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ORIGINAL RESEARCH

Outcomes of Ab-Interno Canaloplasty and Gonioscopy-Assisted Transluminal Trabeculotomy in Eyes with Sustained Intraocular Pressure Elevation Following Intravitreal Injections

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Purpose: To evaluate the long-term efficacy and safety of combined ab-interno canaloplasty (ABiC) and gonioscopy-assisted transluminal trabeculotomy (GATT) with the iTrack microcatheter in patients with sustained intraocular pressure (IOP) elevation following intravitreal anti-VEGF or steroid injections.

Patients and Methods: This was a retrospective, single-center study of patients who underwent ABiC and GATT with the iTrack microcatheter between 2017 and 2021 for secondary open-angle glaucoma or ocular hypertension following intravitreal injections. Eligible eyes had a preoperative IOP of ≥18 mmHg while on maximal tolerated medical therapy. Primary outcomes included IOP and glaucoma medication burden. Surgical success was defined using American Academy of Ophthalmology (AAO) criteria. Subgroup analyses were conducted by etiology (anti-VEGF vs steroid-induced). Kaplan-Meier analysis estimated cumulative success rates.

Results: Thirty-four eyes from 30 patients were included, with a mean last follow-up of 15.3±9.8 months. Mean IOP was reduced by 46%, from 28.1±6.0 mmHg at baseline to 14.3±5.6 mmHg ($p<0.001$) at the last follow-up, while the number of medications decreased from 2.79±0.9 to 1.76±1.5 ($p=0.001$). Surgical success was achieved in 71% of eyes. Medication-free status was reached in 29% of eyes, compared with none at baseline, and 26% achieved IOP ≤15 mmHg without medications. Additional glaucoma procedures were needed in 11.8% of eyes. Combined ABiC and GATT remained effective in eyes receiving post-procedure intravitreal reinjections or prolonged topical steroid use. Kaplan-Meier analysis showed a survival probability above 70% at 25 months.

Conclusion: Combined ab-interno canaloplasty and GATT using the iTrack microcatheter is a safe surgical option for selected eyes with sustained IOP elevation following intravitreal injections. The procedure achieved meaningful reductions in IOP and medication use, including in eyes requiring continued intravitreal therapy, supporting a primary surgical effect. Careful patient selection and long-term follow-up remain essential, as a subset of eyes may require additional intervention.

Plain Language Summary: Some people who receive eye injections for conditions like macular degeneration or diabetic eye disease may develop higher eye pressure over time. This can lead to glaucoma, a condition that damages the optic nerve and can cause vision loss. Medicines to lower pressure do not always work well enough, and traditional glaucoma surgery can carry risks.

We wanted to find out if ab-interno canaloplasty and gonioscopy-assisted transluminal trabeculotomy, combined together, could safely lower eye pressure in these patients. Both surgeries use a fine surgical thread, called a microcatheter, to open the natural drainage system of the eye and improve fluid outflow.

We looked back at the medical records of 30 people (34 eyes) who had these combined procedures after developing high eye pressure following repeated injections or steroid treatment. At the latest follow-up visit, eye pressure had dropped by almost half and most people were able to reduce the number of daily eye drops they needed. About three out of four eyes met the standard definition of

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surgical success, and one in four no longer needed any pressure-lowering medication. Only a small number of patients required another glaucoma operation.

Our results suggest that these combined procedures can be an effective and safer option to control high eye pressure after eye injections. This may help reduce the need for more invasive surgery. Long-term follow-up remains important, as some people may still require additional treatment later on.

Keywords: microcatheter-assisted glaucoma surgery, secondary open-angle glaucoma, steroid-induced ocular hypertension, anti-VEGF therapy, surgical success criteria

Introduction

Intravitreal injections, commonly used to treat various ocular conditions, have been associated with both transient and sustained intraocular pressure (IOP) elevation.[1–3] While transient IOP increases are expected due to the additional fluid volume in the vitreous cavity, sustained elevations are less understood and are thought to result from reduced aqueous outflow. Contributing factors may include repeated damage to the trabecular meshwork from high-volume injections, changes in vasodilating modulators such as nitric oxide, drug toxicity, or inflammation-induced injury.[2]

Sustained IOP elevation following intravitreal injections has been reported in approximately 3.5% to 8.5% of cases.[1,2] Several risk factors increase the likelihood of developing this condition, including older age, male sex, South Asian ethnicity, narrow angles, preexisting glaucoma, a history of repeated injections (more than six), and underlying diseases such as age-related macular degeneration (AMD) or retinal vein occlusion (RVO).[3] Additionally, bevacizumab, ranibizumab, and steroid use are associated with IOP elevation. Steroid administration, regardless of route, can impair trabecular meshwork (TM) function by inhibiting proteases and phagocytosis, rendering the extracellular matrix of the TM less permeable.[3–5] However, the mechanisms underlying acute and/or delayed IOP elevations after anti-vascular endothelial growth factor (VEGF) injections are not yet fully elucidated. Proposed mechanisms include ultrastructural changes within the trabecular meshwork, such as micro-obstruction by protein aggregates, reduced trabecular phagocytic activity, extracellular matrix remodeling, and potential toxic effects on trabecular endothelial cells. These changes may cumulatively impair conventional aqueous outflow, predisposing susceptible eyes to persistent IOP elevation after chronic anti-VEGF exposure.[6,7] Gonioscopy-assisted transluminal trabeculotomy (GATT) is a minimally invasive procedure that incises the trabecular meshwork to enhance aqueous outflow into Schlemm's canal.[8] GATT has demonstrated efficacy in both primary and secondary open-angle glaucoma, with reported IOP reductions ranging from 37% to 50%, along with an average reduction of 1.43 glaucoma medications over a 24-month period.[9] Ab-interno canaloplasty (ABiC), another minimally invasive glaucoma surgery (MIGS) procedure, is a nonpenetrating surgical technique that targets outflow resistance at Schlemm's canal (SC) and collector channels, as well as the inner wall of the SC and TM. Studies have shown that ABiC can reduce IOP by approximately 2% to 35%, with a decrease in medication usage ranging from 53% to 97%.[10]

Hyphema is the most commonly reported adverse event associated with GATT, typically resulting from blood reflux through the episcleral veins. Reported hyphema rates after GATT range from 36% to 91.3%, with an average incidence of approximately 56.6%.[11] In contrast, ab-interno canaloplasty (ABiC) is generally associated with a lower incidence of hyphema, often reported at rates below 20%.[12] A randomized controlled trial by Yin et al[13] comparing the efficacy and safety of ABiC and GATT reported hyphema in 47% of patients in the ABiC group and 87% in the GATT group.

The use of the iTrack microcatheter (Nova Eye Medical, Fremont, USA) during GATT may offer technical and clinical advantages over traditional suture-based techniques. The microcatheter allows controlled circumferential catheterization of Schlemm's canal with real-time visual guidance via its illuminated tip, enhancing procedural accuracy and reducing the risk of false passage or canal misdirection. Its ability to deliver a titrated and pressurized volume of ophthalmic viscosurgical devices (OVD) during circumnavigation helps viscodilate Schlemm's canal and collector channel ostia, improving outflow facility and reducing the incidence of intraoperative and postoperative hyphema through tamponade of refluxing blood. These features may be advantageous in eyes with secondary glaucoma or prior angle surgery, where anatomical distortion can increase procedural complexity.[14]

Historically, glaucoma drainage devices like the Ahmed Glaucoma Valve have been the standard surgical treatment for ocular hypertension (OHT) or secondary open-angle glaucoma (OAG) when medical therapy fails. However, MIGS has emerged as a safe and effective alternative. The effects of MIGS on post-injection IOP remain underexplored. This study aims to evaluate the long-term efficacy and safety of combined ab-interno canaloplasty (ABiC) and gonioscopy-assisted transluminal trabeculotomy (GATT) using the iTrack microcatheter in eyes with sustained intraocular pressure elevation associated with or following intravitreal injections, regardless of pre-existing glaucoma or ocular hypertension status.

Patients and Methods

This was an observational retrospective study conducted at a single center (El Paso Eye Surgeons, PA, USA). The study involved a retrospective analysis of patient data including the collection of IOP, ocular hypertensive medications, and safety data for cases that underwent combined ab-interno canaloplasty and GATT using the iTrack microcatheter from 2017 to 2021 by surgeons from El Paso Eye Surgeons, PA for treatment of sustained IOP elevation resulting from intravitreal injections by surgeons at Southwest Retina Consultants, PA. The study was conducted in accordance with the ethical standards of 1964 Declaration of Helsinki and its later amendments. The research protocol was reviewed by Advarra Institutional Review Board (IRB#00000971) and determined to be exempt from IRB oversight under category 4 of 45 CFR 46.104(d), under project number Pro00076136. Patient consent was waived due to the retrospective nature of the study.(d), under project number Pro00076136. Patient consent was waived due to the retrospective nature of the study.

Patient Selection

Patients were eligible for inclusion if they had sustained IOP elevation or secondary open-angle glaucoma (OAG) following intravitreal injections and subsequently underwent combined ab-interno canaloplasty and GATT using the iTrack microcatheter. In this study, "secondary glaucoma" or sustained IOP elevation is defined as an immediate or delayed postoperative elevation in intraocular pressure (IOP) exceeding 18 mmHg, regardless of the presence of optic nerve or visual field glaucomatous damage. Eligible eyes had a preoperative IOP of ≥18 mmHg while receiving maximal tolerated medical therapy. Because steroid-induced and injection-related IOP elevations frequently overlap in clinical practice, eyes with multifactorial secondary glaucoma (eg, associated with uveitis, PDR, or prior glaucoma surgery) were also included to reflect real-world patient heterogeneity. Despite the presence of heterogeneous underlying ocular conditions, the unifying indication for surgical intervention in all included eyes was a sustained elevation in intraocular pressure temporally associated with intravitreal injection therapy and refractory to maximal tolerated medical treatment.

Exclusion criteria included other forms of secondary OAG, history of ocular trauma, complicated cataract surgery resulting in intraocular lens placement outside the capsular bag, or inability to visualize the trabecular meshwork (TM). Patients were also excluded if they had corneal pathology limiting angle visualization or IOP measurement, absence of extensive peripheral anterior synechiae, were on systemic anticoagulation, or had incomplete records or were lost to follow-up by both the glaucoma and retina teams.

Surgical Procedure

All surgeries were performed by experienced surgeons from El Paso Eye Surgeons, PA, each trained in and adhering to a standardized surgical protocol for gonioscopy-assisted transluminal trabeculotomy (GATT) using the iTrack microcatheter. Preoperative preparation, intraoperative steps, and postoperative management were uniform across surgeons following the technique described by Grover et al and Al Habash et al[8,15] A corneal paracentesis was created, and the anterior chamber was filled with an OVD. The iridocorneal angle was visualized nasally using a Swan-Jacob gonioscope, and a 1–2 mm goniotomy was created in the trabecular meshwork (TM) using a crescent blade.

An illuminated iTrack microcatheter (Nova Eye Medical, Fremont, USA) was then inserted through a separate paracentesis into the goniotomy site. It was advanced circumferentially through Schlemm's canal with microsurgical forceps, assisted by OVD injection (two clicks per clock hour) while guiding the catheter's illuminated tip, thereby expanding the canal and distal collector channels and lowering outflow resistance.

Once the entire canal was cannulated, the distal end of the microcatheter was externalized through the main corneal incision, and the proximal end was pulled into the anterior chamber to complete a 360° GATT. If a full 360°

trabeculotomy or canaloplasty could not be achieved due to obstruction, the catheter was redirected in the opposite direction to access the remaining portion of the canal.

At the conclusion of the procedure, the anterior chamber was irrigated to remove residual viscoelastic and blood, leaving a small amount to minimize bleeding from the canal. Corneal incisions were sealed with hydration or sutures as needed, and a subconjunctival steroid injection was administered. In combined procedures, canaloplasty and GATT were performed immediately following standard phacoemulsification and intraocular lens implantation.

Postoperative Assessment

All patients were prescribed postoperative topical antibiotics and corticosteroids. In addition, some patients also received topical nonsteroidal anti-inflammatory drugs (NSAIDs), either in combination with steroids or as the sole anti-inflammatory treatment, depending on the surgeon's preference and clinical judgment. Topical antibiotics were continued until the 1-week follow-up, whereas steroids were tapered individually based on postoperative inflammation. The duration of NSAID therapy varied from 1 week to 1 month, according to the surgeon's discretion. All glaucoma medications were discontinued unless the intraocular pressure exceeded 20 mmHg, in which case they were reintroduced as deemed necessary.

Data Collection and Parameters

Preoperative assessments included corrected distance visual acuity (CDVA), IOP measured using Goldmann tonometry, slit-lamp examination, and fundus and optic disc evaluation.

Additional data collected included age, indication for intravitreal injection, type and frequency of intravitreal injections administered before and after combined ab-interno canaloplasty and GATT, and any prior cataract or glaucoma procedures. Adverse events, such as IOP spikes, the need for secondary surgical intervention, and/or recurrent hyphema, were also recorded.

Follow-up timing varied after the first visit. To help standardize visits despite differing follow-up schedules, the visits were selected on the basis of closest proximity to 1 week and 1, 3, 6, 12, and 24-month postoperative appointments. IOP, medication use, and complications were documented at all follow-up visits. All examinations were conducted by experienced ophthalmologists and technicians.

Outcome Measures

The primary outcomes were IOP and the number of glaucoma medications. Secondary outcomes included the surgical success rate as per the American Academy of Ophthalmology (AAO) criteria, defined as an IOP of $\leq$21 mmHg with a reduction of $\geq$20% from baseline without an increase in glaucoma medications, additional laser or incisional glaucoma surgery, loss of light perception, or hypotony.[16] Kaplan-Meier analysis was applied to estimate cumulative probabilities of surgical failure using the AAO criteria at the last available follow-up. Additional assessments included combined ab-interno canaloplasty and GATT outcomes in eyes requiring intravitreal re-injection, additional topical steroid use and the complication rate. For overall cohort-level postoperative outcomes, the Last Follow-Up (LFU) value of each eye was used; mean follow-up duration and corresponding outcome measures were calculated based on these LFU data.

Statistical Analysis

Descriptive statistics were used to summarize patient data. Changes in IOP and the number of medications at various time points (baseline, 1 week, 1 month, 3 months, 6 months, 12 months, and 24 months) were compared using the Wilcoxon signed-rank test (SPSS Statistics for Windows version 27, NY: IBM Corp.). Comparisons of mean IOP and mean medication use between groups were calculated using the Mann–Whitney *U*-test. A p-value of <0.05 was considered statistically significant. Graphs and tables were prepared in accordance with World Glaucoma Association (WGA) guidelines.[17]

Results

Thirty-four eyes from 30 patients who underwent combined ab-interno canaloplasty and GATT using iTrack microcatheter for sustained IOP elevation following intravitreal injections were included in this study. Among them, 16 eyes (47%) had anti-VEGF-induced hypertension, while 18 eyes (53%) had steroid-induced hypertension. The cohort consisted of 63% male and 37% female; mean age was 65.4±14.0 years. Eight eyes had previous glaucoma surgery: five eyes had received an iStent

implant, and three eyes had been implanted with a glaucoma drainage device (2 eyes with Ahmed Glaucoma Valve implantation and 1 eye with a Baerveldt explantation). Four patients had both eyes included in this study. The mean follow-up duration (last follow-up or LFU) was 15.3±9.8 months (range 0.25–36 months). The cumulative number of intravitreal injections prior to surgery varied widely, ranging from 1 to 31 injections per eye (mean 11.76). The mean intraocular pressure before initiation of intravitreal therapy was 16 mmHg, suggesting that most eyes did not exhibit elevated IOP prior to injection exposure. All eyes in this cohort for which number of injections is recorded (n=21), experienced a rise in IOP following IV injection: mean raise was 12.6 mmHg (range 4 to 25; median 13). Baseline demographic data are summarized in Table 1.

Table 1 Demographics Presented as Mean±SD or N (%)

Patients	**N=30**
Age (years)	65.4±14.0
Sex	
Male	19 (63%)
Female	11 (37%)
Ethnicity	
Hispanic	16 (53%)
Missing	14 (47%)
Eyes	**N=34**
Left	21 (62%)
Right	13 (38%)
Ocular History	
Chronic uveitis	12 (35.3%)
PDR	6 (17.6%)
Retinal vein occlusion	4 (11.8%)
Wet AMD	3 (8.82%)
Chronic steroid use for ocular irritation	1 (2.94%)
Keratoconus	1 (2.94%)
NVG	1 (2.94%)
OAG	1 (2.94%)
RA, corneal melt	1 (2.94%)
VKH	1 (2.94%)
Missing	3 (8.82%)
Type of Injection	
Anti-VEGF induced	16 (47%)
Steroid induced	18 (53%)
Preoperative Measurements	
IOP (mmHg)	28.1±6.0
Medications (no.)	2.79±0.9
Cup-to-disc ratio	0.73±0.19 (n=30)
CDVA (logMAR)	0.72±0.70
Previous Surgery	
Cataract surgery	27 (79%)
Glaucoma surgery	8 (23.5%)
Filter/Conjunctival surgery	3 (8.8%)
MIGS	5 (14.7%)
Follow-up duration (months)	15.3±9.8

Abbreviations: NVG, Neovascular Glaucoma; OAG, Open-Angle Glaucoma; PDR, Proliferative Diabetic Retinopathy; RA, Rheumatoid Arthritis; VKH, Vogt-Koyanagi-Harada Disease; Wet AMD, Wet Age-Related Macular Degeneration; CDVA, corrected distance visual acuity; MIGS, minimally invasive glaucoma surgery.

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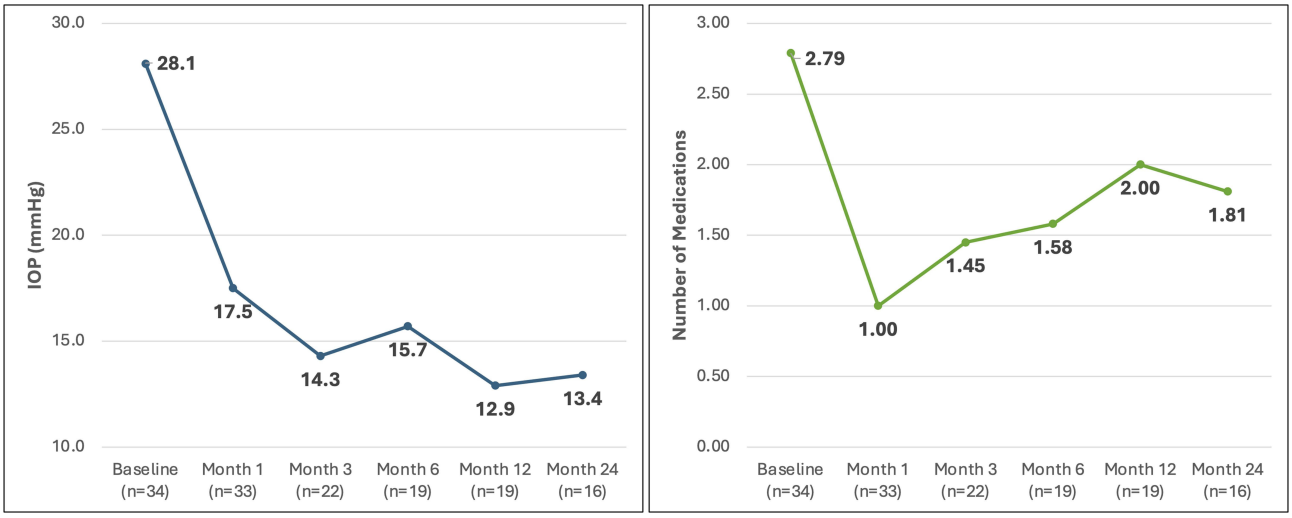

Figure 1 Line graphs showing IOP and medications outcomes at different timepoints.

Chronic uveitis was the most common indication for intravitreal injections (35.3%), followed by proliferative diabetic retinopathy (PDR) (17.6%), retinal vein occlusion (11.8%), wet age-related macular degeneration (AMD) (8.82%), and other conditions (26.5%).

Combined ab-interno canaloplasty and GATT procedure was effective in significantly reducing both IOP and the number of glaucoma medications in patients with sustained IOP elevation, as depicted in Figure 1 and Table 2.

Across all eyes, the mean IOP decreased by approximately 46% from a baseline of 28.1±6.0 mmHg to 14.3±5.6 mmHg at LFU ($p<0.001$). In the anti-VEGF-induced ocular hypertension group, IOP reduced by 42%, from 27.9±5.2 mmHg to 15.4 ±7.5 mmHg ($p=0.001$) at LFU. The steroid-induced group showed a 48% reduction, from 28.3±6.7 mmHg to 13.3±2.9 mmHg ($p<0.001$) at LFU. The difference in IOP between the two groups was not statistically significant at any time point except at Month 6 ($p=0.037$) (Table 2). Combined ab-interno canaloplasty and GATT resulted in a significant decrease in the number of glaucoma medications across all eyes, from an average of 2.79±0.9 at baseline to 1.76±1.5 at the last observation ($p=0.001$), representing a 37% reduction. In the anti-VEGF group, the number of medications decreased by 25%, from 2.75±1.0 to 2.06±1.4 ($p=0.049$) at LFU. In the steroid-induced group, a 47% reduction was observed, from 2.83±0.9 to 1.50±1.5 ($p=0.011$). Notably, at the six-month follow-up, the steroid-induced group had a significantly lower medication use compared to the anti-VEGF group ($p=0.024$) (Table 2).

In Figure 2A, most data points lie below the diagonal black line, indicating a postoperative reduction in IOP. The red line represents a 20% IOP reduction threshold, showing that a considerable number of eyes achieved reductions greater than 20%. Figure 2B compares the number of glaucoma medications used preoperatively and postoperatively as per WGA guidelines. The graph demonstrates a notable reduction in the number of medications postoperatively, with a significant increase in the number of eyes requiring no medications. Additionally, the proportion of eyes needing three or more medications decreased substantially.

Surgical Success Rate

At the last follow-up (15.3±9.8 months), 71% of eyes met the American Academy of Ophthalmology (AAO) criteria for surgical success, with 75% of eyes in the anti-VEGF-induced group and 67% in the steroid- induced group achieving this outcome. Eyes with prior Ahmed Glaucoma Valve implantation met failure criteria postoperatively, whereas the single eye with prior Baerveldt explantation achieved successful IOP reduction. Overall, 29% of eyes were free from glaucoma medications at the last follow-up versus none at baseline. An IOP of ≤15 mmHg without medications was achieved in 26% of eyes at the last follow-up.

The Kaplan-Meier survival curves in Figure 3 show that surgical success gradually declines over time.

The failure rate was calculated on the latest visit available.

Table 2 Efficacy Outcomes for Intraocular Pressure and Number of Medications

Intraocular Pressure									
	Baseline	**Week 1**	**Month 1**	**Month 3**	**Month 6**	**Month 12***	**Month 24****	**LFU**	**Change**
All Eyes	28.1±6.0 (n=34)	18.8±11.4 (n=34)	17.5±10.6 (n=33)	14.3±5.4 (n=22)	15.7±6.3 (n=19)	12.9±2.9 (n=19)	13.4±3.4 (n=16)	14.3±5.6 (n=34)	−13.9
P value	–	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	–
Anti-VEGF induced	27.9±5.2 (n=16)	19.3±10.4 (n=16)	14.9±5.1 (n=15)	12.8±2.0 (n=8)	20.7±8.5 (n=6)	12.9±1.5 (n=8)	12.2±4.1 (n=6)	15.4±7.5 (n=16)	−12.5
P value	–	0.014	<0.001	0.014	0.094	0.014	0.063	0.001	–
Steroid-induced	28.3±6.7 (n=18)	18.3±12.6 (n=18)	19.7±13.4 (n=18)	15.1±6.5 (n=14)	13.5±3.5 (n=13)	12.9±3.7 (n=11)	14.1±2.8 (n=10)	13.3±2.9 (n=18)	−15.1
P value	–	0.008	0.039	0.002	0.002	0.004	0.008	<0.001	–
P value between Anti-VEGF and Steroid	0.876	0.534	0.677	0.555	0.037	0.505	0.153	0.972	0.666
Number of Medications									
	Baseline	**Week 1**	**Month 1**	**Month 3**	**Month 6**	**Month 12***	**Month 24****	**LFU**	**Change**
All Eyes	2.79±0.9 (n=34)	0.32±0.9 (n=34)	1.00±1.2 (n=33)	1.45±1.3 (n=22)	1.58±1.4 (n=19)	2.00±1.6 (n=19)	1.81±1.6 (n=16)	1.76±1.5 (n=34)	−1.03
P value	–	<0.001	<0.001	0.002	0.008	0.033	0.045	0.001	–
Anti-VEGF induced	2.75±1.0 (n=16)	0.44±1.1 (n=16)	1.20±1.1 (n=15)	1.63±1.5 (n=8)	2.67±1.0 (n=6)	2.75±1.3 (n=8)	2.33±1.2 (n=6)	2.06±1.4 (n=16)	−0.69
P value	–	<0.001	0.011	0.174	0.424	0.346	0.586	0.049	–
Steroid-induced	2.83±0.9 (n=18)	0.22±0.6 (n=18)	0.83±1.2 (n=18)	1.36±1.3 (n=14)	1.08±1.3 (n=13)	1.45±1.6 (n=11)	1.50±1.7 (n=10)	1.50±1.5 (n=18)	−1.33
P value	–	<0.001	<0.001	0.010	0.014	0.063	0.073	0.011	–
P value between Anti-VEGF and Steroid	0.731	0.556	0.336	0.725	0.024	0.083	0.291	0.248	0.422

Note: *includes 9M data; ** includes 24m+ data. P values between timepoints (baseline vs follow-up) calculated using Wilcoxon signed-rank test; P values between groups calculated using Mann–Whitney *U*-test. Last Follow-Up (LFU): 15.3±9.8 months.

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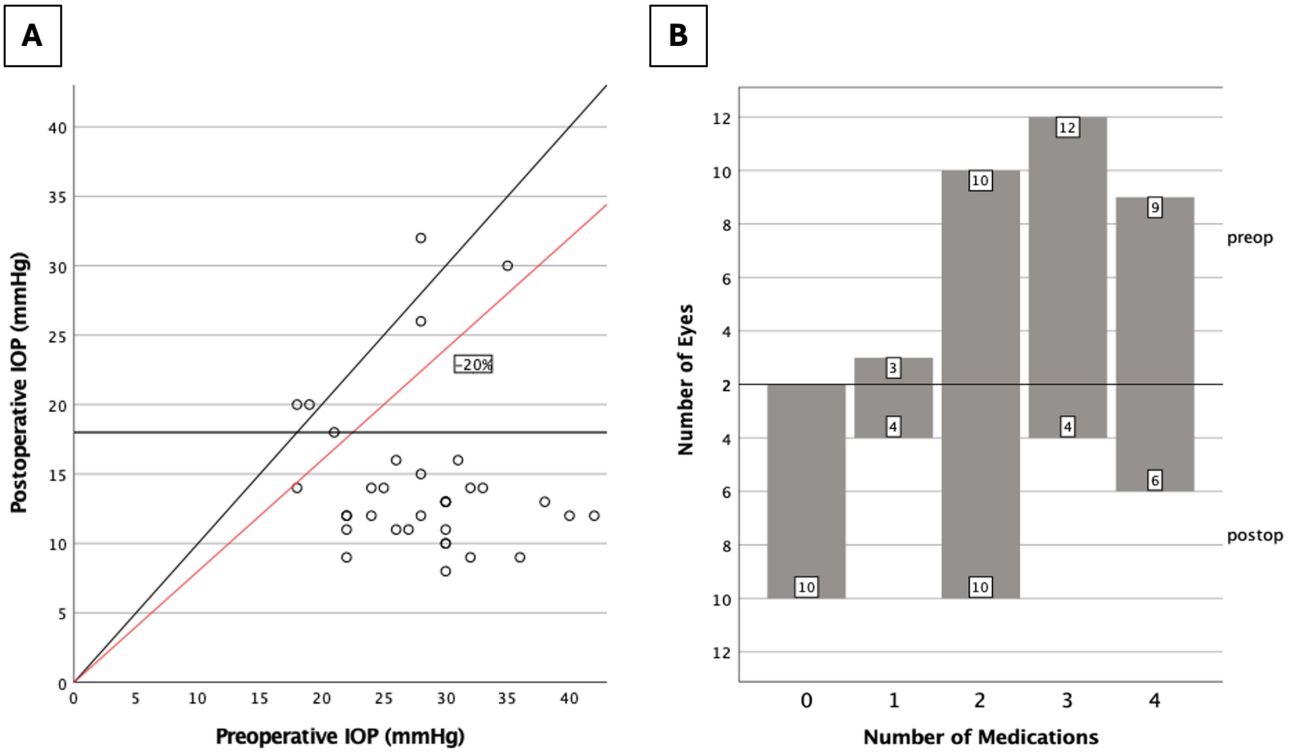

Figure 2 (**A**) Scatterplot of IOP outcomes at baseline vs last observation (mean follow-up: 15.3±9.8 months). Points on or below the red line indicate eyes with ≥20% reduction in IOP from baseline. Horizontal line represents 18 mmHg. (**B**) Bar diagram of medications outcomes at baseline vs last observation.

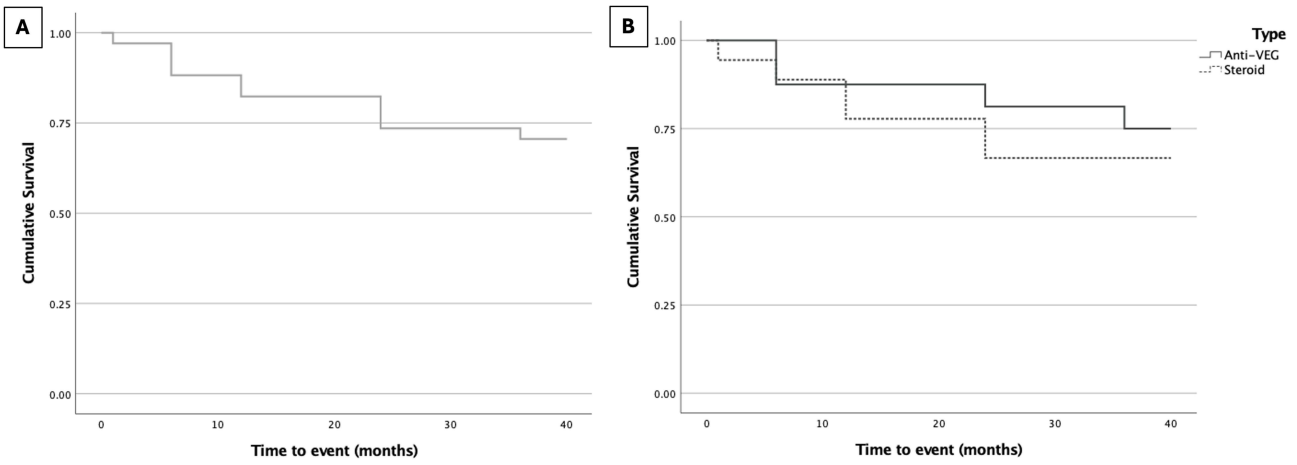

Figure 3 Kaplan-Meier survival analysis of eyes that had additional surgery or did not reach AAO success criteria (n=10, 29%), presented as (**A**) all eyes, and as (**B**) eyes by type.

Ongoing Intravitreal Re-Injection and Steroid Drops

We also evaluated the efficacy of combined ABiC and GATT in reducing IOP and number of medications in patients who underwent subsequent intravitreal re-injection following this procedure. In this subset of patients (n=9), the mean IOP significantly decreased from 27±6.5 mmHg at baseline to 14.6±5.2 mmHg at the last follow-up (p=0.015). Although the number of medications decreased from 3±1.0 to 1.4±1.5, this reduction was not statistically significant (p=0.053). The average time to the first intravitreal re-injection following combined ABiC and GATT was 2.2±1.9 months. Patients underwent an average of 4.3±4.4 injections, ranging from 1 to 13 injections. Notably, those treated with aflibercept (Eylea®) had an average of 5.3±5.3 injections, whereas patients receiving bevacizumab (Avastin) or combination

therapies with aflibercept (Eylea®), dexamethasone (Ozurdex®), fluocinolone acetonide (Iluvien®), or triamcinolone acetonide-dexamethasone (Kenalog®-Ozurdex®) had fewer injections (mean 3.0±3.5).

Additionally, we assessed the efficacy of combined ABiC and GATT in patients who continued using topical steroid eye drops beyond one month after surgery. This subgroup included 10 patients with a mean follow-up of 15.8±7.9 months. The mean IOP was reduced by 53%, from 29.1±7.1 mmHg at baseline to 12.8±2.6 mmHg at the last follow-up (p=0.006). The number of glaucoma medications decreased from 2.9±0.9 to 1.4±1.4, although this reduction was not statistically significant (p=0.057).

Complications

The most common complication was hyphema, occurring in 55.9% of eyes (n=19) on day 1 post-surgery, which resolved spontaneously. Secondary surgical interventions were necessary in 4 eyes (11.8%): two patients (5.88%) underwent Ahmed Glaucoma Valve implantation at 6 months, one patient received selective laser trabeculoplasty (SLT) at 6 months, and another patient required diode laser treatment at 1 month. The results of the eyes undergoing the Ahmed Glaucoma Valve implantation were excluded from the analysis following the additional glaucoma surgery; the results of eyes undergoing laser procedures were not excluded from the analysis as these were considered routine clinical procedures.

Discussion

Published data on the use of combined ab-interno canaloplasty and GATT using the iTrack microcatheter for treating sustained ocular hypertension following intravitreal injections remain limited. Our study contributes to the growing evidence supporting the safety and efficacy of combined ab-interno canaloplasty and GATT in this unique patient population. We found that combined ab-interno canaloplasty and GATT significantly reduced both IOP and glaucoma medication burden in eyes with sustained IOP elevation due to either anti-VEGF or steroid intravitreal injections.

In our cohort, mean IOP was reduced by 46%, from 28.1±6.0 mmHg at baseline to 14.3±5.6 mmHg at the last follow-up, accompanied by a 37% reduction in medication use. These outcomes are consistent with previous reports of GATT and canaloplasty with the iTrack in similar patient populations. Boese et al[18] reported a 63% IOP reduction and a 74% decrease in medication use in patients with steroid-induced glaucoma at 24 months post-GATT. Similarly, Hopen et al[14] documented a 68.4% IOP reduction over two years in a pediatric patient with steroid-induced glaucoma. Lenci et al[19] (device not specified) described a 56% IOP reduction six weeks postoperatively in a case of steroid-induced glaucoma. Sachdev et al[20] observed a 40–60% reduction in patients with uveitic glaucoma. Kanter et al[21] reported a 54.3% IOP decrease with medication independence at nine months following GATT in a patient with neovascular glaucoma and repeated anti-VEGF injections. Additionally, Quan et al[22] demonstrated short-term success of GATT in secondary glaucoma following vitreoretinal surgery, with IOP and medication reductions of 58.4% and 66.7%, respectively, at a median follow-up of four months. Interim results from a small cohort study by Brusini et al[23] reported a 55% reduction in IOP and a 95% reduction in glaucoma medications at 12 months postoperatively in patients with steroid-induced glaucoma treated with canaloplasty. Similarly, Prinz et al[24] demonstrated a 33.7% reduction in IOP and a 56% reduction in medication use at 18 months in a broader population that included steroid-induced glaucoma among other glaucoma types.

Collectively, these findings support the versatility and efficacy of canaloplasty and GATT across a wide range of secondary glaucoma etiologies connected with retinal treatments that can ignite or exacerbate high IOP.

In our study, the overall surgical success rate following combined ab-interno canaloplasty and GATT was 71%, which is lower than the 100% success rate reported by Al Habash et al[15] for the same procedure in patients with POAG. This difference may be attributed to the underlying diagnosis, as our cohort included eyes with secondary glaucoma following intravitreal injections, a population for which published data on this combined approach remains scarce.

In our cohort, three eyes had undergone prior tube shunt surgery before combined ABiC–GATT. Of these, both eyes with a prior Ahmed Glaucoma Valve met failure criteria following ABiC–GATT, whereas the single eye with prior Baerveldt explantation achieved successful IOP reduction. Although limited by small numbers, this finding suggests that eyes requiring prior tube shunt surgery—particularly valved devices in the setting of chronic inflammation—may represent a more advanced disease state with irreversible compromise of the distal outflow pathway, thereby limiting the effectiveness of subsequent angle-based restorative procedures.

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While tube shunt surgery remains essential for advanced or refractory inflammatory glaucoma, ABiC– GATT may offer advantages when performed earlier in selected eyes by restoring physiologic outflow while preserving the conjunctiva and future surgical options. These procedures should therefore be viewed as complementary, rather than alternative, to tube shunt surgery.

The rationale for incorporating GATT, rather than canaloplasty alone, lies in the pathology of this population. Sustained IOP elevation after intravitreal injection is often associated with TM dysfunction, whether due to direct obstruction by injected agents, mechanical trauma from repeated injections, or inflammatory changes.[7] In these scenarios, preserving a compromised TM (as is done with canaloplasty alone) may limit the effectiveness of outflow restoration. Therefore, TM excision through GATT provides a more definitive bypass of the primary resistance point, offering an enhanced therapeutic effect in cases of secondary glaucoma.

This also reflects the clinical reasoning behind choosing a combination of ab-interno canaloplasty and GATT rather than performing canaloplasty alone. While canaloplasty addresses the entire conventional outflow pathway (viscodilating Schlemm's canal and collector channels), it does not remove the TM barrier. The combination approach is particularly relevant in patients with suspected or established TM damage, where both enhancing distal outflow and eliminating proximal resistance are necessary. This dual-targeted mechanism helps achieve greater IOP reduction in these eyes, which may otherwise respond unpredictably to procedures that preserve the TM.

Importantly, the iTrack microcatheter allows a titratable approach, giving the surgeon flexibility to tailor treatment intraoperatively. The procedure can begin with canaloplasty alone, and escalation to GATT can be decided based on real-time visualization of angle structures, resistance encountered, or the degree of TM compromise. This adaptability is a key advantage in secondary glaucoma where disease severity and anatomy may vary significantly between patients.

We also evaluated the efficacy of combined ABiC and GATT in two subgroups: anti-VEGF-induced and steroid-induced ocular hypertension. Both groups experienced significant IOP and medication reductions: the steroid-induced group showed a 48% IOP reduction and 47% medication reduction, and the anti-VEGF group 42% and 25% reduction, respectively; the difference in those reductions was not statistically significant, likely reflecting limited sample size. However, the robust response in the steroid group can be attributed to direct TM dysfunction, which is effectively targeted by GATT. In contrast, the mechanism of IOP elevation in the anti-VEGF group is likely multifactorial and is less clearly defined, potentially contributing to the more variable surgical response.[2,25,26]

Across the cohort, patients had received a mean of 11.76 intravitreal injections prior to combined ABiC and GATT and presented with elevated preoperative IOP (28.1±6.0 mmHg). Following surgery, a rapid and clinically meaningful reduction in IOP was observed, with IOP decreasing to 17.5±10.6 mmHg at postoperative month 1 and further to 14.3±5.4 mmHg by month 3, occurring before any substantial reduction in intravitreal injection exposure.

A subset of eyes required continued intravitreal re-injection after surgery (n=9) with a mean of 4.3 ± 4.4 injections and a mean time to first re-injection of 2.2 ± 1.9 months. Despite ongoing injection exposure, these eyes demonstrated sustained IOP reduction from baseline (27.0±6.5 mmHg preoperatively vs 14.6±5.2 mmHg at last follow-up; p=0.015).

Although fewer intravitreal injections were administered postoperatively, the early and sustained reduction in IOP—preceding or overlapping with reinjection—supports a primary surgical effect of combined ABiC and GATT rather than IOP improvement driven by reduced injection frequency alone.

The high proportion of patients requiring continued steroid eye drops (55.5%) aligns with findings from Boese et al[18] who reported ongoing topical steroid use in 67% of patients throughout follow-up. Notably, IOP reduction remained sustained in these patients, averaging a 53% decrease from baseline, despite continued topical steroid use. While these findings are promising, further studies with larger samples and longer follow-up are needed to confirm whether GATT remains effective in the setting of prolonged steroid exposure.

The safety profile of combined ABiC and GATT was favorable, with hyphema being the only complication observed. It occurred in 55.9% of eyes on the first postoperative day, and all cases resolved spontaneously without the need for intervention. This is consistent with previous reports confirming that hyphema is the most common yet transient, complication associated with both GATT and canaloplasty.[9,18,20,22] Moreover, hyphema is often considered an indicator of surgical success and typically resolves in the early postoperative period without long-term consequences.

In our cohort, transient hyphema occurred in 55.9% of eyes on day 1 following the combined procedure, noticeably higher than the 30% incidence reported in POAG patients undergoing the same surgery.[15] This discrepancy may be due to vascular and structural changes in Schlemm's canal and the trabecular meshwork associated with secondary glaucomas, particularly those induced by corticosteroids or anti-VEGF agents. In steroid-induced glaucoma, ultrastructural changes such as extracellular matrix accumulation beneath the Schlemm's canal endothelium, thinning of endothelial cells, and occasional herniation at collector channel ostia have been documented, which may increase susceptibility to intraoperative blood reflux during canal manipulation.[23,27,28] Similarly, in eyes receiving repeated anti-VEGF injections, chronic mechanical stress, IOP spikes, and particulate obstruction can lead to trabecular meshwork damage and venous congestion in the angle, further raising the risk of hyphema.[1,29] These findings suggest that the etiology of glaucoma may influence hyphema risk beyond the procedure itself. Overall, our findings support the use of combined ABiC and GATT using the iTrack microcatheter as a safe and an effective treatment for sustained ocular hypertension related to intravitreal injections. It offers significant IOP and medication reduction with a minimally invasive profile and may delay or reduce the need for traditional filtering surgeries. Nevertheless, ongoing steroid exposure and reinjections may influence long-term success and should be considered in clinical decision-making.

This study has several limitations. Its retrospective design and relatively small sample size may limit generalizability, and incomplete documentation regarding the timing of prior glaucoma surgeries limited our ability to analyze the influence of earlier surgical interventions on postoperative outcomes. Subgroup analyses, including eyes requiring re-injection or prolonged topical steroid use post-ABiC and GATT, were limited by small numbers, reducing statistical power. The absence of a comparator group, such as traditional filtering surgery or other MIGS procedures, further limits comparative interpretations. In addition, eyes with active uncontrolled inflammation, extensive synechial angle closure, or severe conjunctival scarring were preferentially managed with glaucoma drainage devices at the surgeon's discretion; therefore, our cohort represents angle-suitable eyes, and findings may not be generalizable to eyes requiring primary tube surgery. Heterogeneity in underlying ocular conditions and variability in intravitreal reinjection timing may have introduced confounding factors on long-term IOP outcomes, particularly in eyes with chronic uveitis or proliferative diabetic retinopathy, which may have disease specific mechanisms of IOP elevation independent of intravitreal injections. Finally, prior tube shunt surgery or advanced inflammatory disease may limit the efficacy of subsequent angle-based procedures, underscoring the importance of careful patient selection. Nevertheless, the consistent and sustained post-operative IOP reduction observed across diagnostic subgroups suggests that combined ab-interno canaloplasty and GATT can effectively restore aqueous outflow in eyes with mixed and multifactorial causes of IOP elevation.

A head-to-head comparison between ABiC standalone and GATT would be valuable in delineating the specific contribution of TM removal to IOP reduction in eyes with post-injection or secondary glaucoma. Given the still unclear pathophysiology of anti-VEGF–induced hypertension, whether it involves fibrosis, particulate obstruction, or cellular dysfunction leading to outflow dysregulation, such a study could clarify the relative importance of addressing TM resistance versus restoring Schlemm's canal patency.

Conclusion

Combined ab-interno canaloplasty and GATT using the iTrack microcatheter appears to be a safe, conjunctiva-sparing option for eyes with sustained intraocular pressure elevation following intravitreal anti-VEGF or steroid therapy. In this heterogeneous real-world cohort, significant and early IOP reduction was observed, including in eyes that continued to receive postoperative intravitreal injections, supporting a primary surgical effect. Nevertheless, variability in underlying ocular diagnoses and injection exposure limits definitive causal attribution in all cases. Larger prospective studies with standardized injection protocols and longer follow-up are warranted to further define patient selection and long-term outcomes.

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