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ORIGINAL PAPER

Clinical experience with urgent tube shunt implantation through the ciliary sulcus in phakic eyes

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Abstract
Purpose To review the clinical course and outcomes of 3 phakic, ischemic, and inflamed eyes in which we performed urgent tube shunt implantation through the ciliary sulcus without lensectomy.
Methods This is a retrospective interventional case series. Three eyes of 3 diabetic patients with uncontrolled severe neovascular glaucoma, shallow anterior chambers with closed angles and poor view to the posterior segment, where concomitant lensectomy was not recommended due to uncontrolled uveitis and ischemia, underwent tube shunt implantation through the ciliary sulcus. Main outcome measures were surgical complications, especially injury to the crystalline lens, and postoperative intraocular pressure (IOP).
Results No surgical complications, including injury to the crystalline lens, have occurred. We used surgical modifications to allow sufficient visualization of the sulcus area to avoid injury to the crystalline lens during scleral tunneling and tube insertion through the ciliary sulcus. Postoperatively, the uveitis, ischemia, and vision have improved and IOP was controlled throughout follow-up. Cataract surgery with pupilloplasty was performed in one eye a year later with no complications and no interruption to IOP control.
Conclusions Based on our small and limited retrospective study, and under unusual circumstances, urgent tube shunt implantation through the ciliary sulcus may be considered in phakic eyes with severely uncontrolled IOP, shallow anterior chambers and poor view to the posterior segment, and when concomitant lensectomy is not recommended. We advise the use of appropriate surgical modifications by experienced glaucoma surgeons to prevent intraoperative complications. Further and larger studies are needed to evaluate the safety of this surgical option.

Keywords Tube shunt implantation · Ciliary sulcus · Glaucoma surgery · Intraocular pressure · Phakic · Crystalline lens · Cataract

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Introduction

We have previously demonstrated that Baerveldt tube shunt implantation through the ciliary sulcus is a safe and effective means to reduce intraocular pressure (IOP) in eyes with uncontrolled glaucoma and a posterior chamber intraocular lens (PCIOL) [1, 2], a finding supported by other studies as well [3–6].

Recently, we have encountered 3 phakic eyes of 3 diabetic patients with uncontrolled neovascular glaucoma and an acute need for IOP reduction in the presence of severe inflammation and ischemic retinopathy where our retina consultants recommended to defer crystalline lens removal and to proceed with urgent glaucoma surgery alone. However, these eyes presented with shallow anterior chambers with nearly or completely closed angles where tube shunt implantation through the angle into the anterior chamber without lensectomy would result in tubes positioned too close to the corneal endothelium potentially leading to future corneal failure [7–15]. Our retina consultants considered tube shunt implantation through the pars plana, with the required complete vitrectomy, unsafe due to the poor view to the posterior segment in these eyes, and trabeculectomy was reported to have a limited long-term success in inflamed eyes [16–18] with complications likely in the presence of shallow anterior chambers. Thus, we performed an urgent tube shunt implantation through the ciliary sulcus without crystalline lens removal in these 3 phakic eyes, and in the present study, we describe our clinical experience, surgical modifications, and outcomes. To the best of our knowledge, this procedure has never been described before.

Patients and methods

The Human Investigation Committee, St. Peter's Hospital, Albany, New York, approved this study. We reviewed the clinical course and outcomes of 3 phakic eyes of 3 diabetic patients in whom we performed an urgent Baerveldt 350 tube shunt (Advanced Medical Optics, Santa Ana, CA) implantation through the ciliary sulcus without crystalline lens removal based on our retina consultants' recommendations, and following lengthy discussions with each of our patients regarding the risks and benefits of all available surgical options.

Patients

Patient 1

A 59-year-old Caucasian man with adult-onset diabetes mellitus, bilateral idiopathic chronic uveitis and proliferative diabetic retinopathy (PDR), presenting OS with best-corrected vision of count fingers (CF) at 4 feet with mild myopic correction (− 0.75 D s.eq.), ocular discomfort, neovascular glaucoma (NVG), IOP 36 mmHg on maximal IOP-lowering medications, central corneal thickness (CCT) 555 μ, active panuveitis, extensive posterior synechiae, shallow anterior chamber, florid rubeosis iridis, scattered peripheral anterior synechiae (PAS), nuclear cataract, limited pupil dilation and a poor view to the posterior segment, significant optic disk cupping, and extensive uncontrolled PDR. Other ocular history included multiple sessions of laser peripheral retinal photocoagulation (PRP) and focal laser photocoagulation, and multiple and various anti-vascular endothelial growth factor (anti-VEGF) intravitreal injections.

Patient 2

A 61 year-old Caucasian man with adult-onset diabetes mellitus, systemic hypertension, and a history of central retinal vein occlusion (CRVO) OD several months before, presenting OD with low vision of hand motion with mild hyperopic correction (+ 1.50 D s.eq.), NVG, IOP 53 mmHg on maximal IOP-lowering medications, CCT 592 μ with corneal edema, shallow anterior chamber, florid rubeosis iridis with a 2 mm hyphema, broad PAS with a mostly closed angle, a relatively clear crystalline lens, limited pupil dilation with a poor view to the posterior segment, and uncontrolled CRVO and PDR. Other ocular history included multiple sessions of laser PRP and focal photocoagulation, and multiple and various anti-VEGF intravitreal injections.

Patient 3

A 58-year-old Caucasian woman with insulin-dependent diabetes mellitus, systemic hypertension, migraines, carotid artery stenosis, ischemic heart disease, congestive heart failure, warfarin treatment, and status post-two episodes of cerebral vascular accidents, myocardial infarction and cardiac bypass surgery. She presented OS with recent visual loss, ocular pain, vision of CF at 1 foot with no correction, NVG, IOP 36 mmHg on maximal IOP-lowering medications, CCT 628 with corneal edema, nuclear cataract, florid rubeosis iridis with a 3-mm hyphema, shallow anterior chamber, completely closed angle with high broad PAS, limited pupil dilation with a poor view to the posterior segment, uncontrolled PDR, and a relatively normal optic disk cupping. Ocular history included multiple sessions of laser PRP and focal photocoagulation, and multiple and various anti-VEGF intravitreal injections.

Surgical procedure

All surgical procedures were performed by one investigator (As. W.) following the technique we have previously described of single-stage tube shunt implantation through the ciliary sulcus in pseudophakic eyes [1, 2], including the use of a "rip-cord" valve and fenestrations. However, in the 3 eyes described here, the technique was modified to avoid injury to the crystalline lens as follows:

In addition to the routine inferotemporal limbal incision [1, 2], a superotemporal limbal paracentesis was created through which a surgical peripheral iridectomy (PI), enlarged by Viscoat (Alcon Laboratories, Inc., Fort Worth, TX), was performed in patients 1 and 2 (Figs. 1a, 2a). In patient 3, the pupil margin was pulled out through the superotemporal paracentesis with no PI allowing the small paracentesis to capture and hold the tented iris in place (Fig. 3a).

We injected additional Viscoat behind the superotemporal iris to carefully push the crystalline lens slightly back and centrally to create a safe space between the ciliary sulcus and the crystalline lens with a direct view to this space. A 22-gauge needle, mounted onto the Viscoat syringe, was used to create a shelved scleral tunnel, beginning 2–4 mm from the limbus, directed to enter the Viscoat-enlarged sulcus space. The direct view to this space allowed for the safe introduction of the needle tip into the sulcus without injuring the crystalline lens. The needle was then withdrawn, and the tube was inserted through the scleral tunnel, advanced until its tip emerged into the directly viewed sulcus area, and then advanced further onto the anterior surface of the crystalline lens.

IOP was carefully maintained within normal throughout the procedures, which were completed in the same manner as we have previously described [1, 2] ensuring a water-tight 2-layer closure of Tenon's capsule and conjunctiva and clearing the Viscoat completely from the anterior chamber.

Perioperative care

In all cases, antibiotic, steroid, and nonsteroidal anti-inflammatory eye drops were used 4 times daily starting 3 days prior to surgery, in addition to the maximal IOP-lowering medications. Postoperative therapy included the same eye drops 4 times daily continued until the surgical wound appeared well closed and vascularized, usually for 4–6 weeks. The intraluminal 5-0 nylon "rip-cord" was removed at the slit lamp usually within 5–8 weeks postoperatively. The IOP-lowering medications were titrated to keep IOP within the lower normal range.

Results

Patient 1

During the first postoperative year, IOP remained controlled (range 7–20 mmHg), while vision has improved to 20/80–20/200 without cataract removal. The significant cataract remained stable while the tube prevented the complete closure of the pupil by posterior synechiae by lifting the iris off the cataractous lens at the superior pupil margin (Fig. 1a). Ultrasound biomicroscopy (UBM) showed the tube in good position between the iris and the cataract, with the iris shielding the corneal endothelium from the tube (Fig. 1b).

Thirteen months following surgery, and after intensive treatment for the uveitis and ischemic retinopathy, our retina consultants recommended to proceed with cataract surgery. Pupilloplasty, cataract extraction, and a PCIOL in-the-bag implantation were performed without complications. During the procedure, the tube was exteriorized through a limbal paracentesis while being plugged with a short intraluminal 3-0 nylon suture. At the end of the procedure, the tube plug was removed and the tube was inserted back to its position behind the iris now anterior to the

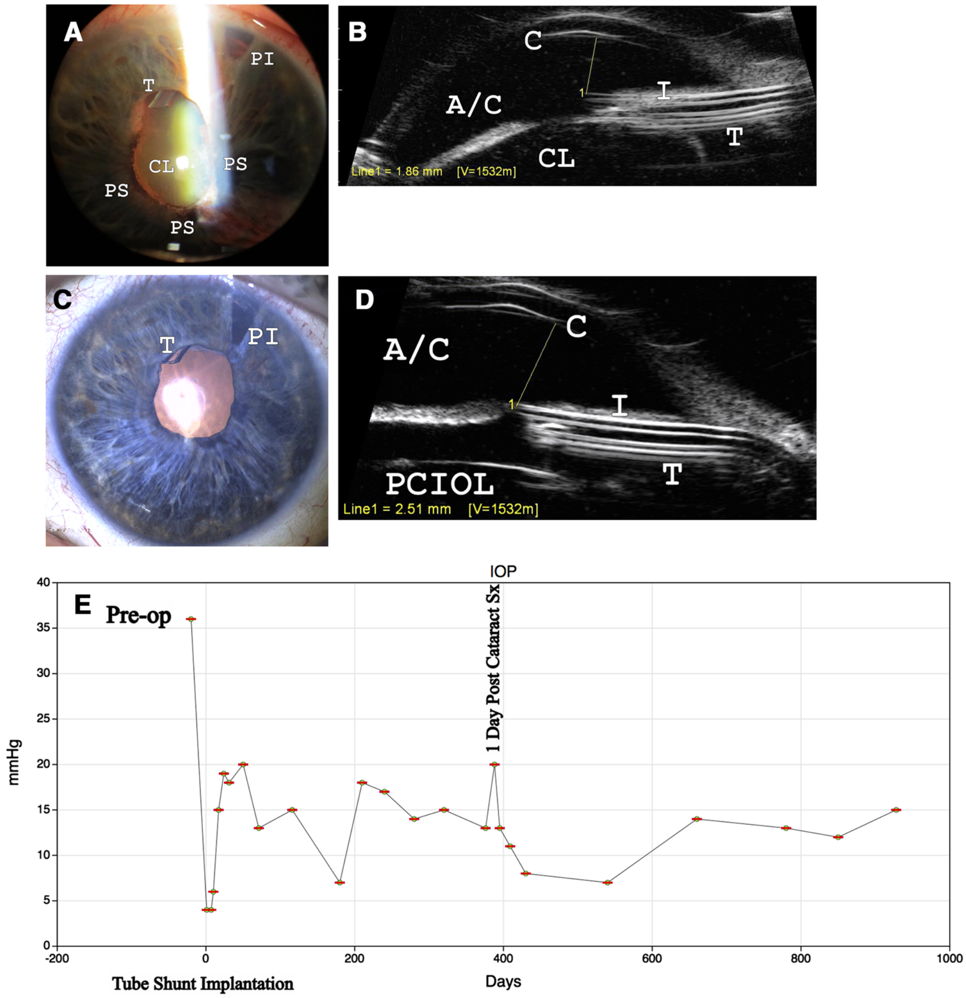

Fig. 1 Patient 1, Left eye: **a** postoperative slit lamp photograph showing the surgical peripheral iridectomy (PI) with the tube (T) presenting at the superior pupil margin and resting between the cataractous crystalline lens (CL) and the iris. The PI served as a viewing window to the sulcus space during the insertion of the tunneling 22G needle and the tube to avoid injury to the CL. Note the tube preventing the complete closure of the pupil superiorly while posterior synechiae (PS) are present everywhere else in this uveitic eye. **b** Ultrasound biomicroscopy (UBM) showing the tube shunt (T) implanted through the ciliary sulcus, resting between the iris (I) and the crystalline lens (CL), as far as possible from the cornea (C; white line 1 = 1.86 mm). The cornea is shielded from the tube by the iris in this phakic eye with shallow anterior chamber (A/C). **c** Postoperative slit lamp photograph 15 months following phakic tube shunt implantation through the ciliary sulcus and 2 months following cataract extraction with pupilloplasty, showing the surgical peripheral iridectomy (PI) with the tube (T) presenting at the superior pupil margin and resting between the posterior chamber intraocular lens (PCIOL) and the iris. The pupil remained free of posterior synechiae in this uveitic eye. **d** Ultrasound biomicroscopy (UBM) 15 months following phakic tube shunt implantation through the ciliary sulcus and 2 months following cataract extraction with pupilloplasty, showing the tube shunt (T) resting between the iris (I) and the PCIOL, as far as possible from the cornea (C; white line 1 = 2.51 mm). The cornea is shielded from the tube by the iris. The anterior chamber (A/C) is still shallow but deeper than prior to cataract surgery (see **b**). **e** Preoperative and postoperative intraocular pressure (IOP) graph. IOP following cataract surgery has stabilized (range 7–15 mmHg) using up to 3 IOP-lowering eye-drop medications

PCIOL (Fig. 1c, d). Following the procedure, vision (range 20/200–20/400) and IOP (range 7–15 mmHg, Fig. 1e) were stable for the next 18 months of follow-up using up to 3 topical medications.

Patient 2

During the postoperative 11-month follow-up (Fig. 2a–c), vision has improved from HM to CF at

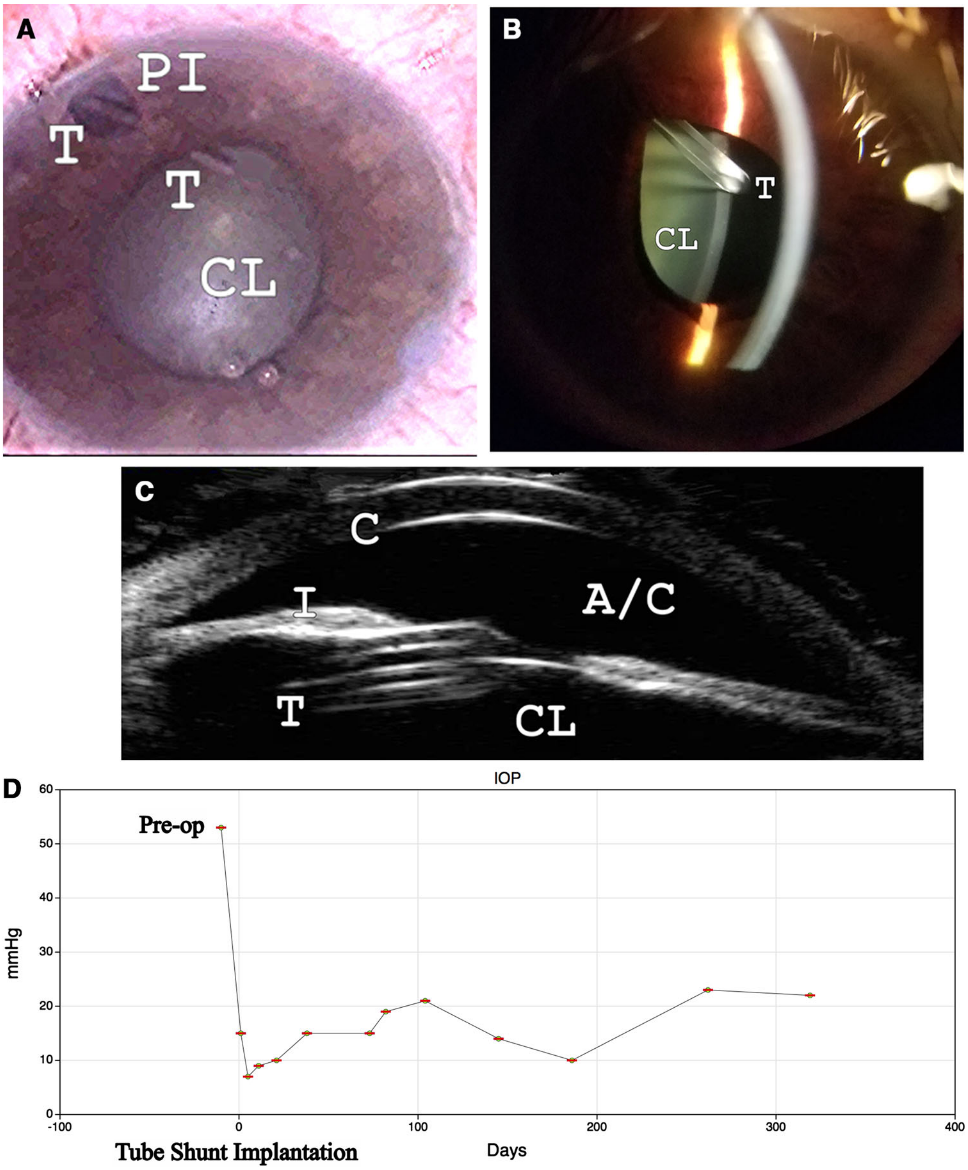

Fig. 2 Patient 2, Right eye: **a** intraoperative photograph showing the surgical peripheral iridectomy (PI) with the sulcus-implanted tube shunt (T) passing under the PI and between the iris and crystalline lens (CL) in this phakic eye with neovascular glaucoma. The PI served as a viewing window to the sulcus area during the insertion of the tunneling 22G needle and the tube. The PI is enlarged by viscoelastic in this photograph. This photograph was enhanced digitally to improve detail. **b** Postoperative slit lamp photograph showing the sulcus-implanted tube shunt (T) in the partially dilated pupil, resting between the crystalline lens (CL) and the iris, and ectropion uveae, in this phakic eye with neovascular glaucoma. The corneal edema has resolved. **c** Postoperative ultrasound biomicroscopy (UBM) showing the tube shunt (T) implanted through the ciliary sulcus, resting between the crystalline lens (CL) and the iris (I), and a very shallow anterior chamber (A/C). The cornea (C) is shielded from the tube shunt by the iris. **d** Preoperative and postoperative intraocular pressure (IOP) graph. IOP has stabilized (range 9–22 mmHg) using up to 2 IOP-lowering eye-drop medications following phakic tube shunt implantation through the ciliary sulcus

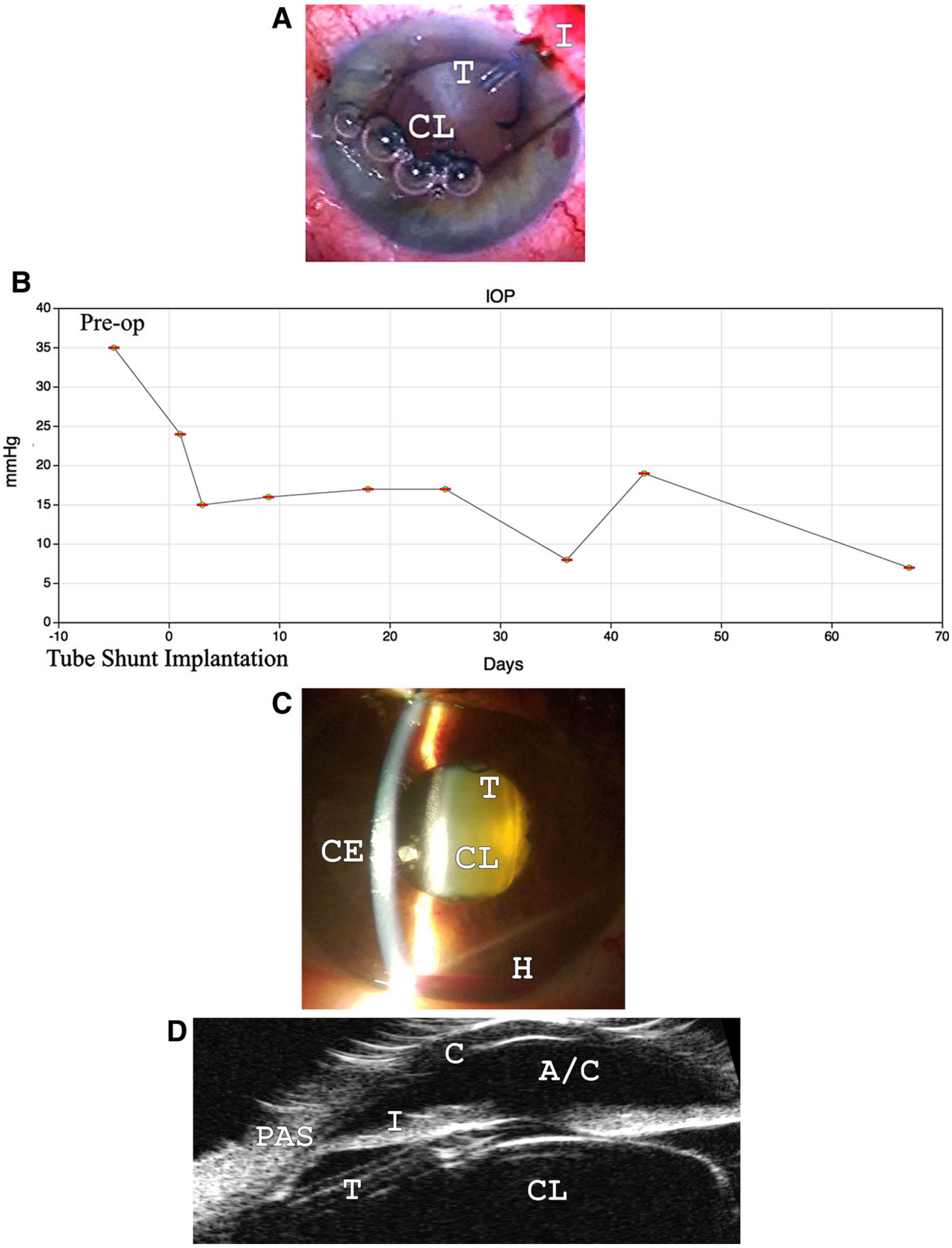

Fig. 3 Patient 3, Left eye: **a** Intraoperative photograph showing the iris (I) pulled through and captured in the limbal paracentesis with the tube (T) passing under the iris onto the cataractous crystalline lens (CL). The iris capture served to provide view to the sulcus space during the insertion of the tunneling 22G needle and the tube to avoid injury to the CL in this phakic eye with neovascular glaucoma. This photograph was enhanced digitally to improve detail. **b** Preoperative and postoperative intraocular pressure (IOP) graph. IOP has stabilized (range 7–19 mmHg) using 1 IOP-lowering eye-drop medication following phakic tube shunt implantation through the ciliary sulcus. **c** Early postoperative slit lamp photograph highlighting the tube well hidden from the cornea behind the iris, peeking at the superior pupil margin (T) while resting between the cataractous crystalline lens (CL) and the iris in this eye with a shallow anterior chamber. The preoperative corneal edema (CE) is improving, and the presurgical hyphema (H) has recurred from the florid iris neovascularization prior to complete resolution. **d** Postoperative ultrasound biomicroscopy (UBM) showing the tube shunt (T) implanted through the ciliary sulcus and resting between the crystalline lens (CL) and the iris (I), a very shallow anterior chamber (A/C), and high broad peripheral anterior synechiae (PAS) completely closing the angle. The cornea (C) is shielded from the tube shunt by the iris

4 feet, the crystalline lens remained relatively clear with no diffuse or focal changes (Fig. 2b), and IOP remained better controlled (range 9–22 mmHg, Fig. 2d) using up to 2 topical medications.

Patient 3

Over the postoperative 9-week follow-up, vision (CF at 1 foot) and IOP (range 7–19 mmHg, Fig. 3b) were stable using 1 topical medication, the significant cataract remained stable, the hyphema has recurred due to the florid rubeosis iridis but slowly resolved, and the corneal edema slowly improved with the tube well shielded from the cornea by the iris (Fig. 3c, d).

Discussion

In the 3 inflamed, ischemic and phakic eyes we describe herein, we were able to implant a Baerveldt 350 tube shunt through the ciliary sulcus using modified surgical techniques without complications and with significant lowering of IOP (Figs. 1e, 2d, 3b) while reducing the number of IOP-lowering medications needed. Specifically, we were able to avoid injury to the crystalline lens while introducing the scleral-tunneling 22G needle and then the tube into the space created between the crystalline lens and the ciliary sulcus. This was achieved by enabling a direct view to that space either by creating a surgical peripheral iridectomy (PI) through a superotemporal limbal paracentesis and enlarging it with a viscoelastic device to improve the view through it, or by pulling the pupil margin through, and capturing it within a similar paracentesis site (Fig. 3a). In either technique, we also used small amounts of viscoelastic to carefully and only slightly push the crystalline lens back and centrally to create a safe space between the ciliary sulcus and the crystalline lens, and to push the iris anteriorly. This slight back pushing of the crystalline lens while lifting the iris with the viscoelastic device, and the direct view we created into that space, allowed us to avoid injury to the crystalline lens and the zonules by directing the 22G needle and then the tube more anteriorly, away from the crystalline lens and the zonules, in all 3 eyes.

The three eyes of 3 patients in our current series were urgent cases where IOP was unacceptably high despite maximal topical and oral medical therapy, while the ocular condition was also critical due to significant and uncontrolled inflammation and ischemia secondary to diabetic retinopathy with nearly or completely closed angles by neovascularization in all 3 eyes, active uveitis in patient 1, and CRVO in patient 2. They were unusual for being phakic while our retina consultants recommended against lensectomy at that stage due to the ocular comorbidities. This recommendation was based on reported risks of worsening macular edema and diabetic retinopathy following cataract removal in uncontrolled diabetic eyes [19–27], and worsening macular edema post-CRVO [22]. Other reports found lower final visual acuity following cataract surgery in eyes with active uveitis [28] and that cataract surgery in the presence of significant uveitis and ischemia can lead to postoperative uveitis flare-up, cystoid macular edema, epiretinal membranes, and other complications [29–31]. While a wait period of at least 3 months without active inflammation is often recommended before any intraocular surgery [30], the critical condition in these 3 eyes required an urgent surgical glaucoma intervention to prevent imminent blindness. Thus, various urgent glaucoma surgical options were considered such as trabeculectomy, cyclophotocoagulation (CPC), tube shunt implantation, and angle surgery, all without lens removal.

We chose not to proceed with trabeculectomy since some reports showed limited success rate in eyes with neovascular glaucoma (NVG) [17, 18] and in eyes with uveitic glaucoma [32] compared to eyes with primary open angle glaucoma [16, 33]. Further, since we planned to defer cataract extraction if possible, performing the latter at a later date following trabeculectomy, and not concomitantly, was shown to decrease long-term IOP control in uveitic glaucoma [34]. Additionally, postoperative hyphema was shown to be a risk factor for trabeculectomy failure in eyes with NVG [18]. Indeed, all 3 eyes in our series had some combination of uncontrolled uveitis, intraocular inflammation associated with NVG, preoperative hyphema, and florid rubeosis iridis increasing the risk of postoperative hyphema. The shallow anterior chambers raised additional concerns for postoperative complications. At the same time, tube shunt success rate in uveitis was 75% compared to 67% post-trabeculectomy [32]. Further, in the tube versus trabeculectomy (TVT) study, the tube success rate was higher than that of trabeculectomy with mitomycin C at the end of a 5-year follow-up, and additional glaucoma surgery was needed more frequently following trabeculectomy [35].

We preferred not to perform cyclophotocoagulation (CPC) in these inflamed and ischemic phakic eyes due to some reports of low long-term success rate of 30–63% [36, 37] and that CPC success rate was inferior to that of tube shunt implantation [38]. Severe complications such as loss of vision, chronic hypotony, and phthisis bulbi were also documented following CPC [39], as well as increased inflammation [40], a further concern in our 3 eyes that presented with active inflammation.

We also chose not to attempt angle surgery such as any of the variety of minimally invasive glaucoma procedures in view of the florid neovascularization and mostly or completely closed angles in all 3 eyes.

In view of the above published data, our retinal consultants' recommendations against lensectomy, and since tube shunt implantation was found effective in emergency settings [41], we decided to proceed with tube shunt implantation as the urgent means to lower IOP while attempting to avoid crystalline lens removal in all 3 eyes.

We then considered 3 different methods of tube shunt implantation, namely tube insertion through the angle into the anterior chamber, through the pars plana into the vitreous cavity, or through the ciliary sulcus to rest between the iris and the crystalline lens. While the first 2 methods are well described in the literature, the third technique has not been previously described to the best of our knowledge.

Tube insertion into the anterior chamber through the angle was of concern in all 3 eyes since their anterior chambers were shallow and the angles were mostly or completely closed with high peripheral anterior synechiae (PAS) with the iris pulled anteriorly away from the crystalline lens. If we were to implant the tube anterior to the high PAS into the shallow anterior chamber, it would insert through corneal tissue and end up positioned too close to the corneal endothelium, even if we were attempting to position it as close as possible to the iris. Inserting the tube through the high PAS would position the tube behind the iris, not unlike our described tube insertion through the ciliary sulcus, and if we were to insert the tube through the high PAS but then through the iris into the shallow anterior chamber, it would again end up positioned too close to the corneal endothelium. Multiple studies have shown that tubes in the anterior chamber can lead to an ongoing corneal endothelial cell loss [7–10, 42, 43], a high failure rate of partial (DSEK) [14] or full-thickness corneal transplants [11–13], and corneal complications in general [15]. In particular, the distance between the tube shunt and the corneal endothelium was found to be the most important risk factor for an ongoing corneal endothelial cell loss following tube shunt implantation [7, 8]. Consequently, we judged tube implantation into the anterior chamber through the angle to be too potentially harmful to the corneal endothelium in all 3 eyes.

We decided to avoid tube shunt implantation through the pars plana into the vitreous cavity in these eyes for the following reasons. First, significant posterior segment complications can occur following pars plana tube insertion [44–48]. Second, the posterior segment view was too poor for a safe complete vitrectomy required to prevent tube block by vitreous, as well as to prevent injury to the crystalline lens during vitrectomy and tube insertion. Thus, our retina consultants recommended against this surgical option.

These considerations left us with the third option of tube insertion through the ciliary sulcus in these phakic eyes. Since we could not find any publication describing such a technique, we developed our own two surgical modifications designed to enable such implantation while avoiding injury to the crystalline lens and the zonules in the area of insertion. The key to the latter was creating a direct view to the space between the ciliary sulcus and the crystalline lens, and enlarging this space carefully while lifting the iris with a viscoelastic device to enable the safe insertion of the 22G scleral-tunneling needle and then the tube more anteriorly into that space thus further away from the crystalline lens and the zonules, as we describe herein.

During the postoperative follow-up period, we observed no significant diffuse or focal cataract progression, including at the area of contact between the tube and the anterior surface of the crystalline lens, in all 3 eyes. Nevertheless, our patients understood that cataract surgery is likely once their eye condition improved sufficiently to enable safe cataract removal. Further, since a crystalline lens injury was possible during our procedure despite our described surgical modifications, we strongly recommend that all patients pre-consent to unplanned cataract surgery, should a crystalline lens injury occur and that the appropriate testing such as IOL power calculation is performed before the tube shunt implantation.

We were able to perform a successful pupilloplasty and cataract extraction with PCIOL implantation in patient 1 once cleared by our retinal consultants 1 year following tube shunt implantation (Fig. 1c, d), with no interruption to IOP control. During the cataract surgery, we exteriorized and blocked the tube through a limbal paracentesis. This handling of the tube may have contributed to its continued function and the ongoing IOP control (Fig. 1e) following the complex cataract surgery.

We have also observed in patient 1 that while the very active uveitis at presentation led to broad posterior synechiae secluding the pupil almost completely, the Baerveldt tube itself did not cause any increase in inflammation despite continuous contact between the tube and both the iris and the cataract. In fact, the tube prevented the pupil from closing completely over time by lifting the superior pupil margin off the lens, leaving the superior pupil margin the only area where the pupil remained open for a year until the cataract surgery (Fig. 1a). After the cataract with pupilloplasty surgery, we observed no uveitic flare-up or any recurrence of posterior synechiae formation during the additional 18-month follow-up.

Our study is very limited by its size, and our surgical modifications have never been described before to the best of our knowledge. The goal of this study was neither to claim nor prove that tube shunt implantation through the ciliary sulcus without crystalline lens removal is superior to any other procedure to control IOP in these uncontrolled, inflamed and ischemic phakic eyes, nor was this study designed to make such comparisons. Instead, this very small case series describes our clinical experience with urgent tube shunt implantation through the ciliary sulcus in phakic eyes under unusual circumstances, using surgical modifications that allowed us a direct view to the ciliary sulcus space to help avoid injury to the crystalline lens and the zonules, while protecting the corneal endothelium in these eyes with shallow anterior chambers. We would not recommend using our described techniques in routine tube shunt implantation, but only in unusual cases while exercising great caution, and to be performed only by surgeons well experienced in tube shunt implantation through the ciliary sulcus.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB), St. Peter's Hospital, Albany, New York, approved this study.

Human and animal rights This article does not contain any studies with animals performed by any of the authors.

Informed consent Since this study is retrospective and does not reveal any identifiable information on any of the patients studied, no informed consent was required or obtained.

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