• Clinical Research •

Impact of residual peripheral anterior synechiae extent on surgical outcomes after viscogonioplasty in primary angle-closure disease

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Received: 2025-03-27 Accepted: 2025-08-08

Abstract

● **AIM:** To compare surgical efficacy based on residual peripheral anterior synechiae (PAS) extent after viscogonioplasty (VGP) combined with phacoemulsification and intraocular lens implantation (PEI) in patients with primary angle-closure disease (PACD) and identify risk factors for extensive postoperative PAS.

● **METHODS:** This prospective cohort study included 73 eyes of 61 patients with PACD undergoing PEI with VGP. Patients were divided into Group A (PAS<90°, *n*=39) and Group B (90°≤PAS≤180°, *n*=34) based on PAS extent at the end of surgery. PAS progression rates were assessed using a linear mixed-effects model. Logistic regression analyzed risk factors for PAS≥180° at 12mo postoperatively.

● **RESULTS:** Both groups showed significant PAS progression at 12mo (*P*<0.001). Group A had smaller PAS extent than Group B at all time points (*P*<0.001). PAS progression rates were similar between groups (*P*=0.335). No significant differences were found in intraocular pressure (IOP), IOP-lowering medications, or surgical success rates (*P*>0.05). Female [odds ratio (OR)=0.211, *P*=0.046], preoperative medication number (OR=1.017, *P*=0.029), and PAS extent at the end of surgery (OR=1.017, *P*=0.018) were risk factors for PAS≥180° at 12mo.

● **CONCLUSION:** Residual PAS extent at the end of surgery predicts postoperative extensive PAS formation but has limited effect on PAS progression rate and IOP control. Female, multiple preoperative IOP-lowering medications, and larger residual PAS extent are independent risk factors for extensive PAS at 12mo postoperatively.

● **KEYWORDS:** primary angle-closure disease; peripheral anterior synechiae; risk factors; viscogonioplasty

DOI:10.18240/ijo.2025.12.08

Citation: Wang J, Wang Y, Zhang Y, Tang X, Wang DB, Wang NL, Mou DP. Impact of residual peripheral anterior synechiae extent on surgical outcomes after viscogonioplasty in primary angle-closure disease. *Int J Ophthalmol* 2025;18(12):2280-2287

INTRODUCTION

Primary angle-closure glaucoma (PACG) is a vision-threatening disease characterized by the closure of the anterior chamber angle (ACA), which leads to obstruction of aqueous humor outflow, resulting in elevated intraocular pressure (IOP) and subsequent damage to the optic nerve[1]. As a significant cause of global blindness, by 2020, approximately 5.3 million people will suffer from bilateral blindness due to PACG[2-3]. By 2024, the global population of patients with PACG is expected to reach 32.8 million, with nearly 24.5 million cases concentrated in Asia, particularly in China[3-5].

The typical anatomical features of PACG include shallow anterior chamber, short axial length, thicker lens with a relatively anterior position, and narrow angle[6-9]. Over half of patients with PACG experience prolonged contact between the peripheral iris and trabecular meshwork (TM), resulting in peripheral anterior synechiae (PAS)[10-12]. Long-term PAS can induce histological alterations in the TM, increasing resistance to aqueous humor outflow, and resulting in uncontrolled IOP[13-15]. Previous studies have confirmed that a larger extent of PAS is associated with higher untreated IOP and more severe glaucoma[11,16-17].

Phacoemulsification and intraocular lens implantation (PEI) combined with goniosynechialysis (GSL) or viscogonioplasty (VGP) is considered an effective treatment for primary angle-

closure disease (PACD), which includes primary angle closure (PAC) and PACG[18-20]. PEI can deepen the anterior chamber and widen the angle, while GSL or VGP can reduce the PAS extent[21-23]. However, studies have shown that despite successful intraoperative angle opening, PAS may continue to progress postoperatively[11,22].

Although previous research has demonstrated that postoperative PAS extent less than 180° can achieve adequate IOP control[24-27], some surgeons still attempt to use additional GSL after PEI-VGP to open the entire angle[10-11]. Interestingly, follow-up studies have revealed that a higher proportion of GSL procedures is associated with larger postoperative PAS extent, suggesting that excessive angle separation may be harmful[11].

Based on our previous studies[28], we incorporated intraoperative gonioscopy to localize the extent of PAS after VGP during and at the end of surgery. To the best of our knowledge, limited studies have examined the relationship between residual PAS extent at the end of surgery and postoperative PAS progression, as well as its impact on surgical outcomes in patients with PACD.

To address this knowledge gap, we conducted a prospective cohort study to evaluate the relationship between residual PAS extent at the end of surgery and postoperative outcomes in patients with PACD, while also exploring risk factors for extensive postoperative PAS progression. This research will provide valuable evidence to optimize surgical protocols, improve outcomes, and guide clinical practice in PACD treatment.

PARTICIPANTS AND METHODS

Ethical Approval This study adhered to the tenets of the Declaration of Helsinki. All patients provided written informed consent, and the study protocol was approved by the Ethics Committee of Beijing Tongren Hospital (TRECKY2021-136).

Study Population This prospective cohort study was conducted at Beijing Tongren Hospital, China. Participants were recruited from patients aged 40y or older who were newly diagnosed with PACD. The study population included individuals with PAC or PACG, exhibiting at least 90° of PAS, and concomitant age-related cataracts. The study period started with each participant's PEI combined with VGP surgery and ended in December 2023.

Diagnoses of PAC and PACG adhered to the criteria established by the International Society of Geographic and Epidemiologic Ophthalmology[29]. PAC was defined by the presence of iridotrabecular contact in at least 180°, as observed through non-indentation gonioscopy, accompanied by either elevated IOP exceeding 21 mm Hg or the presence of PAS, without evidence of glaucomatous optic neuropathy (GON)[29]. PACG was characterized as PAC with concurrent GON[29]. The diagnosis of GON was based on one or more of the following criteria: vertical cup-disc ratio (VCDR) ≥0.7, VCDR asymmetry ≥0.2, presence of optic disc hemorrhage, or visible retinal nerve fiber layer defect[29].

Exclusion criteria included participants with a history of intraocular surgery (except laser peripheral iridotomy or argon laser peripheral iridoplasty), previous eye trauma, evidence of moderate non-proliferative diabetic retinopathy, neovascularization, rubeosis iridis, or secondary glaucoma.

Study Examinations Ophthalmic examinations were performed on all participants included: presenting visual acuity (PVA) and best-corrected visual acuity (BCVA) using logMAR charts, slit-lamp examination (Haag-Streit, Switzerland), IOP measured by non-contact tonometer (CT-60, Topcon, Japan), visual field testing using a Humphrey 24-2 perimeter with SITA standard strategy (Carl Zeiss Meditec, Germany) and fundus examinations using a 78-diopter (D) or 90-D lens. The intraocular lens (IOL) parameters, anterior chamber depth, lens thickness, and axial length were measured using IOL Master 700 (Zeiss, Germany). B-scan ultrasound was used to assess vitreous status and rule out posterior segment pathology.

All gonioscopic evaluations were performed by the same glaucoma specialist (Wang J). Static gonioscopy was conducted using a single-mirror indentation gonioscope (Ocular Instruments, USA). A 1-mm narrow beam was used without applying pressure to the eyeball or causing significant eye rotation. Dynamic gonioscopy was subsequently performed to determine the extent of PAS.

Surgical Technique All surgical procedures were performed by a single experienced surgeon (Mou DP) under either general or peribulbar anaesthesia. An upper or upper temporal clear corneal incision was made, followed by the injection of a viscoelastic agent to deepen the anterior chamber. Subsequently, a continuous curvilinear capsulorhexis was executed. After hydrodissection, the lens nucleus was removed using ultrasonic power, followed by aspiration (automated or manual) of the cortical lens matter. A foldable acrylic intraocular lens was implanted into the capsular bag using an injector system.

To facilitate angle separation, a viscoelastic agent was injected around the entire 360° of the ACAs. The angle status was then examined using a gonioscope (Ocular Ahmed 1.3X Surgical Gonio Lens-H, Ocular Inc., USA) by systematically positioning the goniolens on the cornea and rotating it to visualize all four quadrants (superior, inferior, nasal, and temporal angles), allowing real-time assessment of PAS extent throughout the entire 360° angle circumference to ensure that the PAS extent at the end of surgery did not exceed 180° in any of the study participants. The remaining viscoelastic material was removed *via* automated or manual irrigation and

aspiration, and the anterior chamber was inflated using saline solution.

The standardized postoperative medical regimen for all participants were topical tobramycin/dexamethasone drops four times daily and ointment at bedtime, and pranoprofen drops four times daily for 3wk. IOP-lowering medications were initially discontinued to evaluate the efficacy of the surgical intervention. Postoperative IOP was closely monitored, and if it exceeded 21 mm Hg at any point during follow-up, a stepwise reintroduction of IOP-lowering agents was implemented.

Study Group and Follow-up Based on PAS extent at the end of surgery, patients were divided into two groups: Group A (PAS<90°) and Group B (90°≤PAS≤180°).

Follow-up examinations were conducted at 1d, 1wk, 1, 3, 6, and 12mo postoperatively. At each visit, PVA, IOP, and slit-lamp examination were performed. BCVA and gonioscopy were performed at 1, 3, 6, and 12mo. Postoperative complications and medication use were recorded.

The primary outcome included PAS extent, IOP and number of IOP-lowering medications. Surgical success was categorized as follows: complete success was defined as IOP≤21 mm Hg without medications, while qualified success was defined as IOP≤21 mm Hg with medications.

Statistical Analysis All statistical analyses were performed using SPSS statistical software (version 27.0; SPSS Inc., Chicago, IL, USA). Normality of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed data were presented as mean±standard deviation (SD), while non-normally distributed data were presented as median (interquartile range). Categorical variables were presented as frequencies and percentages.

Intragroup comparisons were performed using paired *t*-tests or Wilcoxon signed-rank tests. Intergroup comparisons were conducted using independent *t*-tests, Mann-Whitney *U* tests, or Chi-square tests. A linear mixed-effects model was used to evaluate PAS progression trends over time and compare progression rates between groups. Kaplan-Meier survival analysis with log-rank tests was used to compare cumulative success rates between groups.

Logistic regression analysis was performed to identify risk factors for PAS≥180° at 12mo postoperatively. Variables with $P<0.1$ in univariate analysis were included in the multivariate analysis. All statistical tests were two-tailed, with $P<0.05$ considered statistically significant.

RESULTS

A total of 61 patients (73 eyes) were enrolled in this study. Among them, 34 patients (39 eyes) with PAS extent <90° at the end of surgery were included in Group A, while 27 patients (34 eyes) with PAS extent ≥90° and ≤180° at the end of surgery were included in Group B. All patients completed the 12-month follow-up, except for one patient (1.6%) who was lost to follow-up.

Table 1 showed the baseline demographic and clinical characteristics of participants in Group A and Group B. Group A exhibited a significantly smaller preoperative PAS extent compared to Group B (207.4°±79.9° *vs* 277.8°±62.8°, $P<0.001$). Conversely, Group B demonstrated significantly higher mean preoperative IOP (46.6±12.1 *vs* 36.9±16.9 mm Hg, $P=0.007$) and a greater number of preoperative IOP-lowering medications [3.0 (3.0, 4.0) *vs* 3.0 (1.0, 3.0), $P=0.010$] compared to Group A. There were no significant differences were observed in other baseline parameters between groups (all $P>0.05$).

Group A and Group B showed significant PAS reduction at the end of surgery compared to the preoperative (all $P<0.001$). At 12mo, PAS extent increased significantly in both groups compared to the end of surgery (all $P<0.001$). Group A showed an absolute increase of 92.8° (from 22.3° to 115.1°), and Group B showed an increase of 81.9° (from 121.0° to 202.9°), representing similar absolute progression despite different baseline values.

Table 2 illustrated postoperative PAS extent comparisons among groups. Group A had significantly smaller PAS extent than Group B at all follow-up time points (all $P<0.001$). At 12mo postoperatively, while the proportion of eyes with PAS extent ≥180° was significantly lower in Group A than in Group B (25.6% *vs* 60.6%, $P=0.003$), the absolute increase in PAS extent from the end of surgery was similar between groups (approximately 80°), suggesting that the mechanism of postoperative PAS progression may be independent of the initial residual PAS extent.

Figures 1A and 1B showed the comparison of PAS extent at different follow-up time points with that at the end of surgery for Groups A and B, respectively. In Group A, the PAS extent at all follow-up time points was significantly increased compared to the end of surgery (all $P<0.001$). In Group B, while no significant difference was observed at 1-month post-surgery ($P=0.065$), significant increases were noted at 3, 6, and 12mo (all $P<0.01$). A linear mixed-effects model analysis revealed no significant difference in PAS progression rates between the two groups ($P=0.335$; Figure 2).

Group A demonstrated a significant reduction in IOP from 36.9±16.9 mm Hg preoperatively to 14.6±2.3 mm Hg at 12mo post-surgery ($P<0.001$). Similarly, Group B showed a significant IOP reduction from 46.6±12.1 to 15.6±4.0 mm Hg ($P<0.001$). There were no significant differences in IOP at any follow-up time point among groups (all $P>0.05$). Both groups showed significant reductions in IOP lowering medication at 12mo postoperatively compared to baseline (all $P<0.001$).

Table 1 Baseline demographic and clinical characteristics of subjects in Group A and Group B

Parameters	Group A (*n*=34)	Group B (*n*=27)	*P*
No. of eyes	39	34	-
Age (y)	66.2±7.9	65.3±7.7	0.652[a]
Sex, *n* (%)			0.743[b]
Male	10 (29.4)	9 (33.3)	
Female	24 (70.6)	18 (66.7)	
PVA (logMAR)	0.40 (0.22, 1.00)	0.46 (0.21, 0.57)	0.466[c]
BCVA (logMAR)	0.10 (0.00, 0.19)	0.10 (0.00, 0.24)	0.826[c]
History of acute attack			0.489[b]
Yes	13 (33.3)	14 (41.2)	
No	26 (66.7)	20 (58.8)	
Preoperative IOP (mm Hg)	36.9±16.9 (11.0-60.0)	46.6±12.1 (14.2-60.0)	0.007[a]
Number of IOP-lowering medications	3.0 (1.0, 3.0)	3.0 (3.0, 4.0)	0.010[c]
History of preoperative laser treatment, *n* (%)			0.295[b]
LPI	20 (51.3)	13 (38.2)	
ALPI	2 (5.1)	2 (5.9)	
No	17 (43.6)	19 (55.9)	
PAS extent (°)	207.4±79.9	277.8±62.8	<0.001[a]
Visual field index (%)	51.5 (22.0,84.0)	39.0 (15.0,64.0)	0.168[c]
Mean deviation (dB)	-17.3±9.4	-20.8±8.1	0.113[a]
Vertical cup-disc ratio	0.70 (0.40, 0.82)	0.77 (0.40, 0.81)	0.908[c]
Anterior chamber depth (mm)	2.28±0.32	2.27±0.23	0.913[a]
Lens thickness (mm)	5.01±0.35	4.97±0.27	0.643[a]
Axial length (mm)	22.29±0.93	22.33±0.73	0.822[a]

[a]Two-sample *t*-test; [b]χ^2 test; [c]Mann-Whitney *U* test. Group A defined as PAS extent <90° at the end of surgery; Group B defined as PAS extent ≥90° and ≤180° at the end of surgery; PVA: Presenting visual acuity; BCVA: Best-corrected visual acuity; PAS: Peripheral anterior synechiae; LPI: Laser peripheral iridotomy; ALPI: Argon laser peripheral iridoplasty; IOP: Intraocular pressure.

Table 2 Comparison of PAS extent (°) between the two groups at different follow-up time points

Parameters	Group A		Group B		*P*[a]
	n	Mean±SD	*n*	Mean±SD	
End of surgery	39	22.3±27.6	34	121.0±36.7	<0.001
1mo	39	70.8±80.4	34	145.3±71.9	<0.001
3mo	39	89.9±90.4	34	159.9±78.4	<0.001
6mo	39	104.0±96.4	34	191.0±84.8	<0.001
12mo	39	115.1±101.6	33	202.9±81.5	<0.001

Group A defined as PAS extent <90° at the end of surgery; Group B defined as PAS extent ≥90° and ≤180° at the end of surgery. [a]Two-sample *t*-test. PAS: Peripheral anterior synechiae; SD: Standard deviation.

At the 12-month follow-up, the overall complete and qualified success rates were 72.2% (52/72) and 97.2% (70/72), respectively. In Group A, the complete success rate was 76.9% (30/39), and the qualified success rate was 100.0% (39/39). In Group B, the complete success rate was 66.7% (22/33), and the qualified success rate was 93.9% (31/33). Figures 3 illustrated the Kaplan-Meier survival curves for cumulative complete and qualified success rates over time. There was no significant difference between groups in terms of complete success rate (χ^2=2.056, *P*=0.152) or qualified success rate (χ^2=0.089, *P*=0.765).

There were 12 eyes in Group A (30.8%) and 11 eyes (32.4%) in Group B that experienced localized anterior chamber bleeding. Descemet membrane detachment occurred intraoperatively in one eye in Group B, which recovered within 1mo postoperatively. Superior or inferior zonulysis was observed in two eyes in Group B. Transient IOP elevation occurred in 6 eyes (15.4%) in Group A and 3 eyes (8.8%) in Group B (*P*=0.489). Shallow ciliary body detachment occurred in 2 eyes in Group A and 3 eyes in Group B, recovering within 1wk. One eye in each group experienced corneal edema. No serious complications such as malignant glaucoma, choroidal detachment, retinal detachment, hypotony maculopathy, or endophthalmitis were observed.

A total of 30 eyes (41.7%) had a PAS extent ≥180° at the 12mo postoperatively, with 10 eyes (25.6%) in Group A and 20 eyes (60.6%) in Group B. Table 3 shows the results of univariate and multivariate logistic regression analyses for PAS≥180° at 12mo postoperatively. Multivariate regression analysis

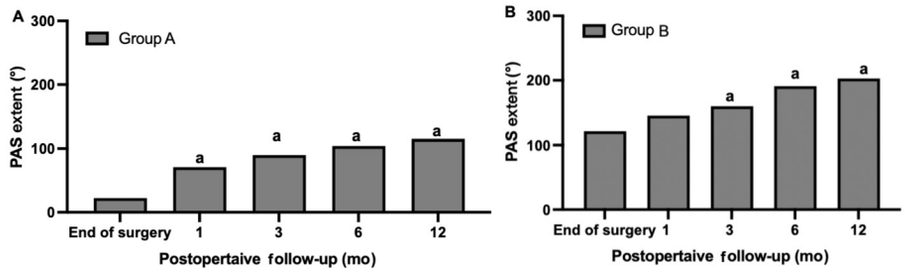

Figure 1 Comparison of PAS extent at different postoperative follow-up time points with end of surgery in Group A and Group B A: PAS extent in Group A (PAS extent <90° at end of surgery); B: PAS extent in Group B (PAS extent ≥90° and ≤180° at end of surgery). [a]*P*<0.001 compared to end of surgery. PAS: Peripheral anterior synechiae.

Table 3 Logistic regression model analysis of risk factors for PAS≥180° at 12mo postoperatively

Parameters	Univariate analysis		Multivariate analysis	
	OR (95%CI)	*P*	OR (95%CI)	*P*
Age	1.024 (0.955–1.098)	0.503	-	-
Female	0.338 (0.110–1.038)	0.058	0.211 (0.046-0.971)	0.046
History of acute attack	0.485 (0.176–1.337)	0.162	-	-
Preoperative laser treatment	1.583 (0.616–4.068)	0.340	-	-
PVA (logMAR)	0.765 (0.356–1.644)	0.443	-	-
Preoperative IOP (mm Hg)	1.017 (0.985–1.049)	0.299	-	-
Preoperative PAS extent (°)	1.007 (1.001–1.014)	0.028	-	-
Preoperative IOP-lowering medications	1.721 (1.165–2.543)	0.006	1.017 (1.056-2.690)	0.029
MD (dB)	1.953 (0.899–1.010)	0.106	-	-
ACD (mm)	3.533 (0.601–20.776)	0.163	-	-
LT (mm)	0.478 (0.081–2.807)	0.413	-	-
AL (mm)	0.944 (0.538–1.655)	0.840	-	-
PAS extent at the end of surgery (°)	1.019 (1.008–1.029)	<0.001	1.017 (1.003-1.031)	0.018
Intraoperative combined ECP	1.850 (0.508–6.742)	0.351	-	-
Intraoperative hemorrhage	1.879 (0.689–5.124)	0.218	-	-

OR: Odds ratio; CI: Confidence interval; PVA: Presenting visual acuity; PAS: Peripheral anterior synechiae; MD: Mean deviation; ACD: Anterior chamber depth; LT: Lens thickness; AL: Axial length; ECP: Endoscopic cyclophotocoagulation.

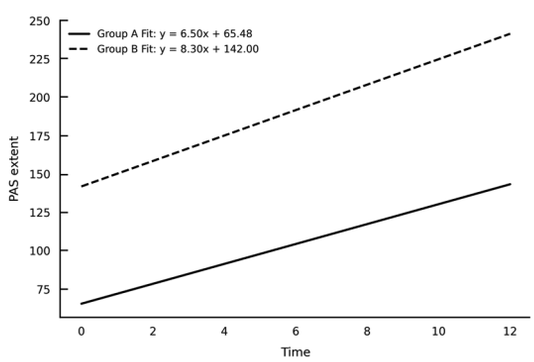

Figure 2 Linear regression of PAS extent progression over time for Group A and Group B Group A (PAS extent <90° at end of surgery) is represented by the solid line, with a fitted equation of y=6.50x+65.48. Group B (PAS extent ≥90° and ≤180° at end of surgery) is represented by the dashed line, with a fitted equation of y=8.30x+142.00. The x-axis represents time in months after surgery, and the y-axis represents PAS extent in degrees. There was no significant difference in PAS progression rate between the two groups (*P*=0.335). PAS: Peripheral anterior synechiae.

revealed that female [odds ratio (OR)=0.211, 95% confidence interval (CI): 0.046-0.971, *P*=0.046], number of preoperative IOP-lowering medications (OR=1.017, 95%CI: 1.056-2.690, *P*=0.029), and PAS extent at the end of surgery (OR=1.017, 95%CI: 1.003-1.031, *P*=0.018) were independent risk factors for PAS≥180° at 12mo postoperatively.

DISCUSSION

PAS play a pivotal role in the pathogenesis of PACD[1], and VGP combined with PEI has served as a crucial treatment targeting this condition[11,20,24]. The advent of intraoperative gonioscopy during VGP surgery has enabled real-time evaluation of PAS extent at the end of surgery[28]. This advancement necessitates a study to determine whether the residual PAS observed at the end of surgery influences surgical outcomes. Furthermore, identifying risk factors for extensive PAS formation would facilitate better recognition and management of patients at high risk for postoperative PAS progression. The findings of our study have the potential to

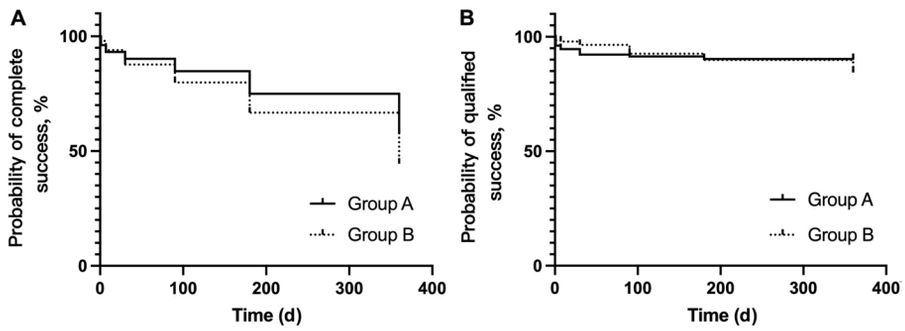

Figure 3 Kaplan-Meier survival curves for complete and qualified surgical success rates over time in Group A and Group B A: Cumulative probability of complete surgical success over time; B: Cumulative probability of qualified surgical success over time. Group A: PAS extent <90° at end of surgery; Group B: PAS extent ≥90° and ≤180° at end of surgery. PAS: Peripheral anterior synechiae.

optimize postoperative management and improve long-term outcomes for patients with PACD.

Our results demonstrate a significant increase in PAS extent at 12mo compared to the residual PAS extent at the end of surgery in both groups. This progression may be attributed to multiple factors. One crucial element is the potentially persistent plateau iris configuration postoperatively[30]. Previous studies have shown that even after PEI-GSL, plateau iris configuration may continue to limit angle widening, leading to re-closure of the opened angle[31]. Additionally, early postoperative inflammatory reactions may promote PAS progression. Research has indicated that elevated levels of inflammatory factors such as interleukin-6, interferon-γ, and monocyte chemoattractant protein-1 are closely related to PAS progression[32]. Moreover, early postoperative complications, including ciliary body detachment[33] and transient IOP elevation, may also contribute to the reclosure of surgically opened angle.

Our study found differences in the timing of when postoperative PAS progression becomes statistically detectable between groups, though the absolute extent and rate of progression were nearly identical. Group A (residual PAS<90°) showed significant PAS progression compared to the end of surgery starting from 1mo postoperatively, while Group B (residual PAS≥90° and ≤180°) only began to show progression at 3mo postoperatively. This difference may reflect distinct mechanisms of PAS progression associated with varying degrees of residual PAS extent intraoperatively. We speculated that the larger initial PAS extent in Group B compared to Group A may make short-term significant changes difficult to detect statistically and PAS progression in these eyes may be more influenced by anatomical angle structural (such as plateau iris), causing a relatively slow and gradual PAS progression[30-31].

The linear mixed-effects model showed no significant difference in PAS progression rates between two groups, suggesting that the extent of residual PAS at the end of surgery may not be a major factor affecting the rate of PAS progression. Some studies suggest that acute angle closure attacks may accelerate PAS progression[34-35]. Postoperative inflammation may also be an important factor accelerating PAS formation[36-37]. Lens extraction can disrupt the blood-aqueous barrier, leading to increased inflammatory mediators in the aqueous humor and causing PAS progression[36]. This inflammatory response has been shown to persist for months or even years after surgery[37]. Additionally, the postoperative angle narrowing may influence the rate of PAS progression, with narrower angles more prone to cause PAS even if the angle is initially open postoperative.

Our study showed no significant difference in IOP control and surgical success rate among groups at 12mo postoperatively, indicating that the extent of PAS at the end of surgery does not affect these outcomes at least within the first year postoperatively. Several mechanisms may explain why groups with significantly different PAS extents achieved similar IOP control and surgical success rates. First, not all PAS may be functionally equivalent in terms of aqueous outflow obstruction. Even with a larger PAS extent in Group B, the remaining functional drainage area may still be sufficient for adequate IOP control. Second, the unconventional outflow pathway, such as the uveoscleral pathway, may compensate for the reduction in conventional outflow. Third, the 12-month follow-up period may be insufficient to detect differences in long-term outcomes. Previous studies have suggested that the impact of extensive PAS on surgical failure may become more apparent over longer follow-up periods[11,17-18,22].

These hypotheses warrant investigation in future studies with more extended follow-up periods and more detailed assessments of aqueous outflow dynamics.

Logistic regression analysis identified independent risk factors for extensive angle closure (PAS≥180°) at 12mo postoperatively: female, preoperative use of multiple IOP-lowering medications, and larger extent of PAS at the end of surgery. This finding emphasizes the importance of using

intraoperative gonioscopy to evaluate residual PAS extent at the end of surgery. Female patients with multiple preoperative IOP-lowering medications and large residual PAS extent at the end of surgery should be closely monitored to prevent further disease progression.

The strength of our study lies in its prospective cohort design, which enables us to examine the relationship between residual PAS extent at the end of surgery and the surgical outcome, although the results did not suggest that PAS residual at the end of the surgery was a risk factor to impact the surgical outcome. Additionally, we utilized a linear mixed-effects model to illustrate the dynamic trend of PAS over time after surgery.

However, several limitations in our study should be noted. First, as a non-randomized clinical trial, our study may be subject to confounding factors affecting result analysis. Further randomized controlled clinical studies are needed to confirm our findings. Second, we did not evaluate TM function, which could provide valuable insights into aqueous outflow dynamics. Third, we used non-contact tonometry rather than Goldmann applanation tonometry for IOP measurements. While previous studies have demonstrated good correlation between these methods, this may introduce some measurement bias. Fourth, we did not use ultrasound biomicroscopy to reevaluate the angle postoperatively, which limits our ability to determine the pathophysiology of progressive PAS formation. Next, participants included in our study were limited to patients with PACD undergoing VGP combined with PEI, which may limit the generalizability of results to other glaucoma surgical methods. Furthermore, most patients in our study had long-standing PAS, which may have resulted in permanent structural and functional changes in the TM and ACA. These irreversible changes could limit the potential benefits of VGP, as the procedure may be more effective in cases with a shorter duration of angle closure where the TM has not undergone extensive remodeling.

In conclusion, while residual PAS extent at the end of surgery predicts postoperative anatomical PAS progression, its clinical significance for functional outcomes requires further investigation with more extended follow-up periods. Female patients with multiple preoperative IOP-lowering medications and large residual PAS extent at the end of surgery require close follow-up to reduce the risk of blindness due to glaucoma disease progression after surgery.

ACKNOWLEDGEMENTS

Availability of Data and Materials: The data that support the findings of this study are available on request from the corresponding author by contacting moudapeng@163.com. The data are not publicly available due to privacy or ethical restrictions.

Foundations: Supported by the National Natural Science Foundation of China (No.62020106015); the Beijing Municipal Public Welfare Development and Reform Pilot Project for Medical Research Institutes (No.PWD&RPP-MRI, JYY2023-6).

Conflicts of Interest: Wang J, None; **Wang Y,** None; **Zhang Y,** None; **Tang X,** None; **Wang DB,** None; **Wang NL,** None; **Mou DP,** None.

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