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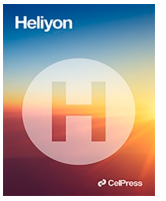

Research article

Surgical outcomes including visual improvement after glaucoma surgery in patients with neovascular glaucoma

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ABSTRACT

Purpose: This study aimed to evaluate the prognostic factors affecting surgical outcomes, including visual acuity (VA) improvement, after glaucoma surgery in patients with neovascular glaucoma (NVG).

Methods: The medical records of 116 patients (116 eyes) with NVG who had undergone trabeculectomy or Ahmed glaucoma valve implantation were reviewed retrospectively. The primary outcome measure was surgical success at 6 postoperative months, defined as sufficient intraocular pressure (IOP) reduction (IOP $\leq$21 mmHg, $\geq$20% reduction, regardless of topical medication use) without additional glaucoma surgery, hypotony, or progression to no light perception. Success was categorized as complete or qualified based on whether an improvement in VA was observed in addition to the abovementioned definition.

Results: The complete and qualified success rates at 6 months were 44.6% and 92.2%, respectively. Age ($p = 0.001$), preoperative best-corrected VA ($p = 0.031$), duration of decreased VA ($p = 0.001$), closed-angle status ($p = 0.013$), and etiology ($p = 0.007$) differed significantly between the groups with and without complete success. Multivariate analysis revealed that age (odds ratio [OR] 1.05; $p = 0.026$), duration of decreased VA (OR 1.05; $p = 0.016$), and 360° closed-angle status (OR 3.27; $p = 0.031$) were risk factors for surgical failure according to the complete success criteria, but not the qualified success criteria.

Conclusions: Patients with NVG showed improved visual prognosis and successful IOP reduction after glaucoma surgery at a relatively younger age if the duration of visual loss was not prolonged and the angle status was not completely closed.

1. Introduction

Neovascular glaucoma (NVG), the most common type of refractory glaucoma, which often results in poor visual outcomes [[1,2]]. NVG is characterized by the neovascularization of the iris or the angle triggered by retinal ischemia [[3]]. The formation of contractile fibrovascular membranes causes secondary angle closure via peripheral anterior synechiae (PAS) and intractable intraocular pressure (IOP) elevation in the advanced stages of NVG [[3]]. The management of NVG consists of two main aspects: the treatment of the underlying retinal diseases to reduce the ischemic burden inducing neovascularization and the control of the elevated IOP through medical and surgical means [[4]]. Surgical interventions include filtering surgery, glaucoma drainage device (GDD) implantation, and

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cyclodestructive procedures; however, the superiority of these procedures in the management of NVG has not been demonstrated [[5]].

Several studies have evaluated the outcomes of various glaucoma surgeries for NVG and the risk factors for surgical failure [6–10]. However, most of these studies defined surgical success and failure according to the criteria defined by the World Glaucoma Association, which mainly focuses on IOP reduction. Few studies have focused on the visual outcomes of patients with NVG after glaucoma surgery. Final visual acuity (VA) below hand motion (HM) or light perception (LP) is common in eyes with NVG, even with appropriate interventions, owing to the presence of underlying retinal diseases [[11,12]]. However, VA improvement after glaucoma surgery is not uncommon in eyes with NVG in clinical practice. Medert et al. reported that the visual outcomes vary according to the underlying etiology in patients with NVG after glaucoma surgery [[13]]. Other studies have also reported that the resolution of the abrupt increase in IOP after glaucoma surgery resulted in VA improvement in patients with NVG [[2,7]].

To the best of our knowledge, no previous study has included VA improvement in the surgical success criteria for NVG. Moreover, the definition of success was limited to not progressing to no light perception (NLP) vision in most studies. Therefore, this study aimed to evaluate surgical outcomes, including VA improvement as success criteria for NVG after glaucoma surgery, and prognostic factors related to these outcomes.

2. Methods

This retrospective cohort study was approved by the Institutional Review Board of our university hospital (IRB number: 2023-02-021) and was conducted in accordance with the tenets of the Declaration of Helsinki. The requirement for written informed consent was waived owing to the retrospective nature of the study.

We reviewed the electronic medical records of patients with NVG who had undergone trabeculectomy (TLE) with mitomycin C (MMC) or Ahmed glaucoma valve (AGV) implantation between March 2016 and December 2022. These patients were unresponsive to maximal medical treatment or had intolerable complications following the administration of anti-glaucoma drugs. NVG was diagnosed based on the presence of neovascularization of the iris and/or the angle triggered by retinal ischemia and an IOP >21 mmHg [[14]]. All patients were followed up for at least 6 months postoperatively, and the postoperative data of the first 6 months were included in this study to avoid visual deterioration caused by the progression of the underlying retinal diseases. The exclusion criteria were as follows: age <18 years; congenital abnormalities in the anterior segment; history of undergoing glaucoma surgery in the same eye or intraocular surgery within the preceding 3 months; maculopathy, including edema or degeneration, potentially affecting vision; and intraocular surgery that might affect vision during the 6-month follow-up period. Patients who were unable to complete the examinations required for this study were also excluded. One eye per patient was included, and the eye that underwent surgery first was included to avoid selection bias.

The following information was collected by reviewing the electronic medical records: age; sex; laterality; number of glaucoma medications; best-corrected visual acuity (BCVA); IOP; systemic diseases; history of previous intraocular surgery; lens status; history of intravitreal bevacizumab (IVB) injections; panretinal photocoagulation (PRP); duration of decreased VA to preoperative BCVA, and duration of IOP >21 mmHg until glaucoma surgery; degree of PAS evaluated from slit lamp gonio photography; and presence of concurrent signs on presentation, such as hyphema or corneal edema. The etiology of NVG was evaluated through consultation with vitreoretinal specialists at the same hospital. If fundus examination could not be performed due to corneal edema or hemorrhage at presentation, it was performed after glaucoma surgery when the media became clear. All patients received at least one injection of IVB preoperatively and PRP in all quadrants, if possible. Incomplete PRP was administered within 3 postoperative months. The angle status of all patients was assessed preoperatively by gonioscopy.

The primary outcome measure was surgical success at 6 months, which was defined as IOP ≤21 mmHg, ≥20% IOP reduction with or without topical medication use, and no progression to NLP vision. Success was further categorized as complete or qualified. Complete success was defined as an improvement in the final BCVA of two or more Snellen lines in addition to the abovementioned definition. In contrast, qualified success did not include visual criteria. Snellen VA was converted to logMAR for analysis. Non-Snellen VA was converted as follows: count fingers = 2.0, HM = 2.3, LP = 2.6, and NLP = 3.0 [[13]]. Eyes with NLP vision at presentation were excluded from the evaluation of complete success as none of these eyes showed VA improvement at 6 months; the goal in these cases was to improve pain rather than to maintain vision. Surgical failure was defined as IOP >21 mmHg with topical medications or <5 mmHg at two consecutive visits, with clinically significant signs of hypotony, need for additional surgery for IOP control, or removal of the implant. The incidence of serious postoperative complications, such as phthisis bulbi or endophthalmitis, was also considered as surgical failure. Laser suture lysis and bleb needling were not considered glaucoma surgeries. Secondary outcome measures included BCVA, IOP, number of glaucoma medications, and postoperative complications during the follow-up period.

All surgeries were performed by a single surgeon (CKL), and all AGVs were FP-7. The choice of surgery type was based on conjunctival integrity, lens status, age, and compliance. The procedure for TLE with MMC included the creation of a fornix-based flap from the conjunctiva and Tenon's capsule and a 3.5 × 3.5-mm half-layer rectangular-shaped scleral flap, with gentle cauterization to achieve hemostasis. Ten small pieces of sponge soaked in 0.4 mg/mL MMC were inserted under the conjunctival and tenon tissue and over the scleral flap for 5 min. After 5 min, all soaked sponges were removed, and the eye was irrigated with 200 ml of a balanced salt solution. A peripheral iridectomy was performed after the approximately 1.5 mm-sized trabecular block was fully punched out using a Kelly punch. The scleral and conjunctival flaps were closed using 1 or 2 10-0 monofilament nylon sutures according to fluid filtration at the posterior edge of the rectangular scleral flap. The conjunctival flaps were closed using 10-0 nylon, and ophthalmic viscoelastic device (OVD) was injected at the anterior chamber to avoid acute post-operative hypotony. The AGV implantation procedure included the creation of the fornix-based flap from the conjunctiva and Tenon's capsule, and of two partial-thickness scleral flaps. The tube was

flushed with a balanced salt solution to check patency. The tube and the 4-0 nylon intraluminal stent were partially ligated using 8-0 vicryl and the 4-0 intraluminal stent was withdrawn subsequently. The AGV was anchored between the superior rectus and lateral or medial rectus muscles using 7-0 nylon, with the anterior edge of the plate at least 8 mm posterior to the limbus. OVD was injected to maintain the anterior chamber before tube insertion. The tube was trimmed to an appropriate length and inserted into the anterior chamber (AC) or the ciliary sulcus, when the anterior chamber was very shallow owing to the severe angle-closure state of NVG in the pseudophakic eye, through the scleral tunnel using a 23-gauge needle followed by an OVD injection. The scleral flap was sutured with 10-0 nylon, and the conjunctiva was closed using 8-0 vicryl. The patient was observed on the first postoperative day to check for postoperative complications such as hypotony, choroidal detachment, hyphema, and vitreous hemorrhage. Hypotony-related complications were managed using the protocols reported by Barros et al. [[14]]. Topical prednisolone acetate 1% (Pred Forte; Allergan, Inc., Irvine, CA) was prescribed for use four times daily, up to every 2 h, for 1-month post-operation, followed by the administration of lower potency topical corticosteroids for 8–12 weeks according to the bleb status and inflammation signs at the surgical wound. A topical moxifloxacin 0.05% (Vigamox; Alcon Laboratories, Inc., Fort Worth, TX) was prescribed for use four times daily during the topical corticosteroid administration period.

All data were analyzed using SPSS 27.0 (SPSS, Inc., Chicago, IL, USA). Demographic data and surgical results were compared between the groups using the Mann-Whitney *U* test for continuous variables and Pearson's chi-square or Fisher's exact test for categorical variables. Group comparisons were performed between the success and failure groups. Logistic regression analysis was performed for baseline characteristics, clinical features, and postoperative measures according to the characteristics of the factors [[15]] to identify the predictive factors for complete and qualified surgical failure. Factors with significant p-values in the univariate logistic regression analysis were subjected to multivariate logistic regression analysis. Statistical significance was set at $p < 0.05$.

3. Results

In total, 116 eyes of 116 patients were included in this study. The baseline characteristics of the patients are presented in Table 1. Fifty-four eyes underwent TLE with MMC, whereas 62 eyes underwent AGV implantation. Proliferative diabetic retinopathy (PDR) was the underlying etiology in 49.1% of patients, whereas central retinal vein occlusion (CRVO) was the underlying etiology in 31.9% of patients. PDR accounted for nearly half of the cases of NVG in this study. The other causes included uveitis (Table 1).

3.1. Comparison of baseline characteristics

Table 2 presents a comparison of baseline demographics and ophthalmic characteristics between eyes with and without complete surgical success. Forty-one of the 92 eyes met the criteria for complete success. There were no significant differences in sex, laterality, the type of glaucoma surgery, the number of preoperative IVB injections or PRP, systemic diseases, history of previous intraocular surgery, lens status, and concurrent signs on presentation (such as vitreous hemorrhage, hyphema, and corneal edema) between the successful and failed eyes ($p > 0.05$). The mean age was 56.20 ± 11.86 and 65.98 ± 12.52, and the preoperative BCVA (in LogMAR) was 1.35 ± 0.91 and 1.76 ± 0.79 in the successful and failed eyes, respectively, with significant differences observed between the two groups ($p = 0.001$ and $= 0.031$, respectively). The preoperative IOP and the number of glaucoma medications were comparable between the successful and failed eyes. The degree of PAS differed significantly in both ranges and the 360° closed-angle status ($p = 0.018$ and 0.013, respectively). The mean range in the successful and failed eyes was 187.89 ± 131.91 and 253.13 ± 130.12, respectively, and the percentage of 360° closed-angle status of failed eyes was nearly twice that of successful eyes (46.8% and 21.1%, respectively). The duration of decreased VA of the failed eyes was significantly longer than that of the successful eyes ($p = 0.001$);

Table 1
Baseline characteristics of neovascular glaucoma patients.

	Total n = 116
Age (years)	62.37 ± 12.43 (35–77)
Male/Female [n (%)]	80 (69.0)/36 (31.0)
Right/Left [n (%)]	56 (48.3)/60 (51.7)
TLE/AGV [n (%)]	54 (46.6)/62 (53.4)
Preoperative BCVA (LogMAR)	1.87 ± 0.96 (0.1–2.6)
Preoperative IOP (mmHg)	38.90 ± 12.39 (24–67)
Preoperative number of glaucoma medications (n)	3.83 ± 0.69 (0–4)
Etiology of NVG [n (%)]	
PDR	57 (49.1)
CRVO	37 (31.9)
OIS	13 (11.2)
Other[a]/Unknown	9 (7.8)

Continuous variables are presented as means with standardized deviations. Categorical variables are presented as frequencies and percentages, and minimum – maximum values.
TLE, trabeculectomy with MMC; AGV, Ahmed glaucoma valve implantation; BCVA, best-corrected visual acuity; IOP, intraocular pressure; NVG, neovascular glaucoma; PDR, proliferative diabetic retinopathy; CRVO, central retinal vein occlusion; OIS, ocular ischemic syndrome.
[a] Other etiology included uveitis.

Table 2
Comparison of demographics and ophthalmic characteristics between eyes with and without complete surgical success.

	Total n = 92	Success n = 41 (44.6%)	Failure n = 51 (55.4%)	*p* value[a]	NLP vision at presentation n = 24
Age (years)	62.37 ± 12.43	56.20 ± 11.86	65.98 ± 12.52	0.001	65.25 ± 9.03
Male/Female (n)	63/29	29/12	34/17	0.677[b]	17/7
Systemic diseases [n (%)]					
DM	75 (81.5)	33 (80.5)	42 (82.4)	0.819[b]	
HTN	50 (54.3)	25 (61.0)	25 (49.0)	0.252[b]	
Right/Left (n)	44/48	22/19	22/29	0.315[b]	12/12
TLE/AGV (n)	52/40	25/16	27/24	0.440[b]	2/22
Preoperative BCVA (LogMAR)	1.87 ± 0.96	1.35 ± 0.91	1.76 ± 0.79	0.031	3.00
Preoperative IOP (mmHg)	38.90 ± 12.39	36.76 ± 11.69	36.73 ± 11.14	0.903	47.17 ± 13.05
Preoperative number of glaucoma medications (n)	3.83 ± 0.69	3.85 ± 0.65	3.84 ± 0.64	0.918	3.75 ± 0.85
IVB before surgery (n)	1.78 ± 1.30	1.98 ± 1.31	1.82 ± 1.38	0.361	
PRP before surgery (n)				0.369[b]	
0 or 1 round	21	7	14		
2 rounds	57	26	31		
≥3 rounds	14	8	6		
PAS (°)	249.81 ± 130.75	187.89 ± 131.91	253.13 ± 130.12	0.018	
<360° [n (%)]	55 (64.7)	30 (78.9)	25 (53.2)	0.013[b]	
360° closed [n (%)]	30 (35.3)	8 (21.1)	22 (46.8)		
Duration (day)					
decreased VA[d]	301.59 ± 725.79	42.90 ± 51.17	287.96 ± 668.46	0.001	
IOP >21 mmHg[e]	149.14 ± 481.30	42.32 ± 30.31	98.92 ± 365.48	0.460	
Etiology of NVG [n (%)]				0.007[c]	
PDR	45 (48.9)	27 (65.9)	18 (35.3)	0.004[b]	12 (50.0)
CRVO	34 (37.0)	9 (22.0)	25 (49.0)	0.008[b]	3 (12.5)
OIS	12 (13.0)	4 (9.8)	8 (15.7)	0.401[c]	1 (4.2)
Other[f]/Unknown	1 (1.1)	1 (2.4)	0	0.446[c]	8 (33.3)
Previous intraocular surgery [n (%)]				0.976[b]	
None	28 (30.4)	12 (29.3)	16 (31.4)		
Phaco/c PCL	44 (47.8)	20 (48.8)	24 (47.1)		
Phaco/c PCL and PPV[g]	20 (21.7)	9 (22.0)	11 (21.6)		
Lens status [n (%)]				0.902[c]	
Phakic	28 (30.4)	12 (29.3)	16 (31.4)		
Pseudophakic	63 (68.5)	29 (70.7)	34 (66.7)		
Aphakic	1 (1.1)	0	1 (2.0)		
Concurrent signs on presentation [n (%)]					
NVD	15 (16.3)	6 (14.6)	9 (17.6)	0.697[b]	
VH	15 (16.3)	8 (19.5)	7 (13.7)	0.455[b]	
Hyphema	6 (6.5)	3 (7.3)	3 (5.9)	1.000[c]	
Corneal edema	38 (41.3)	16 (39.0)	22 (43.1)	0.689[b]	
TRD	1 (1.1)	0	1 (2.0)	1.000[c]	

TLE, trabeculectomy; AGV, Ahmed glaucoma valve implantation; BCVA, best-corrected visual acuity; IOP, intraocular pressure; IVB, intravitreal bevacizumab injection; PRP, panretinal photocoagulation; PAS, peripheral anterior synechiae; NVG, neovascular glaucoma; PDR, proliferative diabetic retinopathy; CRVO, central retinal vein occlusion; OIS, ocular ischemic syndrome; DM, diabetes mellitus; HTN, hypertension; Phaco/c PCL, phacoemulsification with posterior chamber IOL implantation; PPV, pars plana vitrectomy; NVD, neovascularization at the disc; VH, vitreous hemorrhage; TRD, tractional retinal detachment; NLP, no light perception.

[a] Results of the Mann-Whitney *U* test.

[b] Results of Pearson's chi-square test.

[c] Results of Fisher's exact test. Continuous variables are presented as means with standardized deviations. Categorical variables are presented as frequencies and percentages.

[d] Duration of VA reduced to preoperative BCVA and maintained until glaucoma surgery.

[e] Duration of IOP remained >21 mmHg until glaucoma surgery.

[f] Other etiology included uveitis.

[g] Phaco/c PCL and PPV were performed either combined or sequentially.

however, the duration of increased IOP was comparable. The etiology of NVG differed significantly (p = 0.007), and the most prevalent etiologies in the successful and failed eyes were PDR (65.9% and 35.3%, respectively) and CRVO (22% and 49%, respectively).

3.2. Analysis of risk factors for surgical failure

The factors related to the duration of clinical features are presented in Table 3, and their influence on failure according to the complete and qualified success criteria was analyzed using logistic regression. The complete and qualified success rates at 6 months

were 44.6% and 92.2%, respectively. The multivariate model demonstrated that the duration of decreased VA and 360° degree of PAS made a significant contribution to the prediction of failure according to the criteria for complete success ($p = 0.016$ and 0.031, respectively). The duration of decreased VA, increased IOP, and 360° degree of PAS made no significant contribution to increasing the risk of failure according to the criteria for qualified success.

Other demographics and ophthalmic factors and their influence on failure according to the criteria for complete and qualified success were analyzed using logistic regression (Table 4). A multivariate analysis, including age, preoperative BCVA, and etiology of NVG (PDR and CRVO), was performed based on the findings of the univariate regression analysis. This model demonstrated that only age significantly predicted the failure of complete success ($p = 0.026$). CRVO was a significant prognostic factor for failure based on the criteria for qualified success in the univariate analysis ($p = 0.038$); however, a multivariate model was not created.

3.3. Comparison of postoperative factors

The postoperative data were compared between eyes with and without complete surgical success (Table 5). The last IOP, last number of glaucoma medications, and postoperative complications within or after 1 month of surgery were comparable; however, the postoperative BCVA differed significantly during the follow-up period with preoperative BCVA adjustment ($p < 0.001$). Multivariate logistic regression that modeled postoperative BCVA at 1 week, 1 month, and 3 months indicated that postoperative BCVA at 3 months predicted the failure of complete surgical success at 6 months (OR 33.51, $p = 0.002$; Table 5).

3.4. Comparison of trabeculectomy and ahmed glaucoma valve implantation

Table 6 presents a comparison of the baseline and postoperative factors between the eyes that underwent TLE with MMC and AGV implantation. The TLE group had a significantly lower mean age than the AGV group (54.37 ± 9.52 and 71.05 ± 11.02, respectively, $p < 0.001$). The most common early postoperative complications were flat AC and/or hypotony in the TLE group and hyphema in the AGV group. The TLE group had a significantly higher incidence of vitreous hemorrhage and flat AC and/or hypotony within the postoperative 1 month than the AGV group ($p = 0.003$ and 0.008, respectively). The preoperative BCVA, IOP, number of glaucoma medications, and postoperative complications after 1 month did not differ significantly between the two groups.

This study demonstrated the changes in BCVA, IOP, and the number of glaucoma medications according to the type of surgery over time. The mean postoperative BCVA did not differ significantly between the TLE and AGV groups during 6 months of follow-up (Fig. 1A). However, the mean postoperative IOP of the TLE group was significantly lower than that of the AGV group during the follow-up period ($p < 0.05$, Fig. 1B), and the mean postoperative number of glaucoma medications of the AGV group was significantly higher than that of the TLE group from 1 month to 6 months ($p < 0.05$, Fig. 1C).

4. Discussion

This study aimed to evaluate the surgical outcomes and risk factors for failure after TLE with MMC and AGV implantation in terms of sufficient IOP reduction and VA improvement in eyes with NVG. The success criteria were subdivided into complete and qualified success. Qualified success included IOP control without the incidence of serious complications, which was considered a successful outcome in most previous studies [[6,8,10]]. An improvement in VA was required to meet the complete success criteria; however, this was not a requirement in previous studies on NVG.

Various rates of surgical success following glaucoma surgery have been reported in patients with NVG by different studies based on different success criteria, inclusion criteria, and surgical methods: TLE with MMC has success rates of 61.6–86.9% at 1 year [[6,7,10]], whereas tube shunt surgery has success rates of 59.1–75% at 1 year [[2,8,10,13]]. Previous studies have reported poor visual prognosis after glaucoma surgery in patients with NVG. Large prospective studies, such as the ABC and AVB trials, have included

Table 3
Comparison of factors related to the duration of clinical features as a risk for surgical failure by complete and qualified success criteria.

	Complete success[c]				Qualified success[d]	
Success rate (%) at 6 months	44.6				92.2	
	Univariate analysis		Multivariate analysis[e]		Univariate analysis	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Duration (day) rowhead decreased VA[a]	1.012 (1.002–1.022)	0.019	1.054 (1.010–1.099)	0.016	1.001 (1.000–1.005)	0.079
IOP >21 mmHg[b]	1.011 (0.992–1.023)	0.428			1.001 (1.000–1.005)	0.198
PAS 360° closed	3.094 (1.202–7.921)	0.019	3.265 (1.115–9.564)	0.031	2.000 (0.453–8.830)	0.360

VA, visual acuity; IOP, intraocular pressure; PAS, peripheral anterior synechiae; OR, odd ratio; CI, confidence interval.
[a] Duration of VA reduced to preoperative BCVA and maintained until glaucoma surgery.
[b] Duration of IOP remained >21 mmHg until glaucoma surgery.
[c] Complete success analyzed in total 92 eyes, excluding 24 eyes with NLP vision at presentation.
[d] Qualified success analyzed in total 116 eyes, including 24 eyes with NLP vision at presentation.
[e] Variables with $p < 0.05$ in the univariate logistic regression analysis were entered into the enter multivariate analysis and adjusted for age.

Table 4
Comparison of demographics and ophthalmic characteristics as a risk for surgical failure by complete and qualified success criteria.

	Complete success[a]				Qualified success[b]	
	Univariate analysis		Multivariate analysis[c]		Univariate analysis	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Age (years)	1.07 (1.03–1.11)	0.001	1.05 (1.01–1.10)	0.026	1.01 (0.95–1.06)	0.830
Male/Female (n)	1.21 (0.50–2.94)	0.677			1.12 (0.26–4.76)	0.877
Preoperative BCVA (LogMAR)	1.75 (1.07–2.86)	0.027	1.34 (0.77–2.34)	0.307	1.84 (0.76–4.41)	0.175
Preoperative IOP (mmHg)	1.00 (0.96–1.04)	0.990			1.05 (0.99–1.10)	0.107
Preoperative number of glaucoma medications (n)	0.98 (0.51–1.86)	0.975			0.68 (0.36–1.31)	0.248
Etiology of NVG rowhead						
PDR	0.28 (0.12–0.67)	0.004	0.74 (0.19–2.94)	0.670	0.45 (0.11–1.91)	0.282
CRVO	3.42 (1.36–8.59)	0.009	1.19 (0.28–5.02)	0.815	4.65 (1.09–19.77)	0.038

BCVA, best-corrected visual acuity; IOP, intraocular pressure; NVG, neovascular glaucoma; PDR, proliferative diabetic retinopathy; CRVO, central retinal vein occlusion; OR, odd ratio; CI, confidence interval; NLP, no light perception.
[a] Complete success analyzed in total 92 eyes, excluding 24 eyes with NLP vision at presentation.
[b] Qualified success analyzed in total 116 eyes, including 24 eyes with NLP vision at presentation.
[c] Variables with $p < 0.05$ in the univariate logistic regression analysis were entered into the enter multivariate analysis.

Table 5
Comparison of postoperative factors between eyes with and without complete surgical success.

	Total n = 92	Success n = 41	Failure n = 51	*p* value[a]	*p* value
Last IOP (mmHg)	13.03 ± 6.04	11.73 ± 3.06	13.57 ± 7.67	0.536	
Last number of glaucoma medications (n)	1.04 ± 1.18	0.68 ± 1.04	1.04 ± 1.26	0.181	
Postoperative complications ≤1 month [n (%)]					
Hyphema	21 (22.8)	6 (14.6)	15 (29.4)	0.093[b]	
Vitreous hemorrhage	14 (15.2)	6 (14.6)	8 (15.7)	0.889[b]	
CD	15 (16.3)	5 (12.2)	10 (19.6)	0.339[b]	
Flat AC[d] and/or Hypotony[e]	19 (20.7)	9 (22.0)	10 (19.6)	0.783[b]	
Postoperative BCVA (LogMAR)					
1 week	1.88 ± 0.69	1.56 ± 0.70	2.11 ± 0.58	<0.001[c]	
1 month	1.55 ± 0.80	1.11 ± 0.63	1.89 ± 0.74	<0.001[c]	
3 months	1.34 ± 0.82	0.80 ± 0.58	1.85 ± 0.68	<0.001[c]	0.002[f]
6 months	1.30 ± 0.91	0.68 ± 0.63	1.89 ± 0.73	<0.001[c]	

IOP, intraocular pressure; CD, choroidal detachment; AC, anterior chamber; IOL, intraocular lens; BCVA, best-corrected visual acuity.
[a] Results of the Mann-Whitney *U* test.
[b] Results of Pearson's chi-square test.
[c] Results of repeated ANCOVA adjusting preoperative BCVA with Bonferroni correction. Continuous variables are presented as means with standardized deviations. Categorical variables are presented as frequencies and percentages.
[d] Viscoelastic injection into the AC required.
[e] Intraocular pressure ≤5 mmHg by Goldmann applanation tonometry.
[f] Multivariate logistic regression that modeled postoperative BCVA at 1 week, 1 month, and 3 months together.

patients with NVG as a subgroup; NVG was a risk factor for failure, accounting for half of the patients who progressed to NLP at 5 years in the AVB study [[9,16]]. Tokumo et al. conducted a prospective study comparing tube shunt surgery with trabeculectomy in eyes with NVG and reported the cumulative probability of success as 59.1% in the Baerveldt group and 61.6% in the TLE group after 1 year of follow-up. Retinal diseases accounted for VA reduction in half of the cases at 1 year, followed by poor IOP control [[10]]. Long-term retrospective studies also reported that the most common cause of failure of glaucoma surgery in patients with NVG was due to the progression of the underlying retinal disease, not by uncontrolled IOP [[17,18]]. Therefore, this study investigated the effect of glaucoma surgery during a relatively short follow-up period of 6 months as VA deterioration due to retinal diseases occurs over a longer period of time.

VA improvement of ≥2 Snellen lines and sufficient IOP reduction without the incidence of severe complications was observed in 44.6% of eyes in the complete success group at postoperative 6 months. These patients were approximately 10 years younger and had better preoperative VA, lesser extent of PAS, lesser duration of decreased VA, and PDR as the etiology (Table 2). The mean duration of IOP elevation and decreased VA were similar in the complete success group; however, the mean duration of decreased VA was longer than that of IOP elevation in the group without complete success. Long-term vision loss prior to IOP elevation may imply more severe retinal ischemia or more optic nerve damage in eyes with NVG. These results are consistent with those of previous results, which reported that retinal diseases are responsible for the majority of poor visual prognoses in NVG [[11,12]]. Although the mean duration of increased IOP was relatively longer in the group without complete success, the difference was not significant (Table 2). Treatments that reduce vascular endothelial growth factor production and retinal ischemia in NVG include IVB injections and PRP, and their beneficial effect on the visual prognosis of NVG has been established [[15]]. Consequently, preoperative IVB injection was performed

Table 6
Comparison of baseline and postoperative factors between eyes underwent trabeculectomy with mitomycin C and Ahmed glaucoma valve implantation in the complete success analysis group (n = 92).

	TLE n = 52	AGV n = 40	*p* value[a]
Age (years)	54.37 ± 9.52	71.05 ± 11.02	<0.001
Preoperative BCVA (LogMAR)	1.45 ± 0.90	1.74 ± 0.80	0.114
Preoperative IOP (mmHg)	37.48 ± 12.30	35.78 ± 9.99	0.717
Preoperative number of glaucoma medications (n)	3.87 ± 0.60	3.83 ± 0.71	1.000
Postoperative complications ≤1 month [n (%)]			
Hyphema	9 (17.3)	12 (30.0)	0.150[b]
Vitreous hemorrhage	13 (25.0)	1 (2.5)	0.003[c]
CD	12 (23.1)	3 (7.5)	0.052[c]
Flat AC[d] and/or Hypotony[e]	16 (30.8)	3 (7.5)	0.008[c]
Postoperative complications >1 month [n (%)]			
Hyphema	1 (1.9)	1 (2.5)	1.000[c]
Vitreous hemorrhage	6 (11.5)	2 (5.0)	0.458[c]
Hypotony[e]	4 (7.7)	0	0.130[c]
IOL or cataract opacity	4 (7.7)	3 (7.5)	1.000[c]

BCVA, best-corrected visual acuity; IOP, intraocular pressure; CD, choroidal detachment; AC, anterior chamber; IOL, intraocular lens; TLE, trabeculectomy; AGV, Ahmed glaucoma valve implantation.
[a] Results of the Mann-Whitney *U* test.
[b] Results of Pearson's chi-square test.
[c] Results of Fisher's exact test. Continuous variables are presented as means with standardized deviations. Categorical variables are presented as frequencies and percentages.
[d] Viscoelastic injection into the AC required.
[e] Intraocular pressure ≤5 mmHg by Goldmann applanation tonometry.

in all cases in this study, and PRP was performed preoperatively in all possible cases, or postoperatively in cases where preoperative administration was not possible. The frequency of retinal treatment before glaucoma surgery did not differ significantly between the groups with and without complete success (Table 2).

The factors related to the duration of clinical features were analyzed using univariate and multivariate logistic regression analyses to determine their influence on surgical outcomes (Table 3). The factors that showed the time course of the disease were grouped as follows: duration of decreased VA, duration of IOP elevation, and completely closed-angle status. PAS plays an important role in the pathogenesis of NVG as its progression follows a common pathway from the open to the closed stage [[1,3,19,20]]. The rate of PAS formation and progression varies from case to case, and progression to complete closure may occur over 13 weeks or months and years [[12]]. Therefore, although the elapsed time and the degree of PAS do not show a definite linear relationship, it is evident that NVG has progressed and that time has passed in the eyes with complete angle closure. The effect of PAS on surgical outcomes has not been consistent in previous studies, owing to different study designs. Extensive PAS was identified as a risk factor for surgical failure in one study [[21]], whereas it was not related to surgical failure in other studies [[6,7]]. In our study, the prolonged duration of decreased VA and 360° of PAS increased the risk for surgical failure according to the criteria for complete success independently after adjusting for age. Because these factors had no influence on qualified success, the time course of clinical features should be monitored during follow-up if VA improvement after surgery is considered.

Other baseline factors were analyzed using univariate and multivariate logistic regression analyses to determine their influence on surgical outcomes (Table 4). We aimed to determine which of these relatively fixed factors that did not change over time, unlike the factors listed in Table 3, had a significant effect on surgical outcomes. Univariate analysis revealed that older age and poorer preoperative BCVA were significantly related to surgical failure according to the criteria for complete success. In addition, the presence of CRVO as the etiology increased the risk of failure (OR = 3.42, p = 0.009), whereas the presence of PDR as the etiology lowered the risk (OR 0.28, p = 0.004) of failure according to the criteria for complete surgical success. However, after adjusting for all these factors, only older age appeared to be a risk factor for surgical failure according to the criteria for complete success in the multivariate analysis.

Preoperative VA has shown a linear relationship with postoperative VA on the scattergram in previous studies [[6,8,10]], and it was a factor related to NLP outcome after GDD surgery [[22]]. Preoperative VA may be affected by hemorrhage or corneal edema; however, there was no significant difference in concurrent signs in this study. In contrast, previous studies on TLE have shown that younger age is a risk factor for surgical failure [[6,23]]. It is possible that the relatively shorter follow-up duration and VA improvement included in the criteria of our study differed from that of previous results, as older age was a significant risk factor for complete but not qualified success criteria. Moreover, this study differed from previous studies in that the mean age of completely successful eyes was >50 years and that two types of surgery were included and analyzed together.

The three most common causes of NVG are diabetic retinopathy (33%), ischemic CRVO (33%), and ocular ischemic syndrome (OIS) (13%) [[3]], and several studies have shown that surgical outcomes are influenced by the etiology of NVG. Poor surgical prognosis of NVG owing to RVO and OIS compared with that of other etiologies were explained as visual loss from the aggravation of retinal diseases and systemic comorbidity [[6,20]]. Eyes with PDR as the etiology of NVG showed better final vision than eyes with RVO at 1 year after GDD surgery [[13]]. Moreover, the long-term surgical success rate of AGV implantation after 5 years remained >50% in

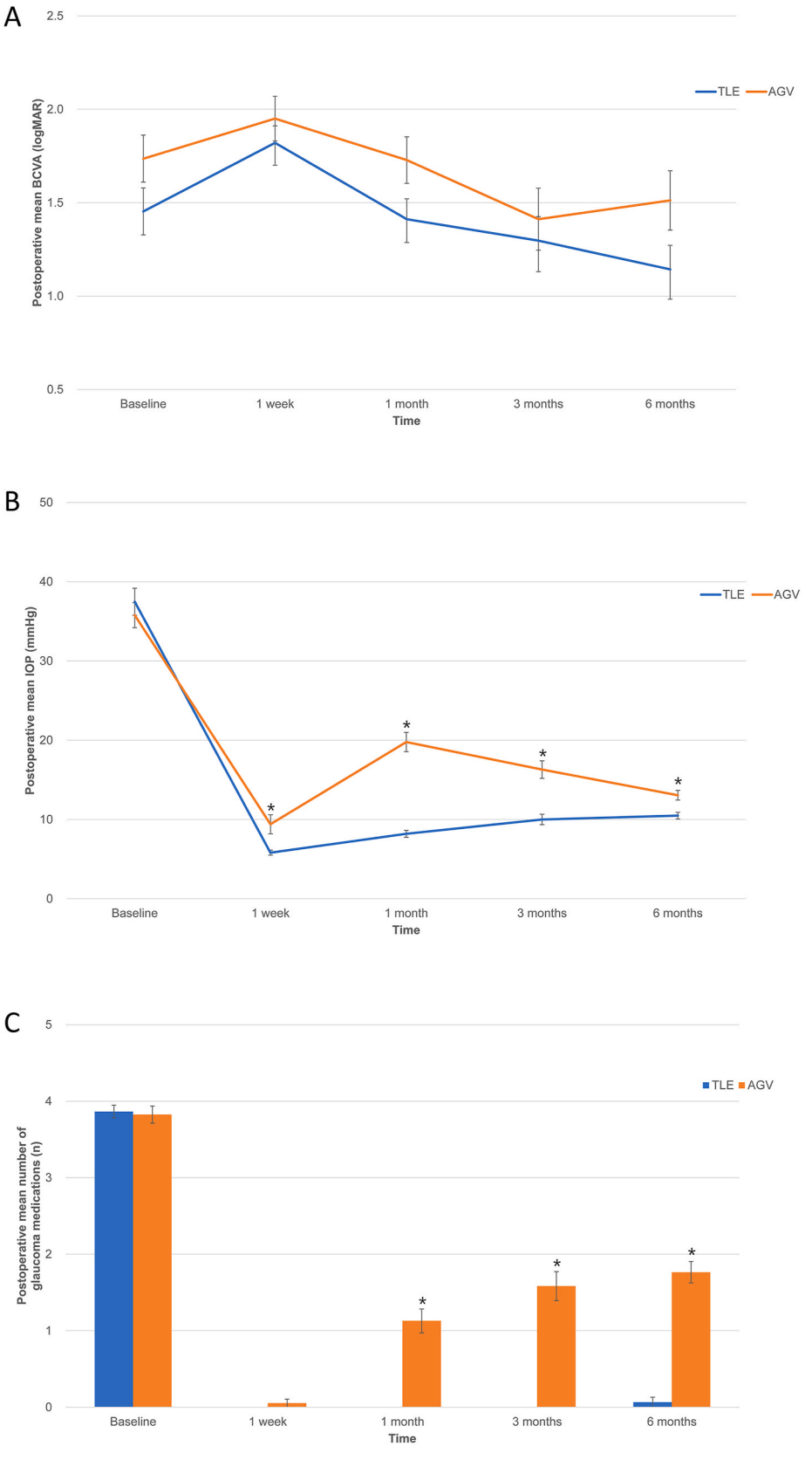

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Fig. 1. Changes in the (A) best-corrected visual acuity, (B) intraocular pressure, and (C) number of glaucoma medications in the eyes that underwent trabeculectomy with mitomycin C and Ahmed glaucoma valve implantation over time in the complete success analysis group (n = 92). * = $p < 0.05$ from the results of the Mann-Whitney *U* test. BCVA, best-corrected visual acuity; IOP, intraocular pressure; TLE, trabeculectomy; AGV, Ahmed glaucoma valve implantation.

NVG due to PDR and OIS, but not in NVG due to RVO [[2]]. In our study, PDR and RVO as etiology of NVG were both associated with complete surgical success, and only RVO was associated with qualified surgical success in univariate analysis; neither had significant associations in multivariate analysis with both success criteria. However, visual prognosis based on etiology should not be generalized as differences in VA can occur depending on the extent of the area of the foveal avascular zone [[24]].

Temporary blurring of vision generally requires several weeks of recovery after glaucoma surgery. Therefore, postoperative BCVA up to 3 months was included in the multivariate logistic regression analysis in consideration of the VA recovery period. In this study, complete surgical success was predicted with postoperative BCVA at 3 months, indicating the importance of follow-up during this period (Table 5).

The two types of surgery included in this study, TLE with MMC and AGV implantation, did not show significant superiority over each other in terms of postoperative VA or complete surgical success (Fig. 1, Table 2). Eyes with NLP vision at presentation were excluded from this analysis owing to bias as these patients generally had poor compliance; thus, AGV implantation was preferred. The mean age of the eyes that underwent TLE with MMC was significantly lower, indicating that age is an important factor for determining the appropriate type of surgery (Table 6). The incidence of early postoperative complications was significantly higher in the vitreous hemorrhage and flat AC and/or hypotony subgroups of the TLE group than in the AGV group. These results are consistent with those of the tube versus trabeculectomy study on various types of glaucoma, wherein the incidence of postoperative complications within 1 month was significantly higher in the TLE group than in the tube shunt group [[25]]. However, other studies on NVG have shown no significant difference in the incidence of early postoperative complications between TLE and tube surgery, although the number of eyes with hypotony tended to be higher in the TLE group [[10,26]]. The slightly different early complication profile in the previous studies may be explained by differences in baseline characteristics such as retinal treatment history or age in our study.

This study has some limitations owing to its retrospective nature. First, there may be a bias in the etiology as NVG due to PDR and CRVO accounted for 80% of cases included in this study. Therefore, the analysis of the effect on the surgical outcomes in eyes with OIS or other causes of NVG may have been insufficient. Second, the two surgical types were combined in the analysis of surgical outcomes. TLE and AGV differ in terms of the employed surgical methods and types of complications; thus, they have generally been treated independently in previous studies. In this study, the choice of surgery type was left to a single surgeon with over 10 years of glaucoma expertise, and the surgery type was selected as the most suitable tool for lowering IOP in patients with NVG. In terms of complete success, there was no significant difference in the number of eyes that underwent the two surgery types. Similarly, no significant difference was observed in the final BCVA (Fig. 1A). In addition, we excluded long-term complications, such as tube-induced corneal insufficiency, that could affect VA by examining the short-term results at 6 months. Third, baseline factors, such as age and preoperative BCVA, differed significantly between the groups with and without complete success. Therefore, we further investigated whether these factors have predictive power for surgical failure beyond group comparisons using multivariate analysis. Moreover, a qualified success analysis was performed in parallel with a complete success analysis to identify the differences in prognostic factors between the conventional success criteria and the success criteria, including VA improvement.

5. Conclusions

Our study findings suggest that although NVG is an intractable disease that often results in disastrous visual loss, VA improvement after glaucoma surgery occurs in approximately 45% of patients at 6 months if they do not have complete blindness at presentation. Risk factors for failure according to the complete success criteria were older age, longer duration of decreased VA, and 360° closed-angle status after age adjustment. Therefore, during the follow-up of relatively young patients with NVG who have uncontrolled IOP, glaucoma surgery should be performed before prolonged visual loss or complete angle closure to achieve VA improvement along with successful IOP reduction. This study distinguishes itself from prior research by establishing visual improvement after glaucoma surgery as the criterion for complete success. Additionally, analyzing factors related to time course offers valuable insights for making surgical decisions in a clinical context. Further studies on the long-term management of NVG are needed to maintain improved vision beyond 6 months after glaucoma surgery to overcome blindness caused by NVG.

Ethics statement

This study was approved by the Institutional Review Board of Ulsan university hospital (approval number: 2023-02-021). The requirement of Informed consent was waived for this study owing to its retrospective nature.

The data has not been deposited in a publicly accessible repository, but will be made available on request.

CRediT authorship contribution statement

Ji Hyoung Chey: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Chang Kyu Lee:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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