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Complications after Gonioscopy-Assisted Transluminal Trabeculotomy in glaucoma treatment — literature review

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Abstract: Glaucoma is a disease that leads to optic nerve damage and irreversible loss of the visual field. Gonioscopy-assisted transluminal trabeculotomy (GATT) is a minimally invasive glaucoma surgery technique, where the surgeon opens the trabecular network and Schlemm's canal to improve the outflow of the aqueous humor. This method has shown efficacy in reducing intraocular pressure in patients with primary and secondary glaucoma.

GATT has gained popularity due to its minimally invasive nature, compatibility with cataract surgery and relatively low cost. Despite its advantages, the procedure can be associated with many complications such as hyphema, intraocular pressure spikes and corneal edema. In rare cases, it can lead to Descemet's membrane detachment or cystoid macular edema. The success of GATT procedure mostly depends on the surgeon's skill and experience, but also on the patient's risk factors, including age and preoperative intraocular pressure levels. Further studies are required to understand long outcomes and identify the patients, who may be at higher risk of complications.

Keywords: glaucoma, GATT, IOP, gonioscopy, trabeculotomy.

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Introduction

Glaucoma is an acquired optic neuropathy or the loss of retinal ganglion cells and axons within the optic nerve, which causes progressive loss of vision. This is a heterogeneous group of diseases associated with the cupping of the optic nerve head, resulting in damage to the patient's visual field. At the same time, glaucoma is the most common cause of irreversible blindness in the world [1]. There are several main categories of glaucoma occurring in adults. These include primary open-angle and closed-angle glaucoma and secondary open-angle and closed-angle glaucoma. The most common is primary open-angle glaucoma (POAG), which is often asymptomatic until the optic nerve is seriously damaged. Sometimes early glaucoma can be detected during routine tests. The closure of the angle can develop suddenly. Its effects include faster deterioration of vision accompanied by corneal swelling, eye pain, headache, nausea and vomiting. Secondary glaucoma is correlated with prior ocular damage or disease, causing elevated intraocular pressure (IOP) and associated optic neuropathy. The last category of glaucoma discussed is low-tension glaucoma. The pattern of vision loss in patients is almost identical to that in POAG, but intraocular pressure values are normal. It is generally said that the cause of glaucoma is increased intraocular pressure, although no direct evidence indicates a direct relationship between cause and effect [2]. Tonometry, perimetry, OCT, and ophthalmoscopy are used to diagnose glaucoma. In turn, to reduce intraocular pressure, topical medications are used, as well as laser therapy or surgical interventions if other treatment methods do not prevent the progression of the disease [1].

Nowadays, glaucoma surgery is increasingly based on minimally invasive surgery (MIGS). One of these is gonioscopy-assisted transluminal trabeculotomy or GATT for short. This method is pioneered by Redmond Smith in 1969, author of the description of the trabeculotomy technique using a nylon filament [3]. Ab externo trabeculotomy seemed very promising, due to the vision of a reduction in outflow resistance by more than 70%. Unfortunately, the procedure presented was not ideal, as the time to operate was from 30 to 60 minutes or longer. It also involved the necessity of breaching the continuity of the conjunctiva and sclera and the effect of the operation itself was no more satisfactory than that obtained after trabeculectomy. Trabeculotomy ab externo did not allow as much pressure drop as in other procedures. The above arguments determined the decline in popularity of this method, although ultimately the reason for the procedure's low success rate was the opening of only the temporal and nasal upper part of the trabecular meshwork with a metal trabeculotome during the procedure. This is because it turned out that the most important part of the canal, from which the fluid flows into the nasal fossa, remained closed [4]. The use of 360-degree trabeculotomy with nylon suture was more effective in lowering pressure, giving a success rate of primary open-angle glaucoma treatment up to 84%, compared to metal trabeculotomy procedures (treatment success rate was 31%) [5].

Thus, the goal of GATT is to destroy the perimeter of the meshwork and also the inner wall of Schlemm's canal, which underlies the obstruction of the outflow of the aqueous fluid [6].

The GATT procedure

Initially, a needle is placed in a specific supra-nasal or sub-nasal quadrant. At this point, sodium hyaluronate, as a common viscoelastic, is injected into the anterior chamber. Then, using a blade, the ophthalmologist performs a temporal paracentesis to insert a 5–0 prolene suture or microcatheter.

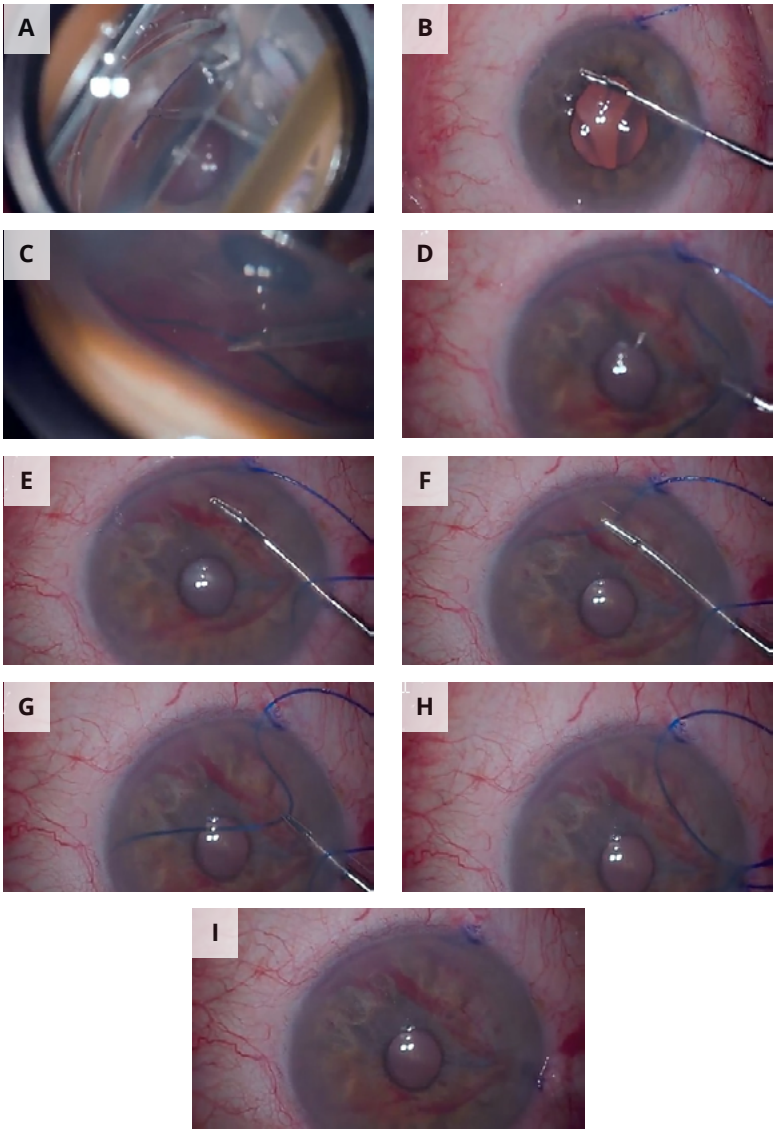

Fig. 1. Gonioscopy-assisted transluminal trabeculotomy performed with the usage of Ahmed DVX goniolens. Photos courtesy of Zbigniew Dyda, M.D.

The GATT procedure is carried out as follows:

(A) The slide shows a blunt 5–0 prolene suture placed in the anterior chamber;

(B) Gradually, the suture is moved along Schlemm's canal;

(C, D) The blue color of prolene allows confirmation of suture placement along the entire canal. After the distal end of the prolene suture moved 360 degrees along the canal, the tip was removed with microsurgical forceps;

(E, F) Traction was placed at the proximal end of the suture;

(G, H, I) By pulling the proximal end of the suture, a complete peripheral trabeculotomy was achieved.

Another important point of the operation is the proper positioning of the patient using direct lenses such as Swan-Jacob goniolens. In that case, the microscope and the patient' head must be in a position to assess the nasal angle via the Swan-Jacob goniolens. Another technique is to use redirected goniolenses, which mirror and magnify the image, like Ahmed DVX, shown in the photos underneath. Redirect goniolenses allow surgeons to operate in a traditional position, without positioning the microscope or patient's head. Then, the surgeon performs a small goniotomy with the use of a blade in the appropriate place. At this place, using microsurgical forceps, the distal end of the suture is placed into the Schlemm's canal. Microsurgical forceps are used to move the suture along Schlemm's canal circumferentially by 360 degrees. As soon as the suture surrounds the entire canal, the surgeon pulls the suture to tear it apart, causing a direct connection between Schlemm's canal and the anterior chamber.

The next step is to use bimanual irrigation aspiration. Then the viscoelastic is partially removed so that only 15–40% remains in the anterior chamber to prevent excessive bleeding from the Schlemm's canal. Drops containing steroids and antibiotics can be used as an option. If there is a situation where the microcatheter blocks at 180–270 degrees, an ab interno incision is made at this site to perform a limited trabeculotomy. The microcatheter is then inserted in the opposite direction through an incision to dissect the remaining trabecular meshwork [7]. There is no doubt that GATT is a method with many advantages, including fast recovery, fewer complications, and low cost of the procedure itself. In addition, GATT like other MIGS procedures, spares the conjunctiva, allowing more invasive and advanced glaucoma surgery to be performed if needed later. Moreover, this procedure can be performed as a stand-alone procedure or combined with cataract surgery, thus optimizing the treatment process (Fig. 1). It is a relatively safe procedure [7]. Moreover, GATT can be used to treat both children and adults and is used for various forms of open-angle glaucoma [8]. While it has many benefits, the main aim of this review is to present possible GATT complications.

GATT indications

It has been discovered that GATT can be a promising surgical procedure for many patients, including those with juvenile-onset glaucoma, pseudoexfoliative glaucoma, patients with prior eye surgeries (including prior incision glaucoma surgery and pars plana vitrectomy) as well as those with steroid-induced glaucoma, uveitic glaucoma, and secondary angle closure glaucoma [9, 10].

Primary congenital glaucoma (PCG) could also be an indication for GATT surgery [7, 11]. PCG, a leading cause of childhood glaucoma, caused by anterior chamber angle malformation and defective outflow of aqueous humor, responds very well to GATT operation, resulting in remarkable effectiveness in reducing IOP [11]. In one of the studies, GATT allowed two-thirds of patients with PCG to discontinue the administration of antiglaucoma medication. It also provided high success rates, without complications such as scarring or leakage [12].

Juvenile open-angle glaucoma (JOAG) is identified as a subtype of childhood glaucoma that lacks ocular enlargement, with the latest onset up to 40 years old [13]. On average, the diagnosis is typically made during the third decade of life, and there is a higher occurrence among males [14]. Its etiology is associated with myocilin, a protein that plays an important role in IOP regulation. Its mutations cause protein aggregation in the trabecular meshwork, contributing to the development of glaucoma [15]. JOAG has been known to tend to progress more rapidly and be more resistant to treatment than POAG, therefore, surgical procedures are frequently recommended

and in general, younger operation age correlates with better surgical outcomes [13, 16]. In a recent study by Qiao *et al.*, comparing the efficacy of GATT and goniotomy with Kahook Dual Blade (KDB) procedures in JOAG patients, it has been discovered that in the GATT group, both IOP and the number of medications significantly decreased throughout the postoperative period. The average IOP dropped by 37% from 31.5 ± 14.5 mmHg preoperatively to 15.9 ± 4.9 mmHg after 6 months. Additionally, 90.5% of eyes maintained an IOP ≤18 mmHg and 57.1% achieved an IOP ≤15 mmHg at the 6 months. After six months following GATT, 90% of eyes had successfully discontinued at least one glaucoma medication and a decrease in IOP of at least 20% was noted in 71.4% (15 out of 21) of the eyes, with 11 cases demonstrating the absence of any glaucoma medication. Comparatively, the KDB group exhibited shorter-term effects with IOP decreasing by 14% at 3 months postoperatively. The reduction in medications and IOP was less significant, and some eyes in the KDB group experienced poorly controlled IOP (>18 mmHg) and hypotony. The findings suggest that GATT has a more prolonged and sustained efficacy in achieving success compared to KDB in JOAG patients, including a more substantial lowering of IOP and reduced need for glaucoma medications post-op [13].

Another cohort of patients recommended for GATT surgery comprises those who have undergone prior glaucoma surgeries. A retrospective study by Grover *et al.* presented data monitoring patients with various types of open-angle glaucoma and a minimum of one prior incisional glaucoma surgery (GDD — glaucoma drainage device; trabeculectomy; ECP — endocyclophotocoagulation) before GATT operation [17]. The study revealed that GATT operation led to a significant decrease in IOP among all previously operated patients and a modest reduction in postoperative medication. It demonstrated success even after a failed traditional glaucoma surgery, providing patients with additional less-invasive options if the initial surgery failed to adequately control IOP.

For patients requiring simultaneous cataract surgery, the optimal approach is to combine both procedures during a single operation [18]. However, the outcomes do not exhibit a significant difference when cataract surgery is combined with GATT [17, 18]. Additionally, in a study by Chen *et al.*, comparing GATT and goniotomy combined with cataract extraction, it has been proven that steroid-induced and uveitic glaucoma could also be an indication for GATT, since GATT demonstrated great efficacy and safety, with lowering IOP and reducing glaucoma medications in those patients [10].

Patients with prior pars plana vitrectomy (PPV) are a possible group with an indication for GATT surgery. Performing surgery for retinal disorders, such as PPV, can cause temporary increases in IOP in the short term and result in long-term glaucomatous eye damage. Since some patients do not respond sufficiently to medication, some type of glaucoma surgery might be required [19]. GATT proves to be a secure and efficient method for treating secondary open-angle glaucoma in eyes that have undergone vitreoretinal surgery. It results in IOP improvement and medicine reduction post-op, but the majority of patients will still require anti-glaucoma medication, especially within the initial two years after surgery [19]. Further research is required to fully understand the long-term advantages of GATT surgery for eyes experiencing IOP after vitreoretinal procedures.

A group of patients that benefit the most from GATT operation are those with pseudoexfoliation glaucoma (PXG). This particular type of glaucoma is the predominant globally occurring open-angle variant with discernible etiology. It is connected with the accumulation of extracellular material in various parts of the eye, particularly the lens, ciliary body, and trabecular meshwork, crucial for aqueous humor outflow regulation [20]. Those deposits can result in secondary

glaucoma with elevated IOP. Performing GATT surgery in PXG patients results in effectively lowering IOP and glaucoma medication reduction [21]. In one of the studies, the mean IOP decreased by 12.8 mmHg (44.6%) on 2.3 fewer medications after GATT in the PXG patients; what is more, the average reduction in IOP was notably greater in the PXG group compared to the POAG group, at all measured time points up to the 2-year visit [22]. Those findings suggest that GATT demonstrates enhanced efficacy in individuals with uncontrolled secondary open-angle glaucoma (SOAG), compared to POAG. A possible reason for that might be that the GATT intervention targets the trabecular meshwork, which appears to be the primary source of resistance to outflow in PXG. Thus, GATT could be advised for patients with SOAG and affected trabecular meshwork [23]. GATT could also be indicated in the treatment of chronic angle-closure glaucoma (CACG) patients. In a study by Fontana *et al.*, GATT was proven as an effective way of reducing IOP and low risk of complications in 15 eyes with CACG, with the operation success rate of 93% and 100% at 6 and 12 months, respectively [24].

Risk factors contributing to GATT complications

Many factors influence the course and complications of GATT surgery. The operating ophthalmologist's technique and experience significantly impact the procedure's success; however, certain factors have been found to increase the chances of GATT failure.

In general, elderly patients (over 60 years) and those with POAG, pseudophakia and peripheral anterior synechiae (PAS) are more prone to GATT operation failure while people with more advanced disease and eyes developing IOP spikes have a higher risk of postoperative vision deterioration [16, 25, 26]. Patients of African descent are more likely to develop GATT complications since they are more susceptible to developing open-angle glaucoma with more severe progression. This group of patients has a higher risk of GATT failure as well as the failure of other glaucoma surgery types, including trabeculectomy, Ex-PRESS shunt or canaloplasty [27, 28].

A postoperative IOP spike (>30 mmHg) in the operated eye is one of the identified unfavorable factors for developing complications after GATT [9]. The duration of the IOP spike plays an important role in the development of complications with the correlation that the longer the spike, the higher the risk of failure [16]. The link between IOP spikes and operation failure remains unknown, however, there is a connection between spikes and the post-trabecular outflow system. Poor outflow may result in IOP spikes and failure, and an IOP spike modifies post-trabecular outflow. This, subsequently, poses a risk of operation failure [9]. Postoperative drug administration has a big impact on the frequency of IOP spikes: temporary post-operative administration of glaucoma medication considerably lowers the possibility of IOP spikes [29]. The choice of pharmacotherapy after GATT to prevent IOP spikes is crucial, some sources recommend high-dose steroid therapy and possibly atropine as preventive medicine, especially in younger patients [26]. On the other hand, in an article by Chen *et al.*, it was noticed that individuals who received corticosteroid treatment following the operation were at a higher likelihood of experiencing IOP spikes compared to those who exclusively used non-steroidal anti-inflammatory drugs (NSAID). This may be a result of corticosteroid-mediated outflow obstruction distal to the trabecular meshwork [9].

Another prognostic factor is the choice of the operation method: a complete or incomplete (<360 degrees) trabeculectomy performed during GATT [26]. A fully circumferential incision results in more open aqueous humor outflow, leading to more effective IOP reduction, and patients who underwent complete trabeculotomies exhibited a prolonged survival time in comparison to

those with incomplete incisions. On the other hand, some underlying factors in the eyes could explain the less favorable prognosis and inability to perform complete trabeculotomy (scarring, congenital stenosis, or transection of Schlemm's canal) [11]. A summary of risk factors for GATT complications is shown in Table 1.

Table 1. Overview of risk factors for GATT complications.

Type	Risk Factor
Operative	• low experience of the operating ophthalmologist • GATT performed in the technique of incomplete (<360 degrees) trabeculotomy
Clinical	• older age • African descent
Pathological	• postoperative IOP spike (>30 mmHg) in the operated eye • duration of postoperative IOP spike • POAG • more advanced glaucoma • pseudophakia • PAS

GATT — Gonioscopy-Assisted Transluminal Trabeculotomy, IOP — Intraocular pressure, POAG — primary open-angle glaucoma, PAS — peripheral anterior synechiae.

GATT complications

Studies suggest that GATT exhibits favorable effectiveness and safety in eyes affected by steroid-induced glaucoma and uveitic glaucoma [30]. The surgical failure rate for GATT was recorded at 8% in a study conducted at the Cole Eye Institute [10].

One of the most common complications observed after GATT is hyphema, which is the accumulation of blood in the anterior chamber of the eye [18, 31, 32]. Among 13 patients treated for steroid-induced glaucoma (SIG) with GATT, approximately one-third experienced transient postoperative hyphema [33]. At the Ophthalmology Center of Beijing Tongren Hospital, which is affiliated with Capital Medical University, the GATT group treating open-angle glaucoma exhibited a markedly elevated incidence of hyphema (91%, 21 out of 23 cases) within one day following surgery [34]. Moreover, in a group of 69 patients with open-angle glaucoma treated with GATT as the sole procedure or in combination with cataract surgery, hyphema occurred in 50% of patients within the first few days after surgery. The presence of blood in the anterior chamber affected early postoperative Best Corrected Visual Acuity (BCVA) results. During the visit 10 days later, it was found that the hyphema spontaneously resolved in each case without additional interventions [18].

Vitreous haemorrhage may occur as a direct complication of a surgical procedure [18, 35]. The mechanism of bleeding is likely similar to hyphema caused by blood reflux from the episcleral veins opened during suture removal [36]. Although it has been reported as a late postoperative complication, it is unlikely to be related to the GATT procedure itself in that case [37]. Additionally, the analysis of sixty-six adult patients who underwent GATT due to inadequately controlled intraocular pressure (IOP) or medication intolerance, revealed hyphema incidences with a rate of 38% at one week and 6% at one month postoperatively [28].

Among other complications, researchers identified that eight eyes (25.8%) had intraocular pressure above 25 mmHg, with suspected steroid response noted in four of them [23]. Increases in intraocular pressure (IOP >30 mmHg or >10 mmHg above baseline) are common after GATT, particularly within the first two weeks post-operation [38–40]. These elevations typically resolve with local and systemic pressure-lowering treatments. In a single-center study involving 217 consecutive eyes of patients with a minimum 90-day follow-up after GATT, increases in intraocular pressure were observed in 52 eyes (24%) [29].

Less frequent complications described after GATT were Descemet's detachment, iritis and iridodialysis [18].

Corneal edema (CE) is a potential complication following the GATT procedure, along with hyphema and IOP spikes. In the evaluation of the efficacy and safety of GATT, the occurrence of corneal edema was reported in two patients, which accounted for 2.9% of postoperative complications [18]. A very similar occurrence of CE was reported by Grover *et al.* which was 1% [7]. CE was found to be more common in elderly patients. Khan *et al.* report that after GATT performed in advanced-aged patients (>85 years of age) CE, as an early (<3 months) postoperative complication, was the most common postoperative complication observed in 10 eyes which corresponded to 25% of all early complications [37]. This may be due to the simultaneous phacoemulsification cataract surgery performed with the GATT procedure. However, another study did not report CE in patients who underwent GATT combined with phacoemulsification surgery, potentially due to the younger age of the patients involved [25]. In a prospective study comparing the efficacy and safety of phacoemulsification combined with GATT, CE occurred in 8% of eyes and was resolved with conservative treatment [41].

A potential risk associated with GATT is Descemet's membrane detachment, which can result in vision impairment due to corneal edema. While uncommon, it can occur either as an intraoperative or postoperative complication of the procedure. If detachment occurs during the surgery, it can be treated with anterior chamber air [42]. However, postoperative detachment may resolve on its own without any lasting consequences. This particular complication was documented by Belkin *et al.* and Grover *et al.* [7, 43].

Inflammation, in the context of iritis, is a rare but important complication after the GATT procedure and should be well controlled. Anti-inflammatory treatment with topical steroids and NSAID drops is usually effective [7, 28, 37]. Topical NSAIDs may also help prevent IOP spikes [9].

Iridodialysis occurring within the first month after GATT surgery has been reported as one case by Belkin *et al.* [43]. Fortunately, in that case, it was clinically insignificant and did not require any additional treatment. However, Ćwiklińska-Haszcz *et al.* have reported two cases of iridodialysis as an intraoperative complication. In one of these cases, surgical suturing was required the day after GATT surgery. The risk of this complication is partly due to the surgeon's technique as adjacent structures can be damaged during suture placement into the Schlemm canal [18]. Similarly, cyclodialysis can occur as a trauma during GATT surgery [7]. In the years 2021–2022 at the Clinic of Glaucoma Diagnostics and Microsurgery of the Medical University of Lublin, among 69 patients with open-angle glaucoma, in two cases the surgical procedure was complicated by iridodialysis caused by accidental iris damage [18].

Cystoid macular edema (CME) is a rare, sight-threatening complication, that can happen after undergoing the GATT procedure. It is important to identify patients who are at risk of developing CME after GATT. While the initial report of the GATT technique by Grover *et al.* noted only one example of CME, it was in a patient who had also undergone cataract surgery at the

same time [44]. Subsequent studies by other researchers have also reported this complication [35, 37, 43]. A case report of CME after stand-alone GATT by Espinoza and colleagues suggests that patients with risk factors for CME after surgery may benefit from the addition of non-steroidal anti-inflammatories (NSAIDs) during the postoperative period [45].

Other rare complications of the GATT procedure are transient hypotony, peripheral anterior synechia, goniosynechia and choroidal folds [18, 46].

Conclusions

The GATT procedure appears to be an effective method of treatment for many of glaucoma types, including primary open-angle glaucoma (POAG) as well as more complicated cases such as advanced stages of secondary glaucoma, steroid glaucoma, juvenile glaucoma (JOAG) and pseudoexfoliation glaucoma (PXG). Despite the benefits, it is important to consider the potential complications that can occur during and after this procedure. It is significant to consider risk factors that may increase the probability of complications, such as the patient's age or level of glaucoma severity, before deciding to perform GATT. It is also necessary to carry out strict postoperative monitoring of parameters that increase the risk of complications, such as postoperative IOP spike (>30 mmHg) in the operated eye. Complications after GATT most often occur shortly after surgery and are temporary, such as hyphema and a manageable postoperative IOP rise. Unfortunately, serious complications, such as Descemet's membrane detachment or cystoid macular edema (CME), can also occur, both of which are rare, but can lead to vision deterioration. Regular monitoring of inflammation after surgery and the use of anti-inflammatory medications are key to preventing and rapidly treating certain complications, such as iritis and corneal edema. Nevertheless, further prospective studies are required to better understand and prevent post-GATT complications, as well as to identify patients at risk.

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Conflict of interest

None declared.

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