications for laser iridotomy. If narrow angles are identified, then the risks and benefits of treatment should be considered. For example, treatment would be indicated if there are signs of previous attacks or if the fellow eye has CAG. Additionally, patients with narrow angles can undergo tests to provoke angle-closure such as administration of a mydriatic agent, exposure to dark, or placement in the prone position. These tests may cause IOP elevation, and therefore may serve as an indication for treatment. Finally, in eyes where the clinician feels the angle is potentially occludable, laser iridotomy is indicated.

Specific causes of pupillary block include phacomorphic glaucoma (glaucoma caused by an excessively large lens), a dislocated lens, anterior protrusion of the vitreous face, occlusion by an artificial (pseudophakic) lens in the anterior chamber, posterior synechiae (adhesions of the central iris to the lens usually as a result of inflammation), or extreme miosis. This is in contrast to CAG without pupillary block such as vascular or inflammatory diseases that may cause peripheral anterior synechiae (adhesions of the peripheral iris to the cornea). However, patients with CAG without pupillary block may also be treated with laser iridotomy because some degree of pupillary block may be secondarily involved. Nanophthalmic (small eye) eyes frequently develop CAG because they have very small eyes relative to the size of their natural crystalline lens. Pupillary block related to an enlarged lens may be a contributing factor in these cases. The same reasoning may extend to patients with primarily an OAG. If a pupillary block component is suspected, the benefits of eliminating such a factor may outweigh the risks.

Contraindications to laser iridotomy are few and primarily include findings that increase the risk of complications from the procedure. Corneal burns may result from either (1) use of laser through an opacified cornea, or (2) use of laser in an eye with an extremely narrow angle. There is also a risk of increased IOP following the laser procedure, and to avoid that, usually apraclonidine or brimonidine are instilled prior to the procedure, and the IOP is checked 30 min to 2 h following the procedure. Acute CAG with pupillary block is ultimately treated with laser iridotomy; however, the procedure should ideally be done following the acute phase after the eye's inflammation has had a chance to subside and the cornea has cleared. However, this is not always possible and laser iridotomy is still indicated if the cornea is clear enough to perform the procedure. Topical and systemic anti-glaucoma medications can acutely lower the pressure.

Techniques

- Topical anesthetic and miotic medications are applied preoperatively.
- The argon, diode, or Nd:YAG laser is used to apply laser to the peripheral iris through a focusing iridotomy lens.

- The photocoagulative effect of argon laser is dependent upon pigmentation; therefore, techniques vary for irises of different colors.
- The Nd:YAG laser is photodisruptive and therefore does not dependent upon tissue pigmentation.
- IOP-lowering medications are used perioperatively. Corticosteroids may be temporarily used postoperatively to control inflammation.

Pre-operative Management

Topical anesthetics are sufficient to provide anesthesia. A miotic agent is applied topically to thin the iris and pull it away from the angle. This allows for easier penetration and minimizes corneal endothelial injury. An Abraham iridotomy lens will help stabilize the eye, keep the eyelids open, provide a magnified view, and minimize corneal burns by acting as a heat sink and increasing the power density of the laser at the iris. The iridotomy site should be made in a relatively thin region of the iris, or in an iris crypt.

Description of the Technique

Q-switched Nd:YAG laser, the argon laser, and diode lasers can be effectively used for iridotomy. This review will focus on q-switched Nd:YAG and the argon laser because these two are most commonly used in practice. Each has unique properties that affect the selection of laser type and use of the laser for different colored irises. The q-switched Nd:YAG creates the iridotomy by photodisruption, an optical break-down of molecules into their component ions resulting in explosive disruption and essentially excision of tissue. One advantage of photodisruption is that it does not depend upon tissue absorptivity and therefore is equally effective for different colored irises. One disadvantage of photodisruption is its lack of coagulative effect. On the other hand, argon laser has a thermal effect and therefore results in photocoagulation or photovaporization, the specific effect depending upon the duration of exposure and energy density of the laser used. The thermal effect is beneficial in that it can provide coagulation. The disadvantage of argon laser is its dependence upon absorption by tissue pigments. Argon laser is ideal for medium brown irises, but may have a charring effect on dark brown irises and poor absorption in blue irises. As a result of the above differences, q-switched Nd:YAG laser is simpler to use, and argon laser iridotomy techniques vary for irises of different color. Specific descriptions of the techniques follow.

Q-switched Nd:YAG lasers have a wavelength of approximately 1064 nm and can be used at a range of power densities depending upon the number of bursts. Typically, there are 1–3 pulses per burst with each burst delivering 1–10 mJ. The focal point of the laser should be within the iris stroma to avoid corneal damage from the explosive effect. The iridotomy site should be at least 0.1 mm.

The effects of argon laser vary for tissues with different levels of pigmentation, therefore different techniques have been employed. The darker the iris color (i.e. greater amount of melanin

in the stroma), the greater the absorption of the laser energy. Thus, the darker colored iris will require less energy to achieve the same results. Typical settings range between 600 and 1000 mW with a spot size of 50 μm with a duration of 0.02–0.05 s. The pit that is initially formed can be enlarged to a diameter of 0.2 mm with 30–70 pulses. Light blue irises have little pigment anteriorly (in the stroma) but the same iris pigment epithelium as brown irises posteriorly. As a result, the argon laser may penetrate the iris pigment epithelium but leave the stroma intact. A variety of creative techniques can be used to avoid this. One approach is to use longer exposures that generate heat that transmits to the stroma and creates a bubble. Laser entering through the apex of the bubble will repeatedly reflect within the bubble and more effectively ablate the stroma.

Although the first laser iridotomies were performed using the argon laser alone, in the modern era, either the Nd:YAG laser will be used alone or a combination an argon laser. Use of the two lasers minimizes the risk of hyphema and total energy delivered. Argon laser is used to for photocoagulation to increase tissue density and minimize the risk of bleeding. The Nd:YAG laser is then used for photodisruption.

Post-operative Management

Intraocular pressure is generally checked 30–120 min after the procedure. Apraclonidine or brimonidine are given perioperatively to mitigate elevations in pressure. Topical steroids may be given for several days post-operatively to control inflammation. If the angle remains narrow, laser peripheral iridoplasty may be considered, which will be described in the next section.

Adverse Events

Adverse events	Management
Iritis	Corticosteroids if more than mild
Increased intraocular pressure	Topical medications (α-adrenergic agonists, β-blockers, osmotic agents, or carbonic anhydrase inhibitors)
Cataract	No treatment
Hyphema	Pressure with contact lens for hemostasis
Corneal damage	No treatment
Failure to perforate	Retreatment after pigment cloud has dispersed
Late closure	Retreatment
Retinal burn	Avoid with standard precautions

Most side effects of laser iridotomy are often minimal and self-limited. *Iritis* occurs and is treated by post-operative corticosteroids or topical non-steroidal anti-inflammatory treatment. Persistent iritis may be related to a preexisting uveitis. *Intraocular pressure elevations* are common 1–2 h after the procedure but are usually self-limited and resolve within 24 h. Topical medications to lower IOP can be used to limit IOP elevation. Filtering surgery may be required if more severe and sustained elevations occur, more commonly in eyes with a component of OAG.

Most complications can be avoided with appropriate precautions and careful technique. *Cataract* may occur and is more easily formed by the q-switched Nd:YAG laser if it is applied to an open iridotomy site because the effect of the laser does not depend upon pigmentation. *Hyphema* is also much more common with q-switched Nd:YAG laser because it does not have a coagulative effect. Applying pressure with the contact lens usually provides sufficient homeostasis. *Corneal damage* may occur from either argon or Nd:YAG laser iridotomy. If the iridocorneal angle is closed or extremely narrow, the endothelium may be affected. No treatment is generally required, but if the iridotomy is incomplete, a new site may be selected. *Closure* of the iridotomy site may occur if the site is small or if there is an underlying uveitis.

Argon Laser Peripheral Iridoplasty

Argon laser peripheral iridoplasty is the delivery of thermal energy that causes circumferential contraction of the iris away from the trabecular meshwork. Laser iridoplasty is a treatment for certain closed-angle glaucomas, and is often attempted when laser iridotomy fails or is not indicated because the pathophysiology does not involve pupillary block.

Indications and Contraindications

Indications

- Closed-angle glaucoma without pupillary block (e.g. plateau iris syndrome)
- Preceding laser iridotomy for CAG with pupillary block and inflammation
- Preceding laser trabeculoplasty for focal areas of angle narrowing

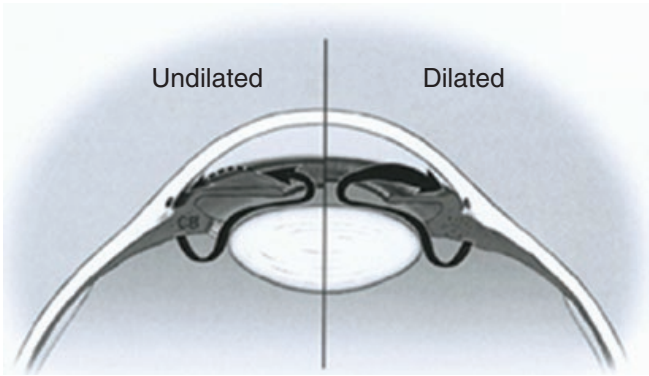
Contraindications

- Severe corneal edema
- Peripheral anterior synechiae
- Corneal opacities—treatment through the opacity is not recommended

Closed-angle glaucoma without pupillary block is the major indication for laser peripheral iridoplasty. Plateau iris, an anatomic variant in which the posterior chamber structures are positioned more anteriorly resulting in an anteriorly displaced peripheral iris, is a configuration which can lead to closed-angle glaucoma without pupillary block (Fig. 6). Similarly, any posterior chamber or segment structure can cause the iris to be anteriorly displaced. This includes nanophthalmos, which results in a crowded anterior chamber, which predisposes patients to CAG.

Additionally, patients with closed or narrow angles that have laser iridotomy performed but continue to have narrow angles may be considered for laser iridoplasty. Laser peripheral iridoplasty may precede laser iridotomy in cases of acute CAG when the cornea is edematous and medications are not sufficient to control the attack. The effect of the iridoplasty lasts long enough for the corneal edema and anterior chamber inflammation to subside so that laser iridotomy can be performed under more optimal conditions.

Fig. 6: Plateau iris.



Argon laser peripheral iridoplasty may also be used prior to laser trabeculoplasty in patients with open-angle glaucoma. It is indicated when patients have focal areas of angle narrowing, which can be opened to permit laser trabeculoplasty.

Contraindications include severe corneal edema and peripheral anterior synechiae. Laser peripheral iridoplasty will generally not open an angle that is scarred closed by peripheral anterior synechiae. Corneal opacities can also be contraindications; however, opacities that cover only a portion of the peripheral iris—such as pterygium—still allow for treatment of the remainder of the iris.

Techniques

- Topical anesthetic and miotic medications are applied preoperatively.
- Argon laser is used to create a photocoagulative effect to large areas of the peripheral iris circumferentially.
- Gonioscopy is used to ensure that the angle has deepened.
- IOP-lowering medications are used perioperatively. Corticosteroids are used postoperatively for inflammation.

Pre-operative Management

Topical anesthetic is sufficient to provide anesthesia. Pilocarpine is applied topically to constrict the pupil which will have the effect of thinning the iris tissue by virtue of spreading it over a larger area (i.e. place the iris under stretch). Apraclonidine or brimonidine is usually given before and after the procedure to reduce the risk of intraocular pressure elevations.

Description of the Technique

The argon laser is used for its coagulative effect to form contraction burns. The spot size is large (500 μm) with low power (200–400 mW) and long duration of delivery (0.5 s). The beam is aimed at the most peripheral iris to apply 20–24 spots are placed circumferentially, avoiding large radial vessels.

Post-operative Management

The peripheral anterior chamber should deepen immediately; therefore gonioscopy can be performed to confirm that the procedure was successful. Apraclonidine and topical steroid are given postoperatively to reduce the risk of intraocular pressure elevations and control inflammation. Topical anti-inflammatory treatment is continued for 3–5 days.

Adverse Events

- Side effects and complications are similar to those of laser iridotomy.
- Additionally, there is the risk of iris necrosis, which can be avoided with appropriate spacing of the laser spots.

Side Effects/Complications: Prevention and Treatment of Side Effects/Complications

Side effects include intraocular pressure elevations and inflammation. Their treatment is described above. Complications are similar to those of laser iridotomy. Additionally, *iris necrosis* may occur if the spots are placed too closely together. Spots should be spaced with 1–2 spot diameters apart.

Laser Trabeculoplasty

Laser trabeculoplasty is the application of laser to the trabecular meshwork with the intention of increasing aqueous outflow to reduce IOP in patients with OAG. It can be used as first line therapy, or after failed medical management. L laser trabeculoplasty can be offered as the initial treatment for patients with open-angle glaucoma as an alternative to medications in patients with early stage disease or in patients who are unable or prefer not to use topical medications.

The mechanism of increased aqueous outflow after laser trabeculoplasty is not well-understood. Three theories have been proposed to explain the efficacy of laser trabeculoplasty: mechanical, biologic, and cellular repopulation theories. The mechanical theory suggests that a thermal burn to the collagen results in local tissue contraction with mechanical stretch to the adjacent tissue. Presumably, the adjacent areas would have increased aqueous outflow. The biologic theory suggests that thermal energy stimulates trabecular endothelial cells to release matrix metalloproteinase enzymes, and recruits macrophages, which results in trabecular meshwork remodeling. The theory proposes that the resultant remodeling of extracellular matrix will increase aqueous outflow. The repopulation theory suggests that the laser energy stimulates trabecular endothelial cell division with downstream effects resulting in increased aqueous outflow.

The mechanisms above are potential explanations for the effect of laser trabeculoplasty performed with argon and diode lasers, techniques that were first proposed by Wise and Witter in 1979. Both of these types of lasers are equally effective in the long term (5 years); however, there are differing results in the short term (3 months), some suggesting a slight benefit to argon laser trabeculoplasty (ALT). ALT may also be technically easier since the end-point of laser application is more evident. A potential disadvantage of ALT is more post-laser pain and inflammation.

In 2001, a technique called selective laser trabeculoplasty (SLT) was approved by the Food and Drug Administration. SLT uses a non-coagulative double frequency Nd:YAG laser to selectively target pigmented trabecular meshwork cells without causing a coagulative effect. The absence of thermal burns suggests that the mechanical theory does not play a role in SLT.

More recently, a new technique called MicroPulse laser trabeculoplasty (MLT) has also come into use for OAG. This laser uses a 15% duty cycle rather than continuous laser wave (100% duty cycle). See "Future Directions" section for further discussion regarding MLT.

Laser trabeculoplasty has gained popularity in recent years. The number of laser trabeculoplasties performed decreased by 57% between 1995 and 2001 (perhaps as a result of the release of several new classes of topical antiglaucoma medications during this time), and then doubled from 2001 to 2004.

Indications and Contraindications

Indications

- Insufficient IOP control with medication
- Poor compliance with medical management
- Adult open-angle glaucomas (with the exclusion of uveitic glaucomas)

Contraindications

- Poor visualization of the trabecular meshwork (e.g. Angle closure, peripheral anterior synechiae)
- Hazy media
- Corneal edema
- Uveitic glaucoma
- Juvenile glaucoma
- Patients younger than 35 years unless their OAG is due to pigment dispersion syndrome

Relative Contraindications

- Patients with intraocular pressures >35 mmHg
- ALT should be withheld in patients with very narrow angles due to the risk of peripheral anterior synechiae; SLT may be used in these situations

The general approach to managing primary and secondary open angle glaucomas was previously to use topical anti-glaucoma medications, such as topical prostaglandin analogs, beta-adrenergic antagonists, carbonic anhydrase is treated initially, and if this fails to control IOP, the ophthalmologist may choose to treat the other 180°.

Smaller prospective randomized controlled studies have shown SLT is at least as effective as modern topical antiglaucoma medications. SLT may have a larger role than ALT because

mechanistically it does not cause as much tissue destruction. Hence, theoretically, SLT treatments can follow ALT treatments or SLT can be used exclusively for multiple treatments. The former has been investigated in a few studies, and results suggest that SLT is effective following both successful and failed ALT treatment. Typically, 180–360° of trabecular meshwork is treated.

Laser trabeculoplasty should not be performed if laser cannot be applied to the trabecular meshwork safely. This includes corneal edema or any corneal opacities, hazy aqueous, or angle closure including peripheral anterior synechiae. Uveitic glaucoma is also a contraindication, as the laser trabeculoplasty is ineffective and may aggravate an existing inflammatory state.

Techniques

Inhibitors, and selective alpha2-adrenergic agonists, as first-line treatments, and laser trabeculoplasty in patients that remain inadequately controlled. However, laser trabeculoplasty is now being used as first line therapy as an equally effective alternative to medical therapy due to its effective IOP lowering and repeatability. Incisional filtering surgical procedures are generally used when all other measures have not successfully controlled the eye pressure. Studies suggest that ALT has similar efficacy as first-line treatment compared with the medications available at that time. The Glaucoma Laser Trial was a randomized control trial that followed patients treated with medication or ALT for 7 years. The final IOP in the ALT group was 1.2 mmHg lower than the medically treated group, and their visual fields were slightly better concluding that ALT is at least as effective as medication as a first-line treatment. A study by Bovell which compared SLT to ALT found that SLT reduced IOP by over 6.5 mmHg at a 3 year follow-up, and that the efficacy of SLT was equivalent to ALT. A study done by Realini in patients from St. Lucia showed a mean 7.3–8.3 mmHg drop in IOP after patients were washed out from medical therapy. A Cochrane review concluded that laser trabeculoplasty of 180° of trabecular meshwork controls IOP at 6 months and 2 years better than the medications used before the 1990s.

Pre-operative Management

Topical anesthetic is sufficient to provide anesthesia. Apraclonidine or brimonidine is usually given before the procedure to reduce the risk of intraocular pressure elevations.

Description of the Technique

A mirrored contact lens such as the Goldmann gonioscopy lens, Ritch lens, or Latina lens is used to stabilize the eye and visualize the angle at the slit lamp (Fig. 7). The laser beam is focused at the junction of the posterior trabecular pigment band and the anterior meshwork (Fig. 8). The specifics of the laser application depend on the type of laser being used.

- Topical anesthetic and miotic medications are applied preoperatively.

- Argon or diode laser is typically applied to 180° of the trabecular meshwork circumference with power settings adjusted to produce minimal blanching.
- Selective laser trabeculoplasty is typically applied to 180–360° of the trabecular meshwork circumference.
- Alpha agonists are used perioperatively. IOP should be rechecked perioperatively, and again after 1–3 weeks to determine the success of the procedure.

ALT and DLT generally require 40–50 spots over 180°. Power settings for ALT range from 400 to 1200 mW with adjustment to produce blanching and occasional gas bubble formation. DLT power settings similarly range from 570 to 850 mW but blanching is usually less noticeable. As a result, the surgeon must be more attentive with regards to which portions of the meshwork have been treated. The spot size with ALT is typically 50 μm with 0.1 s exposures. DLT spot sizes range from 75 to 100 μm with exposures ranging from 0.1 to 0.5 s. With both ALT and DLT, one should try to space the application spots by 1–2 application spot widths apart.

SLT requires a similar technique to ALT and DLT but the 532 nm frequency-doubled q-switched Nd:YAG laser is used with very different parameters. Seventy to 120 spots are applied over 360°. Laser may be applied to 90°, 180°, or 360° of the meshwork, with guidelines still in

Fig. 7: Patient position at slit lamp-mounted laser.

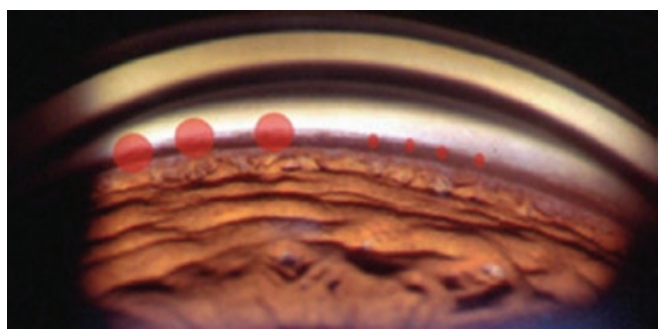


Fig. 8: Approximate sizes and locations of SLT (*left*) and ALT (*right*) laser spots.

evolution; in general, it is recommended to treat 180–360° with most practitioners treating 360°. Only a small fraction of the energy applied in ALT is needed for SLT treatment. The duration of exposure is 3 ns. The power setting is on the same order of magnitude; however, because of the short duration of exposure the energy applied is 0.5–1.2 mJ versus approximately 100 mJ for ALT. Moreover, the difference in energy density is even greater because the spot size used for SLT treatments is 400 μm (0.5 mJ/μm^2 for ALT versus 10–5 mJ/μm^2 for SLT). The application spots should be spaced approximately 1–2 application spot widths apart.

Post-operative Management

Glaucoma medications can be given post-operatively to reduce IOP elevations. IOP should be checked 30–120 min after the procedure and 1–2 weeks later. IOP reductions can be expected 4–6 weeks later, but can be seen as early as 2 weeks. If IOP reduction is inadequate, the remaining meshwork may be treated (for ALT and DLT or if only 180° of the meshwork were treated by SLT). There is no consensus on the treatment of post-operative inflammation following laser trabeculoplasty.

Adverse Events

- Transient and persistent IOP elevations may occur.
- Hyphema is rare and self-limited.
- Appropriate power settings and treatment locations will help avoid peripheral anterior synechiae.
- Mild iritis is common after ALT.

Side Effects/Complications : Prevention and Treatment of Side Effects/Complications

Transient as well as sustained *IOP elevations* may occur. *Hyphema* is rare and self-limited but can be treated by applying pressure to the globe with the goniolens or by photocoagulating with argon laser. *Peripheral anterior synechiae* are more common when areas posterior to the trabecular meshwork are treated. This should be avoided, and only the minimum power required to cause blanching should be used. Mild *iritis* is common after laser trabeculoplasty. Topical anti-inflammatories can control the inflammation, but is used judiciously as it can reduce the efficacy of the procedure. Laser trabeculoplasty is generally not helpful in patients with uveitic glaucoma and therefore should not be performed in most circumstances.

Cyclophotocoagulation

Cyclophotocoagulation is the use of laser energy to destroy ciliary body tissue usually in cases of refractory glaucoma. In contrast to all other procedures that have been described, the mechanism of IOP reduction for this procedure is a decrease in aqueous humor production, although some

newer cyclophotocoagulation lasers may also increase outflow as well, which will be discussed later in the chapter. There are four approaches to cyclophotocoagulation: contact transscleral, noncontact transsceral, transpupillary, and endoscopic. Contact transscleral cyclophotocoagulation can be further separated into a traditional transscleral cyclophotocoagulation diode (TSCPC) and a micropulse transslceral cyclophotocoagulation diode (MPCPC) Cyclodestructive procedures were traditionally used as a last resort for refractory glaucomas because of their relatively high rates of complications and side effects. However, with new advances, certain types of cyclophotocogulation procedures, such as MPCPC and endoscopic cyclophotocoagualation (ECP), are being used more commonly. These newer procedures have gained popularity over other cyclodestructive procedures such as cyclocryo-destruction because of its relatively lower rate of complications and side effects. The developmental trend with cyclophotocoagulation has been the use of lower power due to improved targeting; the lower power settings have improved the safety profile of these laser procedures.

Indications and Contraindications

Indications

- Refractory glaucomas
- Open-angle glaucoma in which other treatments are contraindicated (e.g. neovascular glaucoma)
- Glaucomatous patients with low visual potential or blind, painful eyes
- Poor candidates for incisional surgery

Relative Contraindications

- Glaucomatous patients with high visual potential, for transscleral cyclophotocoagulation

Traditional transscleral cyclophotocoagulation is usually for refractory glaucoma or glaucoma in which other treatments are contraindicated. Patients are already on maximal medication therapy with inadequate control. Filtering procedures have failed or may be high risk for the patient because of aphakic glaucoma, neovascular glaucoma, or perhaps glaucoma after penetrating keratoplasty. A less invasive procedure is also more appropriate for patients with low visual potential due to a decrease in post-operative procedures and visits. Cyclophotocoagulation can also be a procedure of choice for eyes that have very distorted anatomy or eyes with an opaque cornea. ECP was traditionally used for refractory glaucoma, however, is recently being used in less advanced glaucoma cases with cataract surgery, and can help to reduce eye-drop use. A study done by Roberts included 91 eyes in 73 patients who underwent ECP in combination with cataract extraction. The mean number of medications decreased from 1.88 ± 1.07 at baseline to 1.36 ± 1.18 at 1 month, 1.17 ± 1.14 at 3 months, 1.36 ± 1.19 at 6 months, and 1.48 ± 1.27 at 1 year. ECP allows for direct visualization of the ciliary processes allowing for the surgeon to titrate the amount of

energy used. This leads to less complications, and compared to transscleral cyclophotocoagulation, ECP has less risks of hypotony, phthisis inflammation and can spare the conjunctiva and sclera in case of need for incisional glaucoma procedures.

Techniques

- Retrobulbar anesthesia is administered preoperatively if the procedure is done in the minor room. In an operating room setting, intravenous sedation can be used.
- Nd:YAG and diode lasers are the two most commonly used.
- The contact transsceral approach utilizes a fiber-optic probe to apply laser through the conjunctiva.
- The noncontact and transpupillary approaches utilize a slit lamp to apply the laser.
- Approximately 270° of the circumference of the ciliary processes are treated so as to reduce the risk of hypotony.
- Endoscopic delivery of laser for photoablation of the ciliary body is performed as an operative procedure due to the need to have an incision in the eye.
- MPCPC uses a hemispheric tip that is applied 1–2 mm posterior to the limbus, and is applied in a sweeping motion superiorly and inferiorly over 160–240 s.

Pre-operative Management

Retrobulbar anesthesia is usually given for pain during and after the procedure. For the contact transscleral approach the eye is exposed with a speculum and the ocular surface is moistened with a saline solution before applying a fiber-optic probe to the conjunctiva. A slit lamp is used for noncontact transscleral and transpupillary approaches. Endoscopic cyclophotocoagulation is done in the operating room setting in patients who are already pseudophakic or in combination with a cataract extraction. MPCPC can be done in a minor procedure room with retrobulbar anesthesia or in an operating room with intravenous sedation, which is usually a less painful experience for the patient, and eliminates the need for patching the eye.

Description of the Technique

There is no standardized protocol for cyclophotocoagulation procedures, and studies report varying success and complication rates. The two most commonly used lasers are Nd:YAG and diode lasers. A prospective study comparing the lasers found no significant difference in visual acuity or IOP reduction between the two lasers; therefore, the diode laser is often preferred because of its portability and lower energy requirements to achieve the same tissue result. A retrospective review of recent data from transscleral cyclophotocoagulation procedures concluded that the diagnostic category and age of the patients influence outcome more than the specific laser protocol or total energy used. Usually, the circumference is treated while avoiding the 3 and 9 o' clock positions to avoid the long ciliary nerves. Treating more increases the risk of hypotony. Spot

size is 100–400 μm with the 810 nm diode laser and 900 μm with the Nd:YAG laser. With the non-contact approach the laser is focused 3.6 mm beyond the surface of the globe; non-contact techniques are currently not favored. Pulse duration is 2–4 s at 1300–2300 mW with a total of 18–24 applications. The power setting is adjusted so that it is just below the power required to cause a barely audible 'pop.' The transpupillary approach may be used if the aqueous is clear and the pupil is sufficiently dilated so that ciliary epithelium can be directly visualized. Endoscopic cyclophotocoagulation is done through the anterior segment, or the pars plana. These procedures must be done in the operating room, and are often done in adjunct with cataract extraction. After a clear corneal incision is made, a high molecular weight viscoelastic should be inserted into the sulcus to lift the iris and facilitate visualization of the sulcus. An 18–23 gauge probe, 810 nm diode laser, 175-W xenon light source, helium-neon aiming beam, and video imaging are all within a fiber optic cable, which inserted into the anterior chamber via a clear corneal incision. The settings are between 250–350 mW, and 200–360° of the ciliary body are photocoagulated depending on the visualization of the angle. The ciliary processes can be visualized on a screen with an endpoint of photocoagulation leading to whitening and contraction of the processes without rupturing them. After the ECP procedure is completed, the viscoelastic should be aspirated from the eye. The approach for the MPCPC will be described in the "Future Directions" section.

Post-operative Management

Antibiotic and steroid ointments are given and the eye is patched overnight for transscleral cyclophotocoagulation due to the use of a retrobulbar block anesthesia. For ECP, patients may receive intracameral steroids or a subconjunctival injection of steroids in addition to topical drops after the procedure. Glaucoma medications are continued until IOP decreases, which may take several weeks. Retreatment may be necessary if IOP reduction is inadequate after weeks. It is not uncommon to require multiple treatments.

Adverse Events

- Pain is usually managed with systemic acetaminophen, ibuprofen, or cycloplegics depending on the source of the pain. Topical corticosteroid anti-inflammatory agents are also prescribed
- Hypotony, phthisis, hyphema, cataract, and synechia are significant risks

Side Effects/Complications : Prevention and Treatment of Side Effects/Complications

Common side effects include *pain, inflammation, postoperative IOP increases, iritis, reduced vision and macular edema*. Pain is usually managed with acetaminophen or ibuprofen. Pain secondary to iridocyclitis may be relieved with cycloplegics. *Hypotony* may develop after 6–36 months, and is one of the reasons that transsclearal cyclodestructive procedures are a last resort. *Phthisis* is also a possible complication. However, these risks are lower with ECP compared with transscleral cyclophotocoagulation.

Miscellaneous Procedures

There are a number of other applications for laser in glaucoma that are either adjuncts to or very similar to surgical procedures for glaucoma.

Laser can be used to *cut subconjunctival sutures* placed in a number of different surgical procedures. The laser is preferred because the laser can cut the suture without having to incise the conjunctiva. Dark nylon or proline sutures that are too tight can be severed with argon laser. For example, trabeculectomy scleral flap sutures are usually placed tightly to avoid post-operative hypotony. To achieve the appropriate IOP reduction in the long-term, some of these sutures may be lysed with laser post-operatively.

Cyclodialysis clefts occur when ciliary muscle separates from the underlying sclera. This was once a treatment for glaucoma, but can also occur as a result of trauma or a complication of other surgeries. It results in hypotony and decreased vision. Use of the argon laser to deliver photocoagulative burns to the internal surface of the scleral in an attempt to scar these clefts closed has been described.

The iridocorneal angle may become vascularized eventually leading to neovascular glaucoma. This can result from a number of ischemic phenomena including diabetes mellitus and central retinal vein occlusion. Although panretinal photocoagulation is the primary treatment for these conditions because it is treating the source of the ischemic stimulus, *goniophotocoagulation* may be used as adjunctive treatment. Indications include anterior segment vascularization that is unresponsive to panretinal photocoagulation and cases in which angle vascularization is already present when panretinal photocoagulation is begun.

Laser sclerostomy is the use of laser to perforate the sclera at the iridocorneal angle has been investigated as an experimental treatment for glaucoma. Although not exactly the same, it can be thought of as the laser counterpart to a trabeculectomy, which is a guarded filtering surgery that is performed if glaucoma is not controlled with medication and laser trabeculoplasty. The laser can be applied externally with a goniolens or under a conjunctival flap, or internally. Numerous lasers have been studied and antifibrotic agents such as mitomycin C are sometimes used as adjunctive treatment; however, the role of laser sclerostomy in comparison to the well-known trabeculectomy surgery remains undetermined.

Future Directions

Laser-based procedures have been become much more common in all areas of glaucoma treatments. Their less invasive nature and lower rates of complications are appealing and seem to be motivation for research to refine existing procedures and for continued innovation in the field.

MicroPulse laser trabeculoplasty is a new technology. It uses a 15% duty cycle to deliver 300 μm pulses to the pigmented cells of the trabecular meshwork. The laser is believed to lead to release of inflammatory cytokines which increases the permeability of the trabecular meshwork and lead to decreases in IOP. The laser uses a longer wavelength of 532 or 577 nm in comparison to ALT, and is believed to cause less overall damage as it does not cause trabecular meshwork

scarring like ALT, or destroy the pigmented trabecular meshwork cells like SLT does. Early, small scale studies have shown comparable IOP reduction between MLT and SLT.

Transscleral, transpupillary, and endoscopic cyclophotocoagulation procedures have been described above. The micropulse transcclerał cyclophotocoagulation diode is a newer method of transscleral cyclophotocoagulation. Its mechanism of action is not completely understood yet, but it appears to be multifactorial with belief that the diode causes ciliary body destruction, likely increases outflow through the uveoscleral pathway, and possibly causes a trabeculoplasty-like effect as well. MPCPC is believed to cause scleral shrinkage with ciliary body rotation and opening of the conventional outflow pathway. The diode is done transsclerally, but one of the differences between MSCPC and TSCPC is that micropulse diodes are delivered continuously with repeated times of short bursts of energy followed by rest. MPCPC has 0.5 ms in an active phase followed by 1 ms in a rest phase, with an overall duty cycle of 31.3%. The standard MPCPC settings are 2000 mW of 810 nm infrared diode laser on micropulse mode. The laser is then delivered over 360°, sparing the 3 o' clock and 9 o' clock positions, over 160–240 s. In contrast to TSCPC which uses a G probe, the MPCPC uses a G6 probe which has a hemispheric tip that protrudes 0.7 mm from the hand piece, and is held 1–2 mm posterior to the limbus during treatment. Given the duty cycle of the MPTCP, it is less inflammatory than the TSCPC. Although the procedure itself is painful, the post-operative pain is minimal. For this reason, the procedure can be done in a minor procedure room with a retrobulbar block, or in the operating room setting with intravenous sedation without a retrobulbar block. After the procedure, patients will be started on a topical steroid and atropine, and they should continue their current treatment for glaucoma. This procedure is repeatable if needed. Further studies must be done to understand the length of efficacy of the laser as well as the optimal patient.

Goniopuncture is the creation of a hole in the trabecular meshwork that results in a direct connection between the anterior chamber and Schlemm's canal and therefore, theoretically, increased aqueous outflow facility. The technique was initially proposed in 1950 by Harold G. Scheie but has been more intensively studied in the last 10 years as a treatment for open angle glaucoma. An erbium:YAG laser is used endoscopically often in combination with phacoemulsification cataract surgery. The erbium:YAG laser is a 2.94 μm wavelength laser that has a photoablative effect on ocular tissues with minimal thermal damage. One study found IOP reductions after 1 year similar to those after trabeculectomy. Another study found comparable IOP reductions at 1–3 years. Such a new procedure will require studies with longer follow-up and standardization of the technique and laser settings before it is fully incorporated into glaucoma management.

Conclusion

Glaucoma is a multifactorial optic neuropathy resulting in potentially progressive vision loss. Although there are many modalities of treatment that can be successfully employed to slow or stop the progression of glaucoma, the major and only treatable risk factor for glaucoma is elevated intraocular pressure. Diagnosis of glaucoma requires measurement of intraocular pressure, optical coherence tomography of the retinal nerve fiber layer, evaluation of visual fields, funduscopy, and

differentiation of closed-angle glaucoma (CAG) and open-angle glaucoma (OAG) by gonioscopy. The management differs for CAG and OAG. CAG with a pupillary block component is treated by laser iridotomy. CAG without pupillary block may benefit from peripheral laser iridoplasty. Laser trabeculoplasty has been traditionally reserved for those requiring modest, IOP reduction; however, studies suggest that it is equally effective in lowering IOP as medications, and laser trabeculoplasty is a possible alternative as first line treatment for OAG. If IOP remains inadequately controlled, filtration surgical procedures may be used. Cyclodestructive procedures such as cyclophotocoagulation have traditionally been reserved for refractory glaucoma because of their relatively higher rates of side effects and complications.

Iridotomy is the creation of an opening in the iris that provides an alternate route for aqueous to enter the anterior chamber bypassing the space in-between the iris and lens on its way to the pupil. The procedure is treatment for all forms of closed-angle glaucoma that involve pupillary block (i.e. increased resistance through or total occlusion of the space between the iris and lens). Patients with easily occludable anterior chamber angles may also require an iridotomy. Contraindications include an opacified cornea, an extremely narrow angle, or an inflamed eye. A topical anesthetic and miotic medications are applied preoperatively. The argon, diode, or Nd:YAG laser is used to apply laser to the superior peripheral iris through a focusing iridotomy lens. Absorption of argon laser energy causes photocoagulation and is dependent upon pigmentation and therefore techniques vary for irises of different colors. On the other hand, the Nd:YAG laser is photodisruptive and therefore does not dependent upon tissue pigmentation. IOP-lowering medications are used perioperatively, and corticosteroids may be used postoperatively for inflammation. If the angle remains narrow after treatment, laser peripheral iridoplasty may be considered.

Argon laser peripheral iridoplasty causes circumferential contraction of the iris away from the trabecular meshwork. It is another treatment for closed-angle glaucoma, and is often attempted when laser iridotomy fails or is not indicated because the pathophysiology does not involve pupillary block. This includes plateau iris and anterior displacement of the iris by posterior structures such as an enlarging lens. The procedure may be performed prior to laser trabeculoplasty to deepen focal areas of angle narrowing, and prior to laser iridotomy if the eye is acutely inflamed. Severe corneal edema or peripheral anterior synechiae are contraindications. A topical anesthetic and miotic medications are applied preoperatively. Argon laser is applied circumferentally to the peripheral iris to cause contraction burns. The effect should be immediately evident. IOP-lowering medications are used perioperatively, and corticosteroids may be used postoperatively for inflammation. Adverse events are similar to those of laser iridotomy with the addition of iris necrosis, which can be avoided by appropriately spacing laser spots. Laser trabeculoplasty is the application of laser energy to the trabecular meshwork with the intention of increasing aqueous outflow to reduce intraocular pressure in patients with open-angle glaucoma. The precise mechanism by which laser trabeculoplasty increases aqueous outflow is not fully elucidated. There is most support for a biologic mechanism involving enhanced turnover of extracellular matrix and induced trabecular meshwork cell division. Laser trabeculoplasty is now being used as first line treatment for OAG, and especially before filtering surgical procedures are performed for both primary and secondary open-angle glaucoma. Studies strongly suggest that both ALT and SLT are at least as effective as medications for initial treatment. MLT is a newer procedure which is

believed to cause less scarring and destruction to the pigmented trabecular meshwork cells in comparison to ALT and SLT. Small scale studies have shown that it is equivalent to ALT and SLT in lowering IOP, however, larger scale studies are yet to be completed. Laser trabeculoplasty is not very effective in patients younger than 40 years and is contraindicated for uveitic glaucoma. It is also contraindicated if the angle cannot be appropriately visualized. The procedure requires topical anesthesia and IOP-reducing medications. Laser is applied to the trabecular meshwork using a mirrored contact lens. IOP reductions can be expected after 4–6 weeks. Complications include transient or persistent IOP elevations, hyphema, and iritis.

Cyclophotocoagulation is the use of laser to destroy ciliary body tissue in order to decrease aqueous humor production and therefore reduce intraocular pressure. Because of its higher rate of side effects and complications, it is usually reserved for refractory glaucoma. Cyclophotocoagulation has gained popularity over other cyclodestructive procedures such as cyclocryodestruction because of its relatively lower rate of complications and side effects. There are four approaches to cyclophotocoagulation: contact transscleral, noncontact transsceral, transpupillary, and endoscopic. Retrobulbar anesthesia is administered. Beyond general management the technique has not been standardized, and studies report varying success and complication rates. Most commonly, the Nd:YAG laser or diode laser is used to destroy most but not all of the ciliary processes so as to avoid hypotony. The contact transscleral approach utilizes a fiber-optic probe. MPCPC is a newer contact transscleral approach which is believed to work by causing ciliary body rotation and increase output through the uveoscleral and conventional pathways. In comparison to traditional TSCPC, it is less inflammatory and has fewer side effect. It causes less postprocedural pain in comparison to traditional TSCPC, and can be done in operating room with intravenous sedation, without a retrobulbar block. The noncontact transscleral and transpupillary approaches utilize a slit lamp to apply the laser. Glaucoma medications should be continued until IOP decreases, which may take several weeks. It is not uncommon to require multiple treatments.

Laser-based procedures have been become much more common in all areas of glaucoma treatments, in many cases replacing their surgical counterparts. Their less invasive nature and lower rates of complications are appealing and seem to be motivation for research to refine existing procedures and for continued innovation in the field.

Further Reading

General

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Medical and Surgical Management of Uveitic Glaucoma

Rajesh Sasikumar, Piergiorgio Neri

Introduction

Inflammation of the uveal tract might lead to high intraocular pressure (IOP) [1]. A series of components may contribute in the pathogenesis of inflammatory glaucoma, such as trabecular meshwork engorgement by immune-cells and proteins [2, 3], inflammation of the trabecular meshwork itself known as "trabeculitis" [4], peripheral anterior and/or posterior synechiae [5], rubeosis iridis and, consequently, neovascular glaucoma [6], and anterior rotation of the lens-iris diaphragm [7]. In addition, it is well known that the use of steroids in order to control uveitis may lead to secondary IOP elevation [8-10].

Uveitic glaucoma may become a severe complication and contribute to severe visual impairment in patients with uveitis. Although several retrospective reports described the prevalence of glaucoma in patients with uveitis [11-14] the incidence of this complication was more recently reported [15].

Uveitic glaucoma represents one of the pitfalls in the management of uveitis.

Uveitic glaucoma occurs in about 20% of patients with uveitis and requires an urgent treatment that might end in surgery to avoid glaucomatous optic nerve damage. The medical literature reported specific types of uveitis associated with very high rates of IOP elevation. By definition, high IOP occurs in 100% of patients with Posner-Schlossman syndrome, but not all patients suffer glaucomatous optic neuropathy. On the contrary, glaucomatous optic nerve damage is relatively common in Fuch's uveitis syndrome. Therefore, it is crucial to have a consistent definition of glaucoma in uveitis.

The term glaucoma should be reserved for conditions with a clear evidence of glaucomatous optic damage, while uveitic or steroid-induced ocular hypertension should be used in cases where increased IOP is the only hallmark. The differentiation between normal and pathological optic discs represents a concrete challenge in uveitic eyes, where media opacity often makes this evaluation very hard.

Affected segment of the uveal tract may potentially be more or less associated with uveitic glaucoma: uveitis that affects primarily the posterior segment is associated with a lower risk of

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uveitic glaucoma. Behçet's disease and Vogt-Koyanagi-Harada syndrome are significantly associated to both posterior and anterior uveal tract involvement (a so called panuveitis) and the risk of secondary glaucoma increases. Approximately 6% of all uveitis occurs in children and the most common systemic association is with juvenile idiopathic arthritis. These pediatric uveitis are often treated with high dose of steroids at their onset and this may lead to uveitic glaucoma that should be promptly addressed.

Diagnosis

When a patient presents high IOP in uveitis, it is crucial to distinguish the possible syndromes that might be associated with glaucoma, such as Fuch's uveitis syndrome, Posner-Schlossman syndrome and rubella associated anterior uveitis. In addition, it is important to carefully examine the iridocorneal angle for potential signs of obstruction, such as peripheral anterior synechia, pigment smudging and angle closure, or inflammation hallmarks like Busacca nodules, pigment deposition or angle neovascularisation.

It is also crucial to monitor carefully IOP in uveitis since marked fluctuation is often observed between visits. Goldmann applanation tonometry (GAT) represents the gold standard, even though modern dynamic contour tonometry might be less affected by changes in central corneal thickness (CCT). CCT should be measured accurately in all patients, since GAT may underestimate the IOP level in those with a CCT <510 μm. Visual field testing with standard automated perimetry represents the most reliable functional test for an accurate monitoring of potential change in retinal sensitivity over time: the presence of a visual field abnormality represents still the only endpoint for the diagnosis of glaucoma, albeit optic disc changes alone are considered the hallmark of the so called pre-perimetric glaucoma. The toughest issue in uveitis is differentiating visual field defects that are related to chorioretinal scarring or media opacity from those that may be secondary to uveitic glaucoma. This requires a careful examination of the patient and appraisal of the whole picture.

Optic disc interpretation represents a difficult issue in case of media opacities such as cataract, posterior capsule opacification, pupillary membrane, vitritis and high degree of anterior chamber inflammation. In addition, diffuse retinal nerve fiber loss from widespread retinal disease may also mimic the expansion of the optic disc cup. In the past stereo disc photography represented a reliable method of comparison of optic disc change over time, even though newer imaging devices, such as scanning laser ophthalmoscopy, polarimetry or optical coherence tomography may offer a more accurate analysis in order to detect subtle changes over time. Moreover, it is strongly recommended to measure the vertical disc diameter when assessing the optic disc for glaucomatous damage: in optic discs <1.5 mm vertical diameter any cupping at all may be pathological, whereas discs >2.0 mm a correspondingly large cup may still be physiological.

Differential Diagnosis

The important differential diagnoses are the hypertensive uveitis entity and the mechanism of inflammatory glaucoma.

It is crucial to differentiate IOP elevation in open angle from that of a closed angle, in order to appropriately plan the therapeutic strategy. In anterior uveitis, angle closure may be secondary to relative pupil block: fibrin at the pupillary margin may obstruct aqueous flow into the anterior chamber and generate a vicious circle that may lead to the acute occurrence of high intraocular pressure. IOP elevation is relatively infrequent in this situation, due to the cyclitis and the consequent reduction in aqueous production at the onset of the disease. More commonly acute angle closure in uveitis may be secondary to 360° secluded pupil: posterior synechia at the pupil margin may obstruct the aqueous flow and lead to acute angle closure glaucoma. The key features of this condition are a deep central anterior chamber, dramatic iris bombe, often with peripheral iris-corneal contact, corneal edema and a very high IOP.

In certain situations, the IOP elevates in the presence of a very shallow central anterior chamber, almost with irido-lenticular contact. In this case, the diagnosis is either forward movement of the lens-iris diaphragm or a phacomorphic IOP elevation.

In case of phacomorphic glaucoma, the lens is generally not large enough to cause a very shallow central anterior chamber, therefore the suspect of an anteriorization of the lens-iris diaphragm should always be put forward. The causes of the latter are any condition that leads to expand the volume of the posterior segment. This may happen in case of posterior scleritis and inflammatory ciliochoroidal effusions, VKH, without forgetting that this may happen after extensive panretinal photocoagulation, after vitrectomy or aqueous misdirection after decompressive surgery.

A pre-existing narrow angle may lead to synechial closure, resulting from chronic intermittent irido-trabecular contact in an eye with synechia in the angle secondary to inflammatory nodules or neovascular membrane with iris neo-vascularization. Therefore, the careful examination of the angle in all uveitis patients suspected of IOP elevation represent a core component of the correct assessment.

Therapy

An appropriate management of active inflammation represents a priority in uveitic glaucoma. A sub-optimal therapy for the uveitis in the hope of avoiding steroid-induced IOP elevation does not offer any advantage: this is likely to result in further damage to the outflow pathway and to permanent impair of the aqueous flow. Albeit ocular hypotensive medications are always appropriate, in some diseases, such as Posner-Schlossman syndrome and herpetic uveitis, steroids represent the core component of the treatment. Due to the sensitivity of inflammation to topical steroids in these conditions, the IOP usually comes back to normality as soon as the inflammation settles. Conversely, steroid treatment of inflammation in Fuch's uveitis syndrome is mandatorily contraindicated. A balance between adequate control of inflammation and steroid-induced IOP elevation is considered a must, in order to maintain a healthy optic nerve.

Medical Management

Medical approach is the first approach to uveitic glaucoma. No study has specifically addressed the effect of topical glaucoma medication in uveitis.

Non-selective ß-blockers such as timolol are still used as first-line treatment in uveitis glaucoma, in contrast with primary open-angle glaucoma. Among those available, metipranolol is best avoided, since this has been previously reported to induce uveitis in a proportion of cases [16].

Topical carbonic anhydrase inhibitors (CAIs) such as brinzolamide and dorzolamide may exert a minimal action in controlling the IOP in POAG patients but they may surprisingly have a dramatic decrease in some chronic uveitis, and this is presumed to be due to increased sensitivity of the diseased ciliary body to aqueous suppressants.

The prostaglandin agonists are considered the most effective agents in lowering the IOP by increasing uveoscleral outflow through changes in ciliary body matrix. Initial concerns that prostaglandin agents might precipitate or exacerbate uveitis [17-20] and herpetic keratitis [21-23] were raised, although this suspect was never proved [24]. On the other hand, prostaglandins are not safe in patient with previous history of cystoid macular edema (CME) [25-27], aphakia in uveitis, aggressive cases of herpetic keratouveitis, poorly controlled anterior uveitis.

Alpha-adrenergic agonists may efficiently reduce IOP by a combination of aqueous suppression and increased uveoscleral outflow. Unfortunately, these drugs are associated with frequent local side effects and tachyphylaxis when used for prolonged periods: severe allergy to brimonidine and even granulomatous anterior uveitis may also be a prominent feature that limit their use in uveitic patients. These agents also appear to act via prostaglandin release and their efficacy may be reduced if used concomitantly with NSAIDs.

Miotic agents, such as pilocarpine, must be avoided since they lead not only to increased vascular permeability but also may induce formation of posterior synechia.

Systemic CAIs are also required in a significant proportion of patents. It has been reported that patients requiring systemic CAIs in addition to topical therapy fall into 3 broad categories as the following:

1. Group 1: rapid responder. They have a rapid response to systemic CAIs that can often subsequently be managed on topical therapy alone in the long term. Patients in this group may require surgery only in case of advanced glaucomatous nerve damage and/or repeated frequent attacks with acute IOP elevation risk leading to a further visual impairment.
2. Group 2: partially responder. IOP is controlled but only with a heavy regimen of systemic CAIs and maximum quantity of topical agents. Albeit some patients might tolerate this in the long term, this type of treatment does not seem to be sustainable and most patients will opt for surgery.
3. Group 3: they are so called non-responder. Despite maximum medical therapy, the IOP may remain very high, often higher than 30 mmHg. Regardless of the extent of optic nerve damage, surgery is needed as a rescue therapy in order to avoid glaucomatous visual loss.

Acute Pupillary Block

Acute angle closure represents an emergency in uveitis and must always be promptly treated. The correct approach starts with an intensive pupillary dilatation and anti-inflammatory medication that may break posterior synechia and re-establish aqueous flow. It essential to start the treatment immediately with no delay in order to avoid a more radical approach.

The use of intracameral tissue plasminogen activator (TPA) has been described in cases of acute pupil block secondary to fibrinous inflammation [28]. However, acute attack of uveitis with posterior synechia and pupillary seclusion may present a normal or even low IOP because of cyclitis and the need to treat may not be appreciated. If TPA needs to be used in an eye with iridotomy or iridectomy, it is crucial to inject it before performing those, since its injection after either procedure may lead to a significant iris bleeding.

Laser iridotomy may provide temporary relief of pupillary block but this is not a potential curative treatment, since its failure rate is consistently high. Surgical iridectomy with synechiolysis and aggressive control of anterior segment inflammation are nowadays essential for long-term success [30]. Moreover, since secluded pupil rapidly develop peripheral anterior synechia, synechiolysis and surgical iridectomy have to be planned even after laser iridotomy performed as a rescue treatment.

Surgical Management

A high proportion of uveitic glaucoma needs a surgical approach. Compared with primary open-angle glaucoma, IOP in uveitic glaucoma is usually much higher despite medical therapy and most patients are already taking systemic CAIs unsuccessfully. Reluctance to operate may be induced by a higher risk of surgical failure, possible postoperative hypotony and inflammation, leading to a more conservative management. On the other hand, suboptimal control of IOP in uveitic glaucoma will certainly cause severe visual impairment in a consistent number of patients. Modern surgical techniques may minimize the risks of surgery and may offer a stable IOP control for the majority of the patients.

Several surgical options have been proposed such as cyclophotocoagulation, trabeculectomy and aqueous shunts. The decision to operate is based on the following parameters: current IOP level, history of IOP elevation, severity of optic nerve damage, appearance of the drainage angle and response to medical treatment.

Inflammation control has to be the first step in managing uveitic glaucoma in view of a surgery, and elevated IOP has to be managed medically as best as possible in the interim. In some instances hot surgery is needed: under these circumstances, the use of perioperative systemic or intraocular corticosteroids has to be considered.

Cyclophotocoagulation [29] should not be considered as an option in inflammatory glaucoma: ciliary destructive surgery may be associated with severe exacerbations of uveal inflammation and permanent impairment of a ciliary body that is already suffering from inflammatory disease. This could result in a potential irreversible hypotony which can be as dangerous as chronic uveitic glaucoma. In children treatment with cyclophotocoagulation has proven unsatisfactory in the long term since the ciliary epithelium regenerates and leads to new elevations of the IOP [30].

Trabeculectomy with low-dose mitomycin C (0.2 mg/ml) is the most studied surgical approach for phakic patients with uveitis. The caveat in this surgery is that even in the absence of over drainage, hypotony may occur by low aqueous production, particularly in younger patients which are more prone to hypotony maculopathy. Multiple releasable and/or adjustable sutures are

used to ensure tight flap closure and minimal initial drainage, in order to prevent hypotony. Early postoperative period is crucial for a successful long-term outcome: selective suture release is performed to establish adequate flow and a similar control is achieved with fixed scleral flap sutures that might be selectively lasered in the early postoperative period.

Antimetabolites play a primary role in the success of the surgical therapy: 53% of the patients have a complete IOP control after 5 years [31]. The reported success rate in such study was superior than expectancies for trabeculectomy without antiproliferative in uveitic glaucoma [32]: only 30% of eyes achieved a successful IOP control with no need of medications at 5 years after trabeculectomy without antimetabolites. In this second study the success rate increased to 50% in those who received postoperative 5FU injections.

Unfortunately, few studies were published on the long-term control of IOP in mitomycin C-augmented trabeculectomy in patients with uveitis. The use of MMC in uveitic eyes is associated with lower IOP on fewer medications than eyes undergoing trabeculectomy with intraoperative 5FU [33].

Again, it is crucial the stress the role played by the control of inflammation in uveitic glaucoma: in higher-risk cases trabeculectomy surgery may have a poor outcome if the inflammatory component is not optimally suppressed. However, uveitic patients may have a significant risk of later failure provoked by recurrences of uveitis or subsequent cataract surgery. Moreover, nearly 50% of patients develop cataract after trabeculectomy [34]. Cataract may develop for the following reasons: corticosteroid treatment, trabeculectomy surgery itself, uveitis, the initial IOP elevation and aqueous suppressant treatment for IOP elevation. Subsequent cataract surgery may exert a negative influence on trabeculectomy in about one fourth of the patients.

Aqueous shunt implantation may offer a more stable IOP control in patients with high risk of trabeculectomy failure, such as previous failed filter, prior intraocular surgery, aphakia and pseudophakia, young age, black race and patients likely to require cataract surgery.

Aqueous shunts offer a wide range of options: Ahmed glaucoma valve, the Baerveldt glaucoma implant and the Molteno implant are some of the possible devices available in the market. Aqueous shunts are progressively used in the management of patients with refractory glaucoma and in some centers, they have replaced trabeculectomy as the first option in the surgical management of non-uveitic glaucoma. Molteno [35] reported successful IOP control (≤21 mmHg) in 87% of eyes after 5 years and 93% at 10 years. Both the Baerveldt and Ahmed devices may warrant an optimal short-term result. Even though Da Mata reported an excellent 94% of controlled IOP at 1 year after Ahmed glaucoma valve implantation, this time of follow up is too short to be meaningful. On the other hand, it is encouraging that the 10 eyes followed for a further year maintained IOP control. Similar results were obtained by Ceballos, who described successful IOP control with the Baerveldt glaucoma implant in 92% at 2 years [15, 36]. The use of MMC with aqueous shunt implantation is controversial, and no clear benefit has been reported.

Prognosis

The prognosis in most types of uveitic glaucoma often depends on the application of the "zero tolerance" concept for both uveitis and IOP elevation. Sub-optimal treatment of inflammation

in order to prevent a possible steroid-induced IOP elevation leads always to severe worsening of uveitis. Cataract should also be aggressively managed as it hampers optic disc assessment preventing adequate management of glaucoma. In conclusion, the prognosis for eyes with uveitic glaucoma should present a much better outcome than historically has been described, if all the factors would be appropriately addressed.

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Case 47: Zone I/II Open Globe Repair with Post-Operative Elevated Intraocular Pressure

Jonathan C. Chou, Veena Rao, Seanna Grob

History of Present Illness

A 58-year-old man with history of hypertension and hyperlipidemia presents with concern for open globe of the left eye.

- While pulling up a screw that was malpositioned with a screwdriver in the same hand, his hand slipped and the handle of the screwdriver hit his left eye.
- He noticed a sudden decrease in vision and was taken to the nearest emergency department for evaluation.
- He was evaluated at an outside hospital where a computed tomography (CT) scan was concerning for a left open globe with posterior displacement of the lens. He was sent to Mass Eye and Ear for further management.

Initial Trauma Evaluation

Visual Acuity (Without Correction)

OD: 20/20
OS: Light perception

Intraocular Pressure (mmHg)

OD: 15
OS: Deferred

Pupils

OD: Reactive
OS: Irregular, no afferent pupillary defect by reverse

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External Examination

No evidence of facial lacerations or other trauma.

Slit Lamp Examination

	OD	OS
Lids and lashes	Normal	Mild edema
Sclera and conjunctiva	Normal	Diffuse injection
Cornea	Normal	Full-thickness curvilinear rupture from 5 to 8 o'clock following the limbus with significant iris prolapse
Anterior chamber	Normal	Shallow with hyphema
Iris	Normal	Temporal iris avulsed and prolapsed through the rupture site inferonasally
Lens	Normal	Posterolaterally displaced
Vitreous	Normal	Noted anteriorly

Dilated Examination

Macula/Nerve OD: Normal
Periphery OD: Normal
Macula/Nerve: OS: No view
Periphery OS: No view

Radiographic Imaging

CT of the orbits showed ruptured left globe with postero-lateral displacement of lens. There was no evidence of an intraocular foreign body. No fractures were noted (Fig. 1a, b).

Surgeon's Initial Assessment and Pre-Operative Plan

The patient had a Zone I/II open globe injury of the left eye with associated lens dislocation.

Surgical plan was to repair the ruptured globe primarily and then address the dislocated lens at a later date after a post-operative ultrasound, which would give us more information about the status of the lens and the retina. Specifically for this globe, since the rupture site followed the limbus, our plan was to place radial nylon sutures to re-approximate the limbus.

Surgical Exploration and Repair: Operative Note

In the pre-operative area, the patient was identified and the left eye was marked. He was brought into the operating room where a time out per standard protocol was performed. General anesthesia was induced. The left eye was then prepped and draped as per standard ophthalmic fashion,

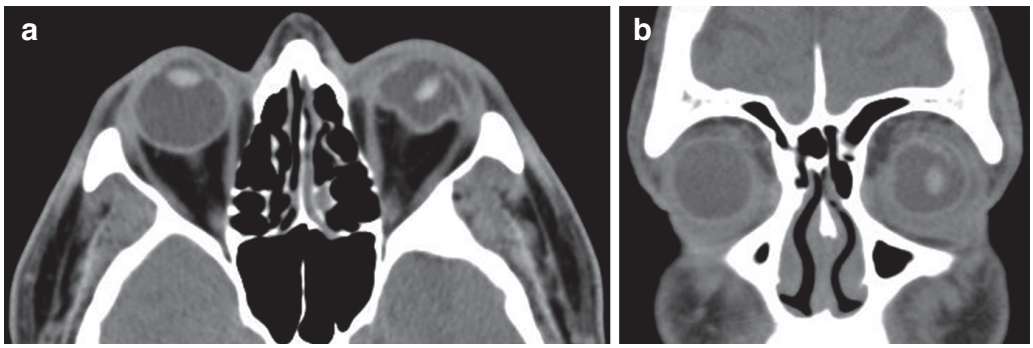


Fig. 1: Non-contrast CT scan of the orbits (**a**) Axial CT image demonstrating the significant irregularity of the globe contour on the left with a displaced intraocular lens. (**b**) Coronal CT image showing irregularity to the scleral contour nasally and a displaced lens.

taking care to be very gentle as there was extruded uveal tissue that was touching the eyelid margin. Jaffe lid specula were inserted for better visualization. The eye was inspected under the surgical microscope. A shelved full-thickness rupture was seen curving along the limbus from 5 to 9 o' clock. There appeared to be iris avulsion from 2:30 to 9:00, but the view into the anterior chamber was hazy due to hemorrhage. A long segment of iris was extruding though the corneal laceration at 6 o' clock (Fig. 2a). Areas of hemorrhage were noted in the anterior chamber, which obscured the view of the lens.

An iris spatula was used to gently reposit the iris into the anterior chamber. Westcott scissors were used to initiate a peritomy at 11 o' clock and to bluntly dissect the conjunctiva and Tenon's from the underlying sclera toward the direction of the limbal wound. The other side of the peritomy was initiated at approximately 4 o' clock and blunt dissection was continued to expose the scleral rupture further. Next, the limbal wound was closed with eight 10-0 nylon interrupted sutures directed radial to the limbus, using an iris spatula with each pass to prevent uveal incarceration in the wound. The wound was tested with fluorescein and was found to be Seidel negative. The globe was further explored and no additional rupture sites were found. 8-0 Vicryl sutures were then used to close the conjunctival peritomy (Fig. 2b). A subconjunctival injection of cefazolin and dexamethasone was then administered. The lid specula were removed under visualization. The patient tolerated the procedure well, without complication.

Surgical Exploration and Repair: Pearls

- For ruptures that follow the curvature of the limbus, radial sutures can be placed to re-approximate the limbus.
- Minimize intraocular tissue loss, repositing uveal tissue when possible and only excising tissue that is necrotic, infected, or not viable tissue.

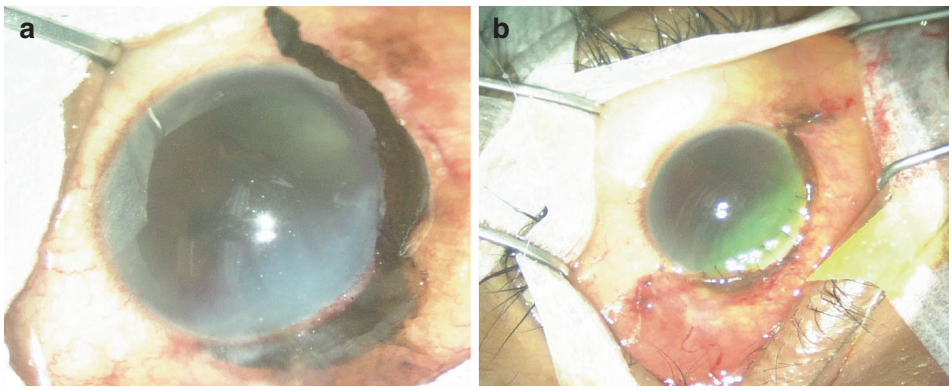


Fig. 2: (**a**) Pre-operative photo showing significant iris avulsion inferiorly; (**b**) Post-operative photo after iris repositioning and corneal limbal wound closure.

Surgical Video

Please see Video 1

Post-Operative Course

The patient was admitted to complete the 48 hour course of intravenous antibiotics. On post-operative day one, visual acuity was hand motion and intraocular pressure (IOP) was 24 mmHg in the left eye. The wound was well-approximated and Seidel negative. There was a layered hyphema and loss of iris tissue noted temporally (Fig. 3a). A B-scan ultrasound showed posterior displacement of the lens (Fig. 3b). He was started on routine post-operative drops including moxifloxacin, 1% prednisolone and atropine. Subsequently, the patient underwent a pars plana vitrectomy and lensectomy 2 weeks after open globe repair (Fig. 4). Intraoperatively, the retina was found to be completely attached and the free-floating lens fragments were removed.

His IOP was 14 mmHg the following day. At his 1 week post-operative visit, his IOP had increased to 31 mmHg and he was started on dorzolamide hydrochloride—timolol maleate (2%/0.5%) twice a day and a prednisolone taper was initiated. Two weeks later his pressure was 36 mmHg with good compliance. Gonioscopy revealed diffuse anterior synechiae nasally and inferiorly with no angle structures identified in these quadrants as well as angle recession superiorly and temporally in the left eye. He was evaluated by a glaucoma specialist and brimonidine tartrate 0.2% three times a day and latanoprost 0.005% at night were added. His IOP improved to the mid-teens after 1 week. Dilated funduscopic exam showed normal optic nerves and the retinal nerve fiber layer optical coherence tomography (OCT) was within normal limits. Initial visual field testing using a + 15.00 D lens for aphakic correction showed possible superior and inferior nasal depressions (Fig. 5a–c). After corneal suture removal, the patient was fitted for an aphakic contact lens and vision improved to 20/60-2. Follow up visual fields showed no evidence of visual field defects (Fig. 5d).

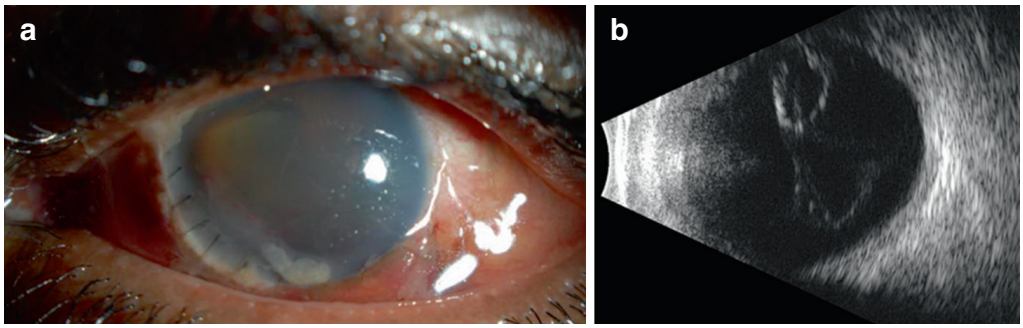
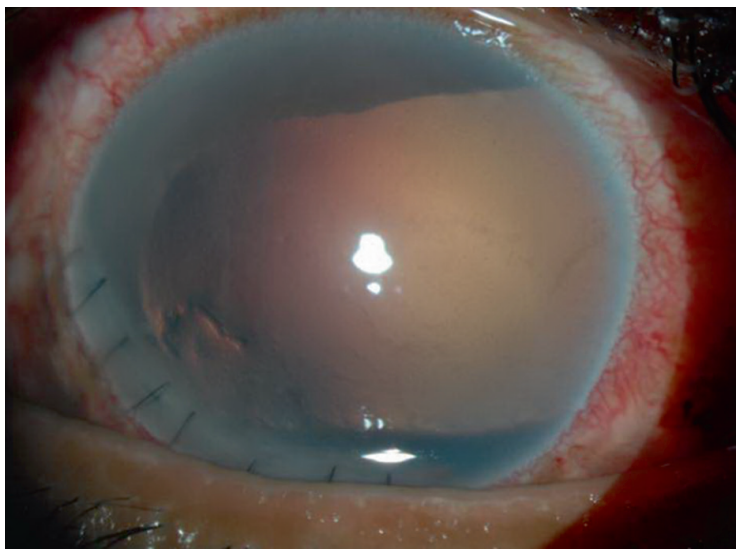


Fig. 3: (**a**) Slit lamp photograph of the left eye at post-operative day 1. Radial nylon sutures are seen inferonasally, with a layering hyphema and loss of iris tissue temporally; (**b**) B-scan ultrasound showing lens dislocation posteriorly into the vitreous.

Fig. 4: Slit lamp photograph of the left eye after pars plana vitrectomy and lensectomy. The eye is now aphakic with notable loss of iris tissue temporally.



Final Trauma Evaluation

Final Visual Acuity

OD: 20/20-
OS: 20/60-2 (best corrected with contact lens)

Intraocular Pressure (mmHg)

OD: 15
OS: 17

Pupils

OD: Normal
OS: Loss of iris tissue temporally, no afferent pupillary defect

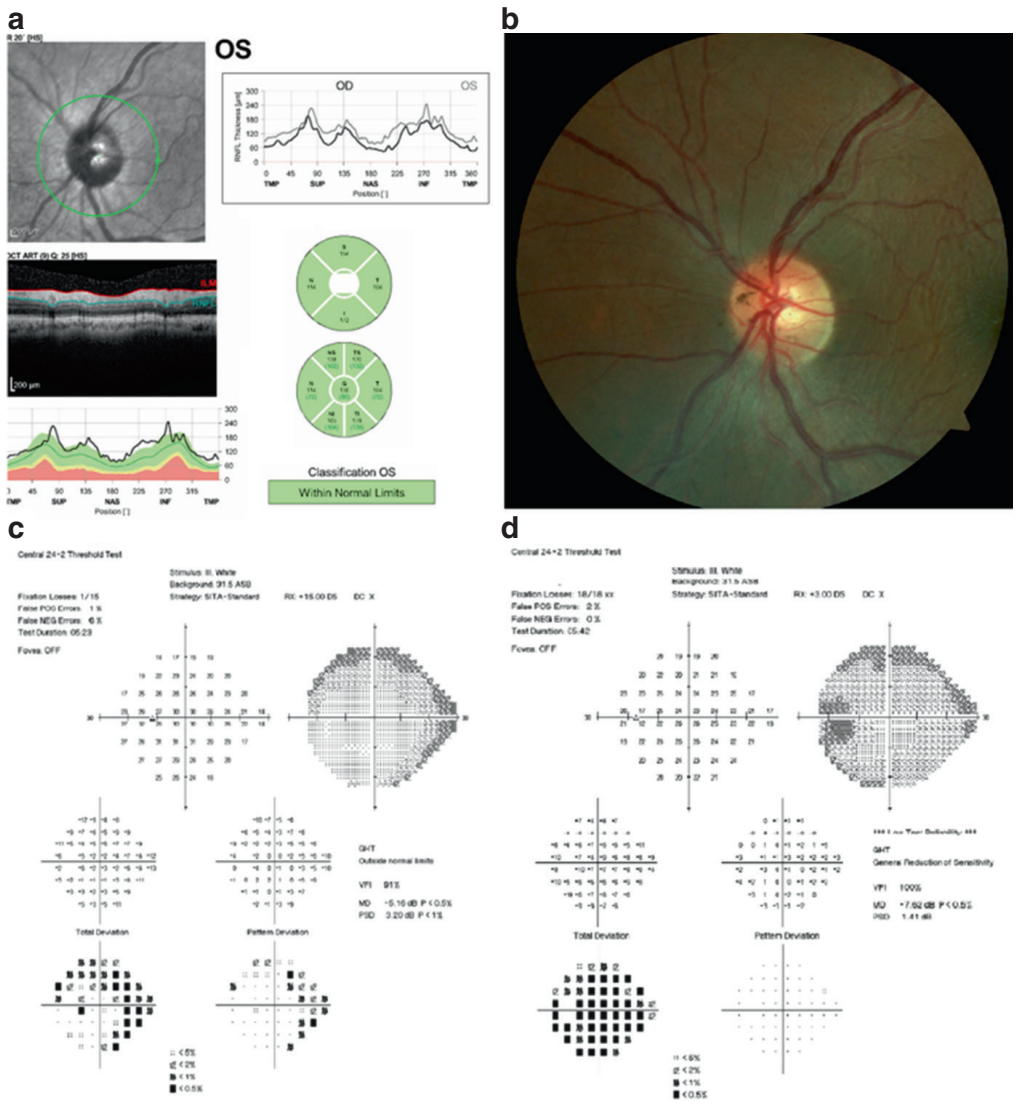


Fig. 5: (**a**) Optic nerve OCT of the left eye showing healthy nerve fiber layer. (**b**) Disc photo of the left eye showing a pink and healthy nerve with a cup to disc ratio of 0.3; (**c**) 24-2 Humphrey Visual Field performed with a + 15.0 lens showing possible superonasal and inferonasal depression of the left eye 1 month after open globe repair; (**d**) Repeat 24-2 Humphrey Visual Field performed 6 months later, after contact lens fitting, showing normal pattern standard deviation without gross defect.

Slit Lamp Examination

	OD	OS
Lids and lashes	Normal	Normal
Sclera and conjunctiva	Normal	Trace injection inferiorly
Cornea	Normal	Mild corneal haze inferonasally, mild pannus inferonasally, trace epithelial edema inferiorly
Anterior chamber	Normal	Rare mixed pigment/old cell, deep
Iris	Normal	Iridodialysis with loss of iris tissue temporally (Fig. 6)
Lens	Normal	Aphakia
Vitreous	Normal	Normal

Dilated Examination

Macula/Nerve OD: Normal
Periphery OD: Normal
Macula/Nerve: OS: Rim intact, cup to disc ratio 0.3, trace epiretinal membrane
Periphery OS: Attached retina, condensed vitreous inferiorly

Review and Lessons Learned

Patients with ruptured globe injuries are at risk of post-operative IOP elevation due to multiple possible mechanisms, several of which are illustrated here. In one case-control study, 17% of patients developed an IOP ≥ 22 mmHg after an open globe injury with an average maximum IOP of 33.4 mmHg at a median follow-up of 21 days. Risk factors found were age, hyphema, lens injury and Zone II injury [1]. The United States Eye Injury Registry indicates an overall 2.67% risk of developing glaucoma following trauma; glaucoma risk was correlated with age, poor visual acuity at presentation, lens involvement, and inflammation [2]. IOP elevation can present early in the post-operative course or even years later, requiring long-term monitoring. An initial low or normal IOP is not reassurance that the IOP will not elevate later in the post-operative course.

Let us review factors that may have played a role in this case. First, at the time of surgery, the patient was treated with subconjunctival and topical steroids, placing him at risk for steroid-induced glaucoma. Steroid-related IOP elevation is thought to be related to decreased trabecular meshwork outflow; some studies show degradation of the extracellular matrix causing accumulation of mucopolysaccharides in the trabecular meshwork [3]. Second, his significant iris trauma led to scarring of the angle with development of peripheral anterior synechiae, which can increase resistance to aqueous outflow. Third, this patient showed signs of angle recession, which is common after trauma and can lead to glaucoma months or years after the initial trauma. Glaucoma related to angle recession tends to develop either in the first year or greater than 10 years after injury [4]. The proposed mechanism is that damage to the iris and ciliary body leads to fibrosis and scarring of the

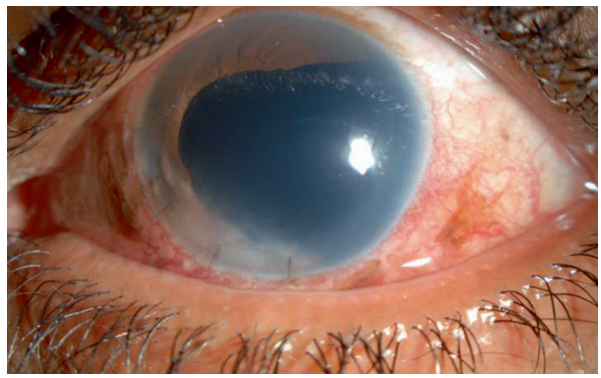


Fig. 6: Final slit lamp photograph of the left eye showing three remaining radial nylon sutures with mild corneal scarring inferonasally and an otherwise clear cornea with loss of iris tissue temporally and aphakia.

trabecular meshwork and/or Schlemm's canal. A hyaline membrane has also been reported to grow over the trabecular meshwork, which can also cause decreased aqueous outflow [5]. Also notable in this case is the presence of lens dislocation and lens fragments that were removed during pars plana vitrectomy; it is possible for lens particles to disrupt the trabecular meshwork and increase IOP. Although not present in this case, it is important to assess for any evidence of pupillary block which might cause IOP elevation.

Treatment of the elevated intraocular pressure depends on the underlying mechanism(s) and, for the most part, is managed similarly to non-traumatic glaucomas. In our case, the topical steroid was tapered and the patient was started on topical IOP-lowering medications. In the acute phase of trauma, the clinician should be cautious when using prostaglandin analogues as they tend to be pro-inflammatory. Cholinergic agonists (e.g. pilocarpine) should be avoided in cases of angle recession and may incite inflammation. Goniosynechialysis can be considered in cases where there is extensive peripheral anterior synechiae and iridotomy and/or lens removal can be useful in cases involving pupillary block. If the IOP continues to be elevated despite conservative treatment with medications, glaucoma filtration surgeries may need to be considered.

In traumatic lens dislocation cases with associated globe rupture, it is important to address the open globe first. This helps minimize tissue loss and possible extrusion from intraocular surgery. Allowing the corneal and scleral tissue to heal can be helpful prior to additional secondary surgeries. In cases where a dislocated lens cannot be safely retrieved via an anterior approach, a pars plana technique is required. It is important to counsel all patients with ruptured globe trauma that they will require careful, often life-long, monitoring of their intraocular pressure.

Key Learning Points

- Elevated intraocular pressure can occur after ruptured globe and has multiple mechanisms (e.g. angle recession, steroid-induced, peripheral anterior synechiae).
- It is important that patients are counselled regarding the importance of long-term follow up (at least on a yearly basis) after post-operative recovery, especially if they have risk factors for glaucoma after the trauma.

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Source: Chou J.C., Rao V., Grob S. (2018) Case 47: Zone I/II Open Globe Repair with Post-Operative Elevated Intraocular Pressure. In: Grob S., Kloek C. (eds) Management of Open Globe Injuries. Springer, Cham. https://doi.org/10.1007/978-3-319-72410-2_52.

In Primary Open Angle Glaucoma & Ocular Hypertension

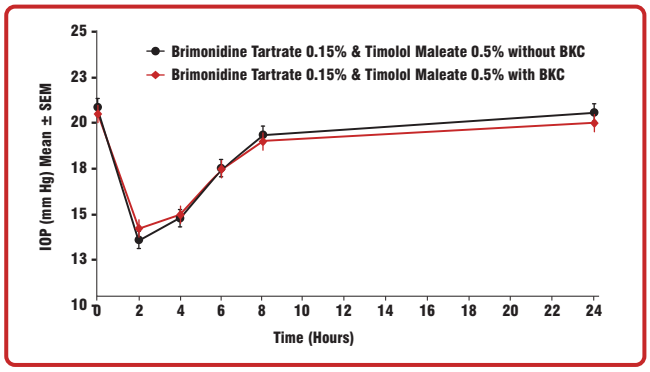
Rx

BRIMOLOL

Brimonidine Tartrate 0.15% + Timolol Maleate 0.5%

Combined power, Greater benefits

BKC free BTFC offers comparable IOP lowering to BKC preserved BTFC[1*]



- Single ocular instillation of BTFC without BKC showed statistically significant IOP reduction at 6 hrs. compared with baseline mean IOP value
- Maximum reduction in IOP observed at 2 hrs. following single instillation:
  - BTFC without BKC was 35.8%
  - BTFC with BKC was 32%

"The efficacy of Brimonidine Tartrate 0.15% & Timolol Maleate 0.5% preserved with PHMB was comparable to reference item Brimolol® (BKC preserved)[1]"

1. Thavkar A et al. Int J Basic Clin Pharmacol. 2020 Jul;9(7):1050-1054 • BTFC - Brimonidine Timolol Fixed Combination *Efficacy study in NZW rabbits
• BKC - Benzalkonium Chloride • PHMB - Polyhexamethylene biguanide • IOP - Intraocular Pressure • SEM: Standard Error of Mean