Gonioscopy-Assisted Transluminal Trabeculotomy Outcomes Under Different Levels of Glaucoma Severity: A Multicenter, Comparative Study

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• PURPOSE: To evaluate the outcomes of gonioscopy-assisted transluminal trabeculotomy (GATT) under different levels of glaucoma severity.

• DESIGN: Retrospective, multicenter, before-and-after study.

• METHODS: One eye from all primary open-angle glaucoma patients who underwent GATT combined with cataract surgery (Phaco-GATT) or GATT stand-alone with 12 months of follow-up were included and divided according to glaucoma severity (mild = GI, moderate = GII, and advanced = GIII) and the outcomes compared.

• RESULTS: A total of 270 eyes were included: 90 in GI, 75 in GII, and 105 in GIII. The IOP was reduced from 18.6 ± 6.0 mm Hg in GI, 19.7 ± 6.4 mm Hg in GII, and 21.0 ± 7.9 mm Hg in GIII, preoperatively, to 11.9 ± 2.6 mm Hg in GI, 11.8 ± 2.1 mm Hg in GII, and 11.9 ± 3.0 mm Hg in GIII at 12 months postoperatively ($P < .001$ for all). The number of hypotensive ocular medications were reduced from 2.7 ± 1.0 in GI, 3.1 ± 0.8 in GII, and 3.2 ± 1.2 in GIII to 0.6 ± 0.9 in GI, 1.0 ± 1.1 in GII, and 1.2 ± 1.1 in GIII at the last postoperative visit ($P < .001$ for all). Relative success was achieved, at 1 year, in 93.8% of the eyes in GI, 89.0% in GII, and 88.1% in GIII ($P = .3$). Complete success was achieved in 61.8% of the eyes in GI, 43.8% in GII, and 37.6% in GIII ($P = .007$). No serious adverse event was observed in any group.

• CONCLUSIONS: GATT is a safe and effective procedure in glaucoma, regardless of its preoperative severity. (Am J Ophthalmol 2024;264: 75–84. © 2024 Elsevier Inc. All rights reserved.)

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GLAUCOMA IS THE LEADING CAUSE OF IRREVERSIBLE blindness in the world, with an estimated prevalence of more than 110 million people in the world in 2040.[1] It is a chronic, progressive and usually nonsymptomatic disease, with glaucomatous individuals at risk of progressing to severe visual impairment or even blindness during their lifetime.[2] Treatment is based on intraocular pressure (IOP) reduction to delay or even prevent progression of the disease.[3] First-line therapy include topical medication and/or laser therapy, with surgical treatment usually performed when the target IOP is not achieved clinically or in other situations such as in combination with cataract surgery and/or in nonadherent patients or with important side effects related to the use of topical hypotensive medications.

Gonioscopy-assisted transluminal trabeculotomy (GATT) is a relatively new micro-invasive, conjunctiva-sparring glaucoma surgery.[4,5] Several studies have demonstrated efficacy and safety of the procedure in treating glaucoma, mainly in different types of open angles, but also in refractory glaucoma such as after corneal transplant or in eyes with a history of incisional glaucoma surgery.[6-12] The rationale of GATT is to improve the aqueous humor flow by tearing the trabecular meshwork and the inner wall of the Schlemm canal (SC) internally, using a microcatheter or a polypropylene suture, consequently reducing IOP.

Initially, the minimally invasive glaucoma surgeries (MIGS) were believed to play an important role in mild to moderate glaucoma.[13] Nevertheless, data on MIGS, especially on GATT, demonstrating its efficacy and safety in eyes with moderate and/or advanced glaucoma are continuously emerging, presenting this surgery as a viable option in those patients as well.[14,15] However, at this point, there is only 1 study[7] related to the differences in the outcomes of GATT according to glaucoma severity. This information is crucial to help surgeons decide if this surgery would be suit-

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able for a certain type of patient, because previous reports usually describe GATT outcomes in a group of patients with a mean preoperative damage. Therefore, eyes with very different levels of glaucoma severity may have been analyzed together. The present study was designed to fill in this gap.

METHODS

This was a retrospective, multicenter, comparative study. All patients who underwent GATT (combined with cataract surgery [Phaco-GATT] or GATT stand-alone) from January 2017, with 1 year of follow-up in any of the centers of the study, were considered. The study was conducted after approval of the Ethical Committee from the Federal University of Goiás, Goiânia, Brazil (#4.408.795) and adhered to the tenets of the Declaration of Helsinki. Owing to the retrospective nature of the study, the requirement for written informed consent was waived.

All patients underwent a complete ophthalmic examination preoperatively at each institution, no more than 30 days before the surgery, including best-corrected visual acuity, slitlamp examination, gonioscopy with 4-mirror goniolens, IOP measurements with the same calibrated Goldmann applanation tonometer at each center, dilated funduscopy, and visual field tests with the Humphrey Field Analyzer Swedish Interactive Threshold Algorithm Standard 24-2 test (Humphrey Systems). Data were collected on postoperative days 1, 7, 30 (±7 days), 3 months (±15 days), 6 months (±30 days), and 12 months (±12-14 months).

Inclusion criteria were individuals from both sexes at least 18 years old and a history of Phaco-GATT or GATT stand-alone procedure, and 1 year of follow-up. Only primary open-angle glaucoma (POAG) patients were included. In bilateral cases, one eye for every patient was excluded, and only the worst eye was selected based on the preoperative Humphrey visual field mean deviation (MD). The exclusion criteria included any previous corneal surgery (such as Excimer Laser refractive surgery or corneal graft), history of ocular trauma, or any complication in previous Phaco-GATT surgery related to cataract extraction.

All surgeries (surgeons: L.M., A.C.A.P., B.T., B.M.F.) were performed under topical or peribulbar anesthesia from a temporal clear-corneal incision (2.2- or 2.4-mm). No. 5-0 Prolene suture was blunted with a hand-held cautery unit before the beginning of the surgeries. After routine phacoemulsification, and intraocular lens in-the-bag implantation (for the Phaco-GATT patients), the anterior chamber was filled with a dense ophthalmic viscoelastic device (4% methylcellulose or sodium hyaluronate 1.0%).

The patient's head was rotated 35° to 45° away from the surgeon, and the surgical microscope was also tilted 35° to 45° downward toward the surgeon to allow maximal visualization of the nasal angle to the surgeon. Using the same ophthalmic viscoelastic device, a direct surgical goniolens was placed on the patient's cornea with one of the surgeons' hands to allow complete visualization of the nasal angle and trabecular meshwork. Then, the surgeon inserted either a 25 × 0.7-mm or a 13 × 0.45-mm needle (according to the surgeon's preference) through the anterior chamber to gently detach the trabecular meshwork and/or perform a small goniotomy. The ophthalmic viscoelastic device was then used to dilate the SC and/or allow clear vision, moving away any blood present in the surgeon's visual field after the goniotomy.

The blunted Prolene suture, previously inserted via a 15° paracentesis, was then introduced into the SC with the assistance of a vitreous serrated 20G foreign body forceps or any similar one. The suture was then pushed forward in the SC until all 360° of the SC was canalized. Using the same forceps, the surgeon then gently pulled the tip of the suture from the SC through the clear-corneal incision, out from the eye. Subsequently, the distal tip of the suture and the part inserted through the paracentesis were smoothly pulled at the same time, completing the trabeculotomy. If, for any reason, the suture could not advance 360° inside the SC, partial trabeculotomy was performed, and its extension annotated. The surgeon could, at his or her discretion, try to complete the trabeculotomy making another paracentesis 180° away from the first one, moving the suture into the opposite direction of the first attempt, in the SC. To be included in the protocol, it was necessary to undergo at least a Hemi-GATT (180° trabeculotomy or more).

Postoperative care included a combined moxifloxacin/dexamethasone eyedrop starting every 4 hours for 1 week, tapered over the next 3 weeks; and a nonsteroidal anti-inflammatory eyedrop, such as ketorolac trometamol, for 3 weeks in Phaco-GATT patients. For the GATT stand-alone, the moxifloxacin/dexamethasone eyedrop was used with the same regimen but tapered every 5 days (20 days of use, instead of 4 weeks). The nonsteroidal inflammatory eyedrop could be used (or not) at the surgeon's preference. As a rule, prostaglandin analogs (if in use) were immediately discontinued after surgery, and 1 or a combination of 2 glaucoma eyedrops was maintained for 15-30 days, even if the IOP was considered adequate. This routine was also used to avoid or at least reduce the risk of any transient elevation of IOP in the initial postoperative period. All surgeons could modify this regimen at any time and at their discretion.

Relative success was considered if, at the last recorded follow-up (12-14 months), an IOP of 6-18 mm Hg was observed with a maximum of 2 glaucoma medications and less than or equal to the preoperative number of glaucoma eyedrops. Absolute success was considered with the same IOP levels but without any glaucoma medication. Any severe complications at any time during follow-up, such as corneal decompensation, loss of vision, or the need for any additional glaucoma surgery, were considered failures of the procedure.

TABLE 1. Baseline Information

Group	Age, y	Gender, n	Eye, n	Race, n
All participants				
GI	65.4 ± 9.5	48 F; 42 M	45 **OD**; 45 *OS*	60 C; 30 AA
GII	64.7 ± 10.7	22 F; 53 M	29 **OD**; 46 *OS*	51 C; 24 AA
GIII	66.5 ± 12.5	49 F; 56 M	53 **OD**; 52 *OS*	73 C; 31 AA; 1 A
Phaco-GATT				
GI	66.1 ± 6.8	38 F; 29 M	34 **OD**; 33 *OS*	41 C; 25 AA
GII	65.7 ± 8.8	16 F; 26 M	17 **OD**; 25 *OS*	30 C; 12 AA
GIII	65.6 ± 10.9	27 F; 31 M	31 **OD**; 27 *OS*	38 C; 19 AA; 1 A
GATT stand-alone				
GI	63.2 ± 14.9	10 F; 13 M	11 **OD**; 12 *OS*	18 C; 5 AA
GII	63.6 ± 12.7	6 F; 27 M	12 **OD**; 21 *OS*	21 C; 12 AA
GIII	67.7 ± 14.2	22 F; 25 M	22 **OD**; 25 *OS*	35 C; 12 AA

A = Asian, AA = African American, C = Caucasian, GATT = gonioscopy-assisted transluminal trabeculotomy, GI = mild glaucoma, GII = moderate glaucoma, GIII = advanced glaucoma.

Statistical analyses were performed using SPSS software (version 26.0; IBM Corp). The Kolmogorov-Smirnov test was used to evaluate sample normality. All variables had normality assumption violation. Because of the large sample size, the violation of the normality assumption should not cause major problems. Therefore, parametric tests were performed since the sampling distribution tends to be normal, regardless of the shape of the data.[16] Additionally, in large data sets consisting of hundreds of observations, the distribution of the data could be ignored.[17]

Patients were categorized according to the glaucoma severity based on preoperative Humphrey visual field MD[18] (GI: initial glaucoma, MD less than –6 dB; GII: moderate glaucoma, MD between –6.01 and 12.00 dB; GIII: advanced glaucoma, MD worse than –12 dB). The analysis of variance (ANOVA) was used to compare the data according to the glaucoma severity, comparing the groups in pairs with the Tukey HSD post hoc test. The Kaplan-Meier curve was used to estimate survival (relative and complete success) in each group; and the results were compared with those of the log-rank (Mantel-Cox) test, both for pooled and pairwise comparisons. The analysis was performed on the whole data, followed by subanalyses considering only Phaco-GATT, and then GATT stand-alone patients. An alpha error of 5% ($P < .05$) was considered statistically significant.

RESULTS

A total of 270 eyes were included (90 in GI, 75 in GII, and 105 in GIII), with 167 eyes with a history of Phaco-GATT (67 in GI, 42 in GII, and 58 in GII) and 103 eyes with previous GATT stand-alone (23 in GI, 33 in GII, and 47 in GII). Age was similar between groups ($P = .5$). Baseline information is displayed in Table 1.

In 6 eyes, a new glaucoma surgery was necessary, 1 micropulse transscleral Laser in GI and 1 in GII; 1 trabeculectomy with MMC in GII and 1 in GIII; 1 glaucoma drainage device and 1 phaco-trabeculectomy in GIII. Transient and small hyphema was observed in 51.3% of all eyes; 94.4% of them had complete and spontaneous resolution within 1 week of follow-up. One patient presented with intracapsular hemorrhage, surgically removed after 1 week; 1 patient presented with vitreous hemorrhage, with complete and spontaneous resolution after 1 month; and 1 patient developed macular cystoid edema (treated with topical nonsteroidal anti-inflammatory eye drops). A small inferior iridodialysis was observed in 1 patient, and neurotrophic keratitis, treated with artificial tears, was observed in another one. An IOP spike was noticed in 1 patient, with complete resolution after topical steroid removal. No further complications were observed in the whole group.

• **PHACO-GATT + GATT STAND-ALONE:** Considering the whole cohort, preoperative MD was –3.07 ± 1.72 dB in GI (1.02 to –5.91 dB, 95% CI: –3.43 to –2.71 dB), –8.58 ± 1.72 dB in GII (–6.06 to –12.00 dB, 95% CI: –8.98 to –8.19 dB), and –20.59 ± 5.72 dB in GIII (–12.28 to –34.28 dB, 95% CI: –21.71 to –19.48 dB), $P < .001$ (group and all pairwise comparisons). The MD was available in 190 eyes at the last follow-up (62 in GI, 54 in GII, and 74 in GIII), demonstrating stability in GI ($P = .7$), GII ($P = .05$), and GIII ($P = .2$).

The IOP and medication behavior during the study are displayed in Table 2. IOP variation during the study is illustrated in Figure 1. At the last postoperative visit, the percentage of IOP reduction was 31.3% ± 20.2% in GI, 36.1% ± 17.8% in GII, and 36.1% ± 24.3% in GIII, $P = .2$ ($P = .3$ for GI vs GII; $P = .2$ for GI vs GIII; $P > .9$ for GII vs GIII); and the percentage of hypotensive medica-

TABLE 2. Intraocular Pressure and Number of Glaucoma Medication During the Study in All Eyes

Time	Group	n (IOP)	IOP (**mm Hg**)	*P* [a]	*P* [b]	n (Meds)	Meds	*P* [a]	*P* [b]
Preop.	GI	90	18.6 ± 6.0	.06	GI × GII: .90	90	2.7 ± 1.0	**.001**	GI × GII: **.04**
	GII	75	19.7 ± 6.4		GI × GIII: .70	75	3.1 ± 0.8		GI × GIII: **.001**
	GIII	105	21.0 ± 7.9		GII × GIII: .50	105	3.2 ± 1.2		GII × GIII: .60
PO 1 d	GI	84	12.8 ± 4.9	.50	GI × GII: .60				
	GII	72	13.7 ± 6.3		GI × GIII: .50				
	GIII	104	13.7 ± 5.2		GII × GIII: >.90				
PO 7 d	GI	85	12.6 ± 4.5	.05	GI × GII: .30	84	1.3 ± 0.8	.30	GI × GII: .90
	GII	74	13.6 ± 5.0		GI × GIII: .60	73	1.2 ± 1.0		GI × GIII: .40
	GIII	101	12.0 ± 3.6		GII × GIII: **.04**	100	1.5 ± 1.0		GII × GIII: .30
PO 30 d	GI	88	11.4 ± 2.5	.40	GI × GII: .40	82	1.0 ± 0.9	.10	GI × GII: .30
	GII	73	12.0 ± 3.2		GI × GIII: .90	73	1.3 ± 1.0		GI × GIII: .10
	GIII	105	11.5 ± 3.9		GII × GIII: .50	102	1.2 ± 1.0		GII × GIII: .90
PO 3 mo	GI	84	11.4 ± 2.2	.20	GI × GII: .30	81	0.8 ± 0.9	**.02**	GI × GII: .70
	GII	71	12.1 ± 3.4		GI × GIII: .30	70	0.9 ± 1.0		GI × GIII: **.02**
	GIII	102	12.0 ± 2.9		GII × GIII: .90	101	1.2 ± 1.1		GII × GIII: .10
PO 6 mo	GI	86	12.1 ± 3.6	.20	GI × GII: .90	81	0.7 ± 0.9	**.01**	GI × GII: .30
	GII	72	12.3 ± 4.2		GI × GIII: .40	71	0.9 ± 1.0		GI × GIII: **.008**
	GIII	100	11.5 ± 2.2		GII × GIII: .20	100	1.1 ± 1.0		GII × GIII: .30
PO 12 mo	GI	89	11.9 ± 2.6	.90	GI × GII: .90	67	0.6 ± 0.9	**.003**	GI × GII: **.04**
	GII	73	11.8 ± 2.1		GI × GIII: .90	63	1.0 ± 1.1		GI × GIII: **.002**
	GIII	102	11.9 ± 3.0		GII × GIII: .90	91	1.2 ± 1.1		GII × GIII: .60

GATT = gonioscopy-assisted transluminal trabeculotomy, GI = mild glaucoma, GII = moderate glaucoma, GIII = advanced glaucoma, IOP = intraocular pressure, PO = postoperative.

Boldface indicates statistical significance ($P < .05$).

[a] Analysis of variance.

[b] Tukey honestly significant difference.

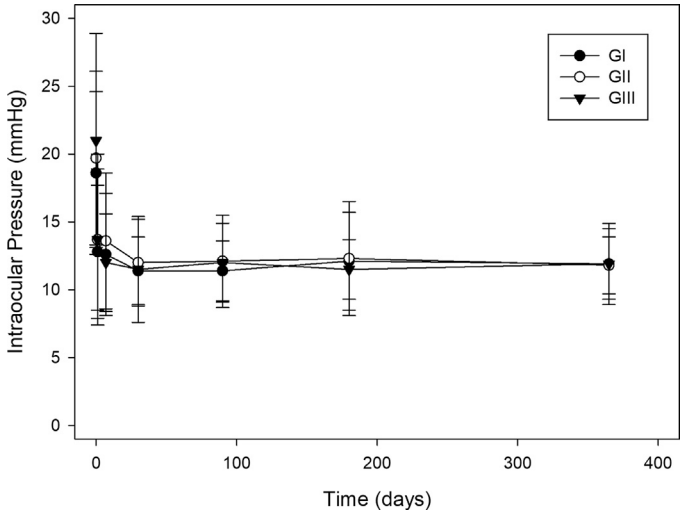

FIGURE 1. Intraocular pressure behavior during the study for all patients. GI = mild glaucoma, GII = moderate glaucoma, GIII = advanced glaucoma.

tion reduction was 78.9% ± 30.3% in GI, 63.1% ± 41.3% in GII, and 61.2% ± 35.2% in GIII, $P = .006$ ($P = .03$ for GI vs GII; $P = .007$ for GI vs GIII; $P = .9$ for GII vs GIII). IOP and number of glaucoma medications were significantly reduced at 12 months compared to preoperative values regardless of glaucoma severity ($P < .001$ for all). Visual acuity (logMAR) improved from 0.69 ± 1.14 to 0.39 ± 0.93 in GI ($P = .001$), 0.73 ± 1.05 to 0.21 ± 0.35 in GII ($P < .001$), and 1.28 ± 2.94 to 0.75 ± 2.03 in GIII ($P < .001$).

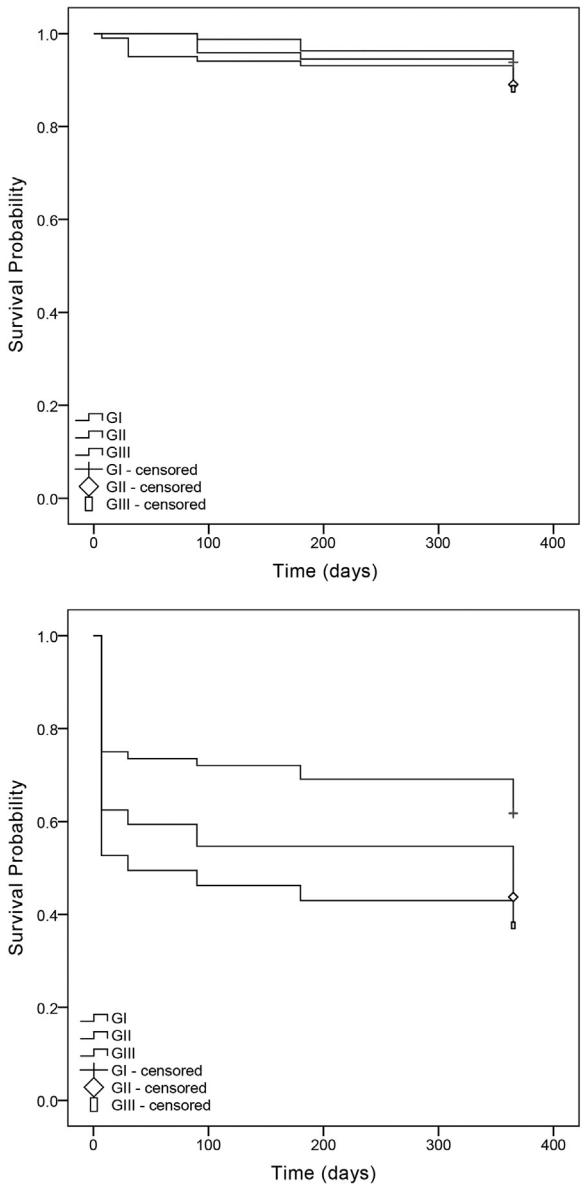

FIGURE 2. Kaplan-Meier curve for relative and complete success in the whole cohort: A. Relative success. B. Complete success. GI = mild glaucoma, GII = moderate glaucoma, GIII = advanced glaucoma

Relative success was achieved in 93.8% of the eyes in GI, 89.0% in GII, and 88.1% in GIII. For relative success, at 1 year, the Kaplan-Meier curve estimated a survival of the procedure in 357.0 days in GI (95% CI: 346.9-367.1 days), compared with 351.1 days in GII (95% CI: 336.8-365.4 days), and 343.6 days in GIII (95% CI: 327.4-359.8 days), $P = .3$ ($P = .2$ for GI vs GII, $P = .1$ for GI vs GIII, $P = .8$ for GII vs GIII) (Figure 2, A).

Complete success was achieved in 61.8% of the eyes in GI, 43.8% in GII, and 37.6% in GIII. Considering complete success, at the last follow-up visit, the Kaplan-Meier curve estimated a survival of the procedure in 261.0 days in GI (95% CI: 222.7-299.4 days), compared with 207.3 days in GII (95% CI: 164.1-250.6 days) and 169.9 days in GIII (95% CI: 134.6-205.3 days), $P = .007$ ($P = .03$ for GI vs GII, $P = .002$ for GI vs GIII, and $P = .3$ for GII vs GIII) (Figure 2, B). In 5 patients, all submitted to Phaco-GATT (3 in GI, 1 in GII, and 1 in GIII) the SC was not canalized 360°, but to at least 180°.

• **PHACO-GATT:** Preoperative MD was –2.93 ± 1.67 dB in GI (1.02 to –5.82 dB, 95% CI: –3.34 to –2.52 dB), –8.22 ± 1.65 dB in GII (–6.06 to –11.85 dB, 95% CI: –8.74 to –7.71 dB), and –20.28 ± 5.30 dB in GIII (–12.55 to –31.23 dB, 95% CI: –21.67 to –18.88 dB), $P < .001$ (group and all pairwise comparisons).

The IOP and medication behavior during the study are displayed in Table 3. At the last postoperative visit, the percentage of IOP reduction was 28.6% ± 20.3% in GI, 32.6% ± 19.1% in GII, and 36.9% ± 24.3% in GIII, $P = .1$ ($P = .6$ for GI vs GII; $P = .08$ for GI vs GIII; $P = .5$ for GII vs GIII), and the percentage of hypotensive medication reduction was 83.7% ± 25.7% in GI, 64.6% ± 50.9% in GII, and 62.9% ± 37.0% in GIII, $P = .02$ ($P = .08$ for GI vs GII, $P = .02$ for GI vs GIII, and $P = .9$ for GII vs GIII).

Relative success was achieved in 93.1% of the eyes in GI, 92.5% in GII, and 92.6% in GIII. For relative success, at 1 year, the Kaplan-Meier curve estimated a survival of the procedure in 357.0 days in GI (95% CI: 344.3-369.7 days), compared with 344.3 days in GII (95% CI: 321.9-366.8 days) and 340.8 days in GIII (95% CI: 318.0-363.7 days), $P = .9$ ($P = .8$ for GI vs GII, $P = .9$ for GI vs GIII, and $P = .9$ for GII vs GIII).

Complete success was achieved in 71.1% of the eyes in GI, 54.8% in GII, and 45.7% in GIII. Considering complete success, at the last follow-up visit, the Kaplan-Meier curve estimated a survival of the procedure in 289.2 days in GI (95% CI: 245.5-333.0 days), compared with 232.5 days in GII (95% CI: 171.2-293.8 days) and 190.1 days in GIII (95% CI: 138.2-241.9 days), $P = .03$ ($P = .1$ for GI vs GII, $P = .01$ for GI vs GIII, and $P = .3$ for GII vs GIII).

• **GATT STAND-ALONE:** Preoperative MD was –3.48 ± 1.81 dB in GI (–0.19 to –5.91 dB, 95% CI: –4.27 to –2.70 dB), –9.04 ± 1.84 dB in GII (–6.30 to –12.00 dB, 95% CI: –9.47 to –8.34 dB), and –20.59 ± 6.15 dB in GIII (–12.14 to –34.28 dB, 95% CI: –22.85 to –19.14 dB), $P < .001$ (group and all pairwise comparisons). The MD was available in 66 eyes at the last follow-up (15 in GI, 22 in GII, and 29 in GIII), demonstrating stability in all groups: GI ($P = .2$), GII ($P = .4$), and GIII ($P = .9$).

The IOP and medication behavior during the study are displayed in Table 4. At the last postoperative visit, the percentage of IOP reduction was 39.5% ± 17.8% in GI, 40.5% ± 15.2% in GII, and 35.1% ± 24.6% in GIII, $P = .4$ ($P = .9$ for GI vs GII, $P = .6$ for GI vs GIII, and $P = .4$ for GII vs GIII). The percentage of hypotensive medication reduction was 69.3% ± 36.8% in GI, 61.8% ± 31.3% in GII,

TABLE 3. Intraocular Pressure and Number of Glaucoma Medication During the Study for Phaco-GATT Patients

Time	Group	n (IOP)	IOP (**mm Hg**)	*P* [a]	*P* [b]	n (Meds)	Meds	*P* [a]	*P* [b]
Preop.	GI	67	17.3 ± 5.5	**.02**	GI × GII: .70	67	2.6 ± 1.0	.20	GI × GII: .70
	GII	42	18.4 ± 5.0		GI × GIII: **.01**	42	2.8 ± 1.0		GI × GIII: .20
	GIII	58	20.7 ± 9.1		GII × GIII: .20	58	3.0 ± 1.5		GII × GIII: .60
PO 1 d	GI	62	13.0 ± 5.1	.30	GI × GII: .30				
	GII	39	14.6 ± 6.8		GI × GIII: .50				
	GIII	57	14.1 ± 5.8		GII × GIII: .80				
PO 7 d	GI	63	12.6 ± 4.7	.10	GI × GII: .20	61	1.3 ± 0.8	.30	GI × GII: .90
	GII	41	14.0 ± 5.0		GI × GIII: .80	40	1.3 ± 1.0		GI × GIII: .40
	GIII	55	12.1 ± 3.7		GII × GIII: .10	53	1.5 ± 0.9		GII × GIII: .30
PO 30 d	GI	65	11.4 ± 2.5	.20	GI × GII: .60	59	1.1 ± 0.9	.30	GI × GII: .60
	GII	40	11.9 ± 3.0		GI × GIII: .60	40	1.3 ± 1.1		GI × GIII: .30
	GIII	58	11.0 ± 2.9		GII × GIII: .20	55	1.3 ± 0.9		GII × GIII: .90
PO 3 mo	GI	61	11.1 ± 2.2	.08	GI × GII: .06	58	0.8 ± 1.0	.08	GI × GII: .70
	GII	38	12.5 ± 4.2		GI × GIII: .50	37	0.9 ± 1.1		GI × GIII: .07
	GIII	56	11.7 ± 3.0		GII × GIII: .40	54	1.2 ± 1.1		GII × GIII: .40
PO 6 mo	GI	63	11.6 ± 3.7	.30	GI × GII: .50	58	0.6 ± 1.0	.05	GI × GII: .40
	GII	39	12.4 ± 5.2		GI × GIII: .80	38	0.8 ± 1.1		GI × GIII: **.04**
	GIII	56	11.3 ± 2.1		GII × GIII: .30	54	1.1 ± 1.1		GII × GIII: .50
PO 12 mo	GI	67	11.6 ± 2.7	.60	GI × GII: .90	45	0.5 ± 0.8	.05	GI × GII: .30
	GII	41	11.7 ± 2.3		GI × GIII: .70	30	0.9 ± 1.1		GI × GIII: **.04**
	GIII	58	11.3 ± 2.0		GII × GIII: .70	46	1.0 ± 1.1		GII × GIII: .70

GATT = gonioscopy-assisted transluminal trabeculotomy, GI = mild glaucoma, GII = moderate glaucoma, GIII = advanced glaucoma, IOP = intraocular pressure, PO = postoperative.

Boldface indicates statistical significance ($P < .05$).

[a] Analysis of variance.

[b] Tukey honestly significant difference.

and 59.4% ± 33.5% in GIII, $P = .5$ ($P = .7$ for GI vs GII, $P = .4$ for GI vs GIII, and $P = .9$ for GII vs GIII). Visual acuity (logMAR) changed from 0.25 ± 0.14 to 0.20 ± 0.14 in GI ($P = .2$), 0.42 ± 0.40 to 0.23 ± 0.26 in GII ($P < .001$), and 0.70 ± 0.75 to 0.49 ± 0.63 in GIII ($P < .001$). Visual acuity (logMAR) changed from 0.22 ± 0.14 to 0.20 ± 0.14 in GI ($P = .5$), 0.41 ± 0.31 to 0.23 ± 0.28 in GII ($P < .001$), and 0.71 ± 0.74 to 0.49 ± 0.62 in GIII ($P = .009$).

Relative success was achieved in 95.7% of the eyes in GI, 84.8% in GII, and 83.0% in GIII. For relative success, at 1 year, the Kaplan-Meier curve estimated a survival of the procedure in 356.9 days in GI (95% CI: 341.5-372.3 days), compared with 359.3 days in GII (95% CI: 347.2-371.4 days) and 346.8 days in GIII (95% CI: 324.8-368.7 days), $P = .3$ ($P = .2$ for GI vs GII, $P = .1$ for GI vs GIII, and $P = .7$ for GII vs GIII).

Complete success was achieved in 43.5% of the eyes in GI, 33.3% in GII, and 29.8% in GIII. Considering complete success, at the last follow-up visit, the Kaplan-Meier curve estimated a survival of the procedure in 205.9 days in GI (95% CI: 133.5-278.2 days), compared with 183.7 days in GII (95% CI: 122.1-245.3 days) and 150.2 days in GIII (95% CI: 101.7-198.7 days), $P = .4$ ($P = .4$ for GI vs GII, $P = .2$ for GI vs GIII, and $P = .6$ for GII vs GIII).

DISCUSSION

The indications for glaucoma surgeries have been modified. Trabeculectomy and tube shunts are still very important, but in some patients, new glaucoma surgeries, or even modification of other surgical techniques, such as new cyclophotocoagulation protocols, are replacing these modalities. In a bid to reduce the complication rates, especially bleb-related ones, promote faster recovery, and diminish the number of postoperative visits allied to enhanced patient's expectations, researchers have sought alternative glaucoma procedures that are safe and effective. A vast body of recent literature has demonstrated the efficacy and safety of the MIGS, including GATT, in different glaucoma populations.[5,6,8,14,19-22]

Previous GATT studies related very similar efficacy and safety outcomes, demonstrating a quite predictable surgery for glaucoma.[5-7,23] GATT was first described by Grover and associates[5] in 2014. They reported a 11.1–mm Hg mean IOP reduction, with 1.1 fewer glaucoma medications at 12 months in POAG. The same group reported similar results (9.43–mm Hg IOP reduction with an average decrease of 1.43 glaucoma medications) at 24 months of follow-up for

TABLE 4. Intraocular Pressure and Number of Glaucoma Medication During the Study for GATT Stand-Alone Patients

Time	Group	n (IOP)	IOP (**mm Hg**)	*P* [a]	*P* [b]	n (Meds)	Meds	*P* [a]	*P* [b]
Preop.	GI	23	22.3 ± 5.9	.80	GI × GII: .80	23	2.7 ± 1.0	**<.001**	GI × GII: **.004**
	GII	33	21.4 ± 7.6		GI × GIII: .80	33	3.4 ± 0.5		GI × GIII: **<.001**
	GIII	47	21.3 ± 6.2		GII × GIII: >.99	47	3.5 ± 0.6		GII × GIII: .80
PO 1 d	GI	22	12.3 ± 4.4	.70	GI × GII: .90				
	GII	33	12.5 ± 5.5		GI × GIII: .70				
	GIII	47	13.2 ± 4.4		GII × GIII: .80				
PO 7 d	GI	22	12.7 ± 4.2	.40	GI × GII: .90	23	1.2 ± 0.9	.70	GI × GII: .90
	GII	33	13.2 ± 5.1		GI × GIII: .70	33	1.2 ± 1.0		GI × GIII: .70
	GIII	46	11.9 ± 3.5		GII × GIII: .30	47	1.4 ± 1.1		GII × GIII: .80
PO 30 d	GI	23	11.6 ± 2.5	.80	GI × GII: .80	23	1.0 ± 0.9	.30	GI × GII: .40
	GII	33	12.2 ± 3.5		GI × GIII: .80	33	1.3 ± 0.9		GI × GIII: .40
	GIII	47	12.2 ± 4.8		GII × GIII: >.99	47	1.3 ± 1.0		GII × GIII: .90
PO 3 mo	GI	23	12.3 ± 2.1	.30	GI × GII: .60	23	0.9 ± 0.9	.30	GI × GII: .90
	GII	33	11.6 ± 2.1		GI × GIII: .90	33	0.9 ± 0.9		GI × GIII: .40
	GIII	46	12.5 ± 3.2		GII × GIII: .30	47	1.2 ± 1.1		GII × GIII: .30
PO 6 mo	GI	23	13.6 ± 2.8	**.02**	GI × GII: .09	23	0.9 ± 0.9	.30	GI × GII: .90
	GII	33	12.1 ± 2.4		GI × GIII: **.01**	33	1.0 ± 0.9		GI × GIII: .40
	GIII	44	11.8 ± 2.2		GII × GIII: .80	46	1.2 ± 1.0		GII × GIII: .50
PO 12 mo	GI	22	12.7 ± 2.0	.30	GI × GII: .50	22	0.9 ± 0.9	.10	GI × GII: .40
	GII	32	11.8 ± 1.9		GI × GIII: >.99	33	1.2 ± 1.0		GI × GIII: .10
	GIII	44	12.7 ± 3.8		GII × GIII: .40	45	1.4 ± 1.1		GII × GIII: .80

GATT = gonioscopy-assisted transluminal trabeculotomy, GI = mild glaucoma, GII = moderate glaucoma, GIII = advanced glaucoma, IOP = intraocular pressure, PO = postoperative.

Boldface indicates statistical significance ($P < .05$).

[a] Analysis of variance.

[b] Tukey honestly significant difference.

POAG.[7] Faria and associates described an IOP reduction from 24.9 ± 8.5 mm Hg to 12.1 ± 2.1 mm Hg ($P < .001$) at 12 months of follow-up, with a reduction in the number of glaucoma medications from 3.5 ± 0.7 to 1.2 ± 1.2 ($P < .001$) in an average moderated glaucoma cohort (MD: –10.8 ± 8.1 dB).[6]

Wan and associates[23] reported similar results in a Chinese population both at 12 and 24 months of follow-up. Additionally, they found no difference in the survival time between mild and moderate POAG (MD ≥ –12 dB) and severe POAG (MD < –12 dB, $P = .4$). The authors, however, did not report the exact preoperative MD in any group and neither performed any statistical analysis considering mild and moderate glaucoma as different groups. In fact, GATT studies usually report results of previous glaucoma damage based on an average. Therefore, patients at very different stages of glaucoma were probably analyzed together, and eventual differences in the outcomes related to the disease severity would not be described.

There are a few publications on minimally invasive surgical treatment for severe glaucoma.[7,14,15,24-27] Chansangpetch and associates[26] compared the 1-year outcomes of single iStent implantation with phacoemulsification among glaucoma severities in POAG. The authors concluded that combined cataract surgery with iStent seems to have better efficacy in mild glaucoma cases. Salinas and associates described the 6-month outcomes of goniotomy with Kahook dual blade (KDB) in a retrospective multicenter case series of 53 eyes with severe or refractory glaucoma.[27] In their study, the proportion of eyes achieving an IOP reduction of >20% from preoperative baseline (18.4 ± 6.1 mm Hg) at 6 months was 57.7%.

Similar results were achieved in a study published in 2023 by Bravetti and associates.[25] The authors described an IOP decrease from 18.1 ± 5.0 mm Hg at baseline to 14.8 ± 3.7 mm Hg (18.2% reduction, $P < .001$) and a reduction of the mean number of glaucoma medications from 2.5 ± 1.4 to 1.7 ± 1.2 at 12 months using the KDB in patients with severe or refractory glaucoma. The results presented here with GATT, considering only severe glaucoma, were apparently more encouraging. However, no direct comparisons can be made, and this is only a superficial assumption. Prospective, randomized, controlled trials comparing different minimally invasive surgical procedures for severe glaucoma are needed to answer this important question.

Grover and associates[7] in a study with 198 patients undergoing GATT divided the POAG group data into 3 different levels of glaucoma severity based on Humphrey visual field preoperative results: MD > –3 dB, MD between –3 and –14 dB, and MD ≤ –15 dB, demonstrating a higher pro-

portion of failure until the 6-month follow-up in the more advanced glaucoma group. Despite not being designed to answer this question, the study suggested that surgeons use preoperative MD as guide to decide whether or not to perform a GATT procedure.

Notwithstanding more conservative success criteria (including only an IOP >21 mm Hg to be considered a failure) than the ones presented here, there are some possible differences that could have led to such different results. The glaucoma classification used could have included in the same group mild, moderate, and advanced glaucoma—considering a well-accepted MD classification in this regard.[18] There is no reference to the number of patients in each group and their preoperative baseline measurements. It is reasonable to hypothesize that the more advanced glaucoma group could have the higher preoperative IOP, and also be on more glaucoma medications preoperatively or even have more refractory glaucoma included. An ideal comparison requires equivalent groups, and it is not possible to obtain these data from their article.

Conversely, we divided the patients according to their basal glaucoma damage (before surgery). Severe glaucoma (mean MD: –20.59 ± 5.72 dB) had similar relative success and final IOP compared with mild or moderate ones (Table 2 and Figures 1 and 2, A). Despite clearly higher preoperative IOP, although not statistically significant, but more glaucoma medication in the advanced glaucoma patients especially compared to the mild ones (Table 2), the patients were quite similar in their inclusion criteria, including age, an indirect measure of the time of the disease for each patient, and also a possible important risk factor for failure. Because previous papers have shown that patients older than 60 years have a significantly greater risk of failure (hazard ratio = 10.96; $P = .026$)[6]—the mean age here was >60 years and similar between groups ($P = .5$).

A few studies have also demonstrated that GATT may be a viable surgical option in moderate and advanced glaucoma.[14,15,24] Another important finding here is that the IOP was significantly reduced since the first postoperative visit in all groups, and remained linear and with few fluctuations (as shown by small SDs) throughout the whole study (Figure 1 and Tables 2-4). These results are very important, because 2 important issues (especially in advanced glaucoma) were satisfied: low target IOP[28] with small long-term fluctuation.[29]

However, mild glaucoma patients achieved similar results with fewer glaucoma medications compared with moderate and advanced glaucoma patients, resulting in a greater number of complete successes (Table 2 and Figure 2, B). Nevertheless, the differences were significant only when comparing mild vs advanced glaucoma in the Phaco-GATT group but not in the GATT stand-alone. These small differences in the subgroup analyses are probably related to the smaller sample sizes (yet large ones) compared to the 270 eyes included in the whole cohort, therefore allowing to suppose comparable clinical results, both in Phaco-GATT and GATT stand-alone.

Another important finding relates to the improvement in the visual acuity for all groups. However, because the majority of the eyes in the study underwent a combined GATT procedure with Phaco, this observation is somehow likely to occur, because of the expected improvement in vision after cataract removal. Therefore, a second analysis was performed, considering only GATT stand-alone patients, demonstrating stability in GI and improvement in the best-corrected VA in GII and GIII after 1 year of follow-up.

Additionally, despite partial data available for MD at 12 months postoperatively, there is no indication of visual field deterioration for patients, regardless of their glaucoma severity. Similar reasoning may be applied to the stability in the MD found at the last visit, both with the whole cohort and considering only GATT stand-alone patients—excluding the expected improvement in the MD related to the cataract surgery in the Phaco-GATT group.

The present study has some limitations, mainly related to the retrospective nature of the design. Data collection was not masked to the severity of the disease, and the choice for GATT in every patient relied only on the surgeon's judgment—and not to randomization. Consequently, at least some patients at higher risk of failure were probably not included in the analysis, artificially enhancing the outcomes.

On the other hand, this is a large cohort analyzing GATT results, with multicenter recruitment that allowed results from different surgeons to be analyzed together. Furthermore, a homogenous cohort was analyzed, because only POAG patients were included, and a defined follow-up time (12 months) was chosen, rather than a minimal one. The study design allowed to evaluate all patients approximately at the same time after surgery and not by means of an average follow-up, which allowed comparison of patients at very different stages after surgery, a hypothetically important inclusion bias. Additionally, this is the first article to look in detail at GATT results according to preoperative glaucoma severity and were also presented considering only Phaco-GATT or GATT stand-alone patients. Despite previous publications indicating good results with GATT even in moderate and advanced glaucoma,[14,15,30] it is very important to better understand every postoperative behavior (and possible differences) at all stages of glaucoma.

Overall, the results presented here demonstrate that GATT (Phaco-GATT or stand-alone) is an effective and safe option for glaucoma—regardless of its severity. All groups achieved similar postoperative IOPs at all time points. However, moderate and advanced glaucoma usually required fewer (but more compared to mild glaucoma) hypotensive medications to obtain comparable outcomes, resulting in similar relative, but inferior, complete success (Figure 2, A and B).

In conclusion, glaucoma severity is not a major variable associated with surgical success, and GATT (Phaco-GATT

or GATT stand-alone) can be safely and effectively performed in glaucoma, regardless of its preoperative severity. However, there might be different features related to the procedure's success other than diagnosis, time of disease onset, or glaucoma severity (eg, preoperative IOP). Prospective trials are needed to better answer this important question.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

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