• Clinical Research •

Long-term outcomes following lens extraction surgery in acute primary angle closure

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Abstract

● **AIM:** To investigate the long-term outcomes in acute primary angle closure (APAC) patients treated with lens extraction (LE) surgery and to identify risk factors for glaucomatous optic neuropathy (GON).

● **METHODS:** In this longitudinal observational study, detailed medical histories of APAC patients and comprehensive ophthalmic examinations at final follow-up were collected. Logistic regression analysis was performed to identify predictors of blindness. Univariate and multivariate linear regression analyses were conducted to determine risk factors associated with visual outcomes.

● **RESULTS:** This study included 39 affected eyes of 31 subjects (26 females) with an average age of 74.1±8.0y. At 6.7±4.2y after APAC attack, 2 (5.7%) eyes had best-corrected visual acuity (VA) worse than 3/60. Advanced glaucomatous visual field loss was observed in 15 (39.5%) affected eyes and 5 (25.0%) fellow eyes. Nine affected eyes (23.7%) had GON, and 11 (28.9%) were blind. Six (15.4%) affected eyes and 2 (9.1%) fellow eyes had suspicious progression. A significantly higher blindness rate in factory workers compared to office workers. Logistic regression identified that worse VA at attack (OR 10.568, 95%CI 1.288-86.695; *P*=0.028) and worse early postoperative VA (OR 13.214, 95%CI 1.157-150.881; *P*=0.038) were risk factors for blindness. Multivariate regression showed that longer duration of elevated intraocular pressure (*P*=0.004) and worse early postoperative VA (*P*=0.009) were associated with worse visual outcomes.

● **CONCLUSION:** Despite LE surgery, some APAC patients experience continued visual function deterioration. Lifelong monitoring is necessary. Target pressure and progression rates should be re-evaluated during follow-up.

● **KEYWORDS:** acute primary angle closure; lens extraction surgery; long-term follow-up; visual impairment; glaucomatous optic neuropathy

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INTRODUCTION

Acute primary angle closure (APAC) is an ophthalmologic emergency presented with a range of symptoms, including sharp vision loss, intense eye pain accompanied with systemic manifestations like severe headache, nausea, and vomiting[1]. If not promptly identified and treated, APAC can lead to irreversible blindness[2]. Over the past two decades, many studies have investigated the long-term prognosis following an APAC attack. It was reported that nearly half (47.8%) of APAC patients exhibited glaucomatous optic neuropathy (GON)[3]. The blindness rate of APAC ranges from 12.54% to 24%[3-9].

APAC is characterized by acute blockage of the trabecular meshwork by the peripheral iris, leading to an elevation in intraocular pressure (IOP) and subsequent damage to the optic nerve[1,10]. The enlargement of the lens can result in greater iridolenticular and iridotrabecular contact, which exacerbates both pupillary block and appositional angle

closure[11]. The goal of treatment for APAC is to relieve the symptoms, through reduction of the IOP and reversal of angle-closure with medications or surgery[2,12-13]. Medical treatment alone often offers limited efficacy for patients with a prolonged disease course, delayed medical consultation, or extremely high IOP[14]. If medications fail to effectively control IOP and relieve angle-closure status, laser peripheral iridotomy (LPI), trabeculectomy, lens extraction (LE) surgery and goniosynechialysis are currently recommended[15-16]. With the widespread adoption of LE surgery, increasing evidence supports the timely performance of LE surgery after APAC[17-19]. LE surgery is increasingly proven to be an effective first-line treatment for APAC, especially in eyes with coexisting cataract[6,20-21]. LE surgery can effectively eliminate lens-induced relative pupillary block, offering both anatomical and physiological advantages[14].

Although some studies have conducted long-term follow-ups after APAC episodes over the past two decades, most have combined data from pseudophakic eyes with phakic eyes. Few studies have conducted long-term follow-up on the outcomes of patients who underwent LE surgery following an episode of APAC. No studies have systematically evaluated how LE influences long-term GON development after APAC. A recent review found that limited evidence suggested that early LE might produce more favorable outcomes compared to initial LPI[22], which underscores the critical need for long-term studies evaluating the effects of LE surgery on the development of GON in APAC-affected eyes.

This study aims to explore the long-term visual outcomes of APAC patients after LE surgery, and identify potential risk factors for glaucomatous visual impairment, ultimately guiding personalized management for high-risk patients.

PARTICIPANTS AND METHODS

Ethical Approval The study adhered to the tenets of the Declaration of Helsinki. The study protocol had the approval of the Ethics Committees of the Peking University Third Hospital (IRB00006761-M2024774). Researchers attempted to contact patients *via* telephone to inquire about their willingness to participate in follow-up assessments between July and August 2024.

Study Population This longitudinal observational study enrolled patients diagnosed with APAC at Peking University Third Hospital from January 2010 to August 2024. Patients aged 50y and above with at least one attack of APAC and then LE surgery [phacoemulsification with intraocular lens (IOL) implantation] were included. Patients with secondary angle-closure glaucoma or medication induced angle-closure glaucoma were excluded. All eligible eyes were assigned to the study group, while contralateral eyes without APAC served as controls. Participants were identified through a retrospective search of the electronic medical records system.

The diagnosis of APAC was established according to the following criteria[4,8,23]: 1) The presence of at least two symptoms from the following list: nausea and/or vomiting, ocular or periorbital pain and a history of intermittent visual blurring accompanied by halos; 2) The presence of at least one of the following clinical signs: conjunctival injection, corneal epithelial edema, or a mid-dilated pupil that is unreactive to light; 3) An IOP exceeding 21 mm Hg, as determined by Goldmann applanation tonometry; 4) A shallow anterior chamber identified on slit-lamp examination and a closed angle confirmed by gonioscopy in the affected eye, along with the presence of 180° or more of iridotrabecular contact with or without peripheral anterior synechiae in the fellow eye on gonioscopic examination.

All participants underwent LE surgery after the acute episode. The procedures were performed under topical or retrobulbar anesthesia. After creating a 3.0–3.2 mm clear corneal incision and completing a continuous curvilinear capsulorhexis, hydrodissection was carried out, followed by phacoemulsification. After cortical removal, the IOL was implanted in the capsular bag or fixated in the ciliary sulcus. All surgeries were performed by experienced surgeons.

Data Collection A trained investigator administered a standardized questionnaire to retrospectively collect demographic characteristics, ophthalmic history, and relevant medical history for each patient. The analysis incorporated acute-phase ocular parameters including best-corrected visual acuity (BCVA), IOP, duration of elevated IOP, history of recurrent attacks, and the interval between acute episode and LE surgery. Postoperative evaluation included early outcomes (stabilized BCVA and IOP at one week after surgery) and long-term monitoring of IOP fluctuations, defined as recurrent elevation of IOP following initial stabilization.

At final follow-up, all participants received comprehensive ophthalmic examinations comprising BCVA measurement (Snellen charts, converted to logarithm minimal absolute resolution, logMAR), slit-lamp biomicroscopy, Goldmann applanation tonometry, stereoscopic optic disc photography, optical coherence tomography of the optic nerve head (Carl Zeiss Meditec, Inc., Dublin, CA, USA), and visual field (VF) testing (OCTOPUS 900 perimeter, Haag-Streit, Switzerland). Current use of IOP-lowering medications was systematically documented. During this follow-up, a glaucoma specialist systematically evaluated the patients' ocular conditions and provided recommendations on whether additional treatments were needed. These interventions may include: 1) using topical glaucoma medications and adjusting target IOP levels; 2) scheduling regular follow-ups for dynamic monitoring; 3) performing LPI or cataract surgery on the fellow eye.

Based on the European Glaucoma Society guidelines for VF staging, glaucomatous damage was classified by mean defect (MD) values into three stages: early glaucomatous loss (MD≤6 dB), moderate glaucomatous loss (6<MD≤12 dB), and advanced glaucomatous loss (MD>12 dB)[24]. GON was defined as a vertical cup-to-disc ratio (VCDR) ratio >0.7 and/or cup-to-disc ratio (CDR) asymmetry >0.2 with the same disc size and/or focal notching/thinning[25]. Blindness was defined as BCVA worse than 6/60 and/or a central VF of less than 20 degrees[3].

Statistical Analysis All statistical analyses were performed using SPSS 23.0 (IBM, Armonk, New York, USA). P<0.05 was considered statistically significant. Categorical variables were presented as absolute numbers and percentages, while continuous variables were reported with means and standard deviations. The Shapiro-Wilk test was used to check for normality. Normally distributed continuous variables were compared using independent-sample *t*-tests, while non-normal variables were analyzed with Mann-Whitney *U* tests. Categorical variables were evaluated *via* Pearson chi-square test or Fisher's exact test (when any cell has an expected count less than 5). Logistic regression was applied to identify the predictive factors of blindness. Univariate and multivariate linear regression analyses were conducted to assess factors associated with long-term BCVA or VF MD. Statistically significant variables in univariate analysis were included in the multivariate analysis. For participants with bilateral involvement, the more severely affected eye was selected for analyzing demographic characteristics in regression models to avoid autocorrelation.

RESULTS

Through a retrospective review of electronic medical records, we identified a total of 200 eligible patients with APAC, and attempted telephone contact for follow-up between July and August 2024. Of 140 successfully contacted patients, 31 (15.5% of total) completed follow-up assessments. The main reasons for non-participation were inability to contact (30.0%), death or severe illness that limited mobility (7.0%), and lack of time or interest (42.5%) (Figure 1). Among 41 initially consenting patients, 32 attended visits, with one excluded due to incomplete examination. Ultimately, 31 individuals were included (15.5% response rate).

The demographic characteristics and baseline ocular characteristics are summarized in Table 1. Participants' mean age was 74.1±8.0y (range: 53-89y), comprising 26 females (83.9%) and 5 males (16.1%). Of these 31 participants, 10 (32.3%) had right eye involvement, 12 (38.7%) had left eye involvement, and 9 (29.0%) had bilateral involvement. There is a significant difference in occupational distribution between the blind and non-blind groups (P=0.006). Post-hoc

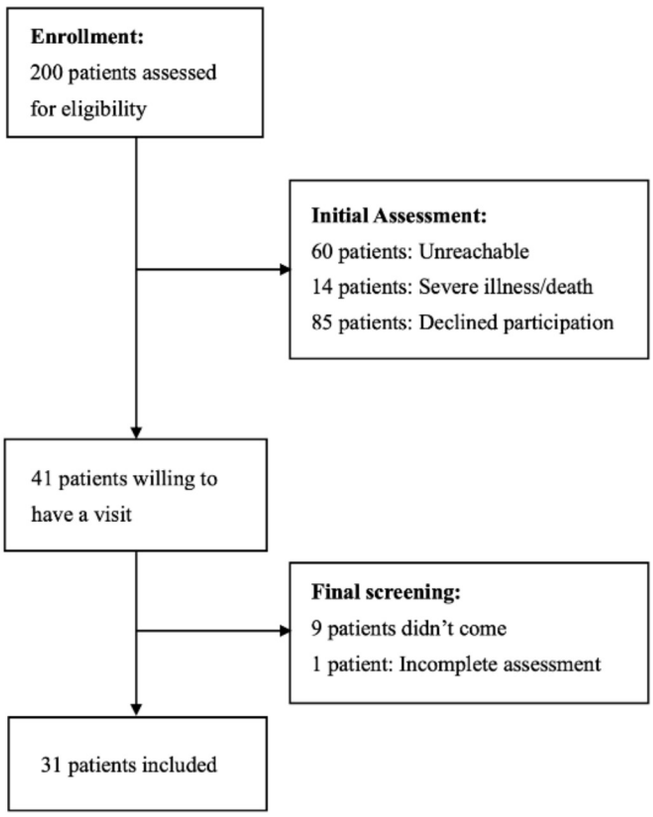

Figure 1 Flowchart of patient enrollment and inclusion.

Bonferroni analysis revealed a significantly higher blindness rate in factory workers compared to office workers, while farmers showed no significant difference with the other two occupations. Independent samples *t*-test revealed that patients who developed blindness had significantly worse VA at attack (P=0.005), longer duration of elevated IOP (P=0.006), and worse early postoperative VA (P=0.027) compared to those without blindness.

Logistic regression analysis was conducted to investigate potential predictors of blindness (Figure 2). Occupation was found to be a significant demographic factor, with both farmers [odds ratios (OR) 12.00, 95% confidence interval (CI) 1.184-121.573, P=0.035] and factory workers (OR 20.00, 95%CI 2.211-180.904, P=0.008) demonstrating significantly higher odds compared to office workers (reference group). Baseline ocular characteristics including worse presenting logMAR VA during the acute attack (OR 10.568, 95%CI 1.288-86.695, P=0.028) and worse early postoperative logMAR VA (OR 13.214, 95%CI 1.157-150.881, P=0.038) were identified as risk factors for blindness.

Basic ophthalmic data at final follow-up from 39 affected eyes and 22 fellow eyes are presented in Table 2. The mean logMAR BCVA was 0.24±0.48 in affected eyes and 0.14±0.14 in fellow eyes. A total of 32 affected eyes (91.4%) had a BCVA of Snellen 6/18 or better. Only 2 affected eyes (5.7%) had severe visual impairment (Snellen BCVA<3/60), attributed to glaucoma and choroidal coloboma, respectively. The mean IOP

Table 1 Demographic characteristics and baseline ocular characteristics of patients after acute primary angle closure and lens extraction surgery

mean±SD (range) or *n* (%)

Parameters	Total	Group 1: blind	Group 2: not blind	*P*
Age (y)	74.1±8.0 (53-89)	76.9±9.0 (63-88)	72.7±7.3 (53-89)	0.280[b]
Gender	n=31	*n*=10	*n*=21	1.000[c]
Male	5 (16.1)	2 (6.5)	3 (9.7)	
Female	26 (83.9)	8 (25.8)	18 (58.1)	
Eye	*n*=31	*n*=10	*n*=21	
Bilateral	9 (29.0)	2 (6.5)	7 (22.6)	0.097[c]
Right	10 (32.3)	6 (19.4)	4 (12.9)	
Left	12 (38.7)	2 (6.5)	10 (32.3)	
Educational level	*n*=30	*n*=10	*n*=20	
Elementary or lower	3 (10.0)	2 (6.7)	1 (3.3)	0.225[c]
Junior high	9 (30.0)	4 (13.3)	5 (16.7)	
Senior high or higher	18 (60.0)	4 (13.3)	14 (46.7)	
Occupation	*n*=30	*n*=10	*n*=20	
Office worker	18 (60.0)	2 (6.7)[a]	16 (53.3)[a]	0.006[c]
Farmer	5 (16.7)	3 (10)	2 (6.7)	
Factory worker	7 (23.3)	5 (16.7)	2 (6.7)	
Family history of glaucoma	*n*=30	*n*=10	*n*=20	
No	25 (83.3)	9 (30.0)	16 (53.3)	0.640[c]
Yes	5 (16.7)	1 (3.3)	4 (13.3)	
Hypertension	*n*=30	*n*=10	*n*=20	
No	17 (56.7)	7 (23.3)	10 (33.3)	0.440[c]
Yes	13 (43.3)	3 (10)	10 (33.3)	
Thyroid disease	30	10	20	
No	21 (70.0)	9 (30.0)	12 (40.0)	0.204[c]
Yes	9 (30.0)	1 (3.3)	8 (26.7)	
History of tobacco or alcohol	*n*=30	*n*=10	*n*=20	
No	28 (93.3)	9 (30)	19 (63.3)	1.000[c]
Yes	2 (6.7)	1 (3.3)	1 (3.3)	
VA at attack, logMAR	*n*=28	*n*=6	*n*=22	0.005[b]
	1.181±0.779	1.950±0.505	0.971±0.710	
IOP at attack (mm Hg)	*n*=26	*n*=6	*n*=20	0.422[d]
	49.8±15.9	45.1±11.4	51.2±17.0	
Duration of elevated IOP (d)	*n*=34	*n*=10	*n*=24	0.006[b]
	2.189±3.516	4.200±5.750	1.350±1.517	
Repeated attack history	*n*=38	*n*=11	*n*=27	0.074[e]
No	19	3	16	
Yes	19	8	11	
Surgery timing (days after attack)	*n*=39	*n*=11	*n*=28	0.206[b]
	582.6±1030.8	510.4±693.6	611.0±1146.5	
Early postop. VA, logMAR	*n*=37	*n*=10	*n*=27	0.027[b]
	0.398±0.499	0.799±0.777	0.250±0.225	
Early postop. IOP (mm Hg)	*n*=36	*n*=10	*n*=26	0.989[d]
	14.5±3.9	14.5±4.1	14.5±3.9	
Repeated postop. IOP fluctuations	*n*=39	*n*=11	*n*=28	1.000[c]
No	35	10	25	
Yes	4	1	3	
Follow-up after APAC attack (y)	6.7±4.2 (1.4-15.2)	7.8±4.4 (2.0-15.2)	6.1±4.0 (1.4-14.8)	0.254[b]
Follow-up after lens extraction surgery (y)	5.3±2.9 (1.4-12.3)	6.3±3.3 (1.5-12.3)	4.9±2.7 (1.4-12.2)	0.197[b]

[a]*P*<0.05 between office workers and factory workers using post-hoc Bonferroni multiple comparisons; [b]Mann-Whitney *U* test; [c]Fisher's exact test (used when the expected count in any cell was less than 5); [d]Independent-sample *t* test; [e]Pearson Chi-square test. SD: Standard deviation; APAC: Acute primary angle closure; VA: Visual acuity; IOP: Intraocular pressure.

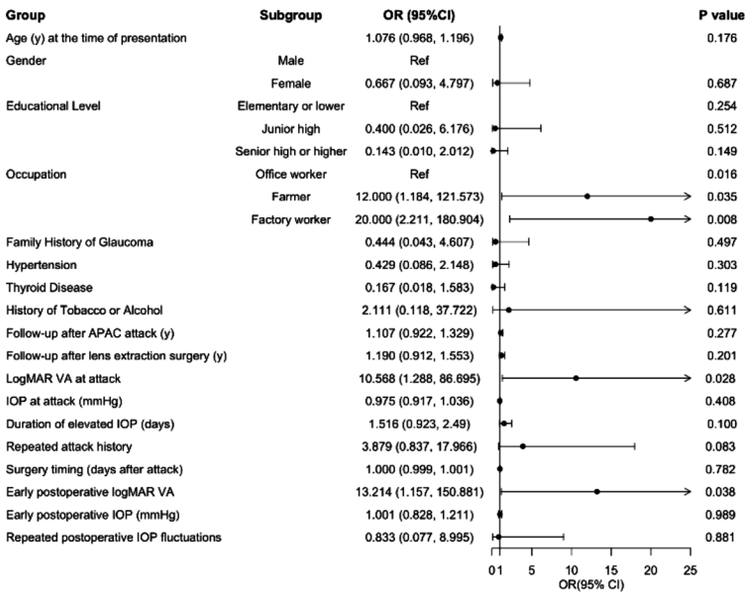

Figure 2 Logistic regression of predictive factors of blindness OR: Odds ratios; Ref: Reference; APAC: Acute primary angle closure; VA: Visual acuity; IOP: Intraocular pressure; CI: Confidence interval.

was 14.9±2.6 mm Hg in affected eyes and 14.9±2.7 mm Hg in fellow eyes. The majority of affected eyes had normal IOP, with only 1 (2.5%) exhibiting an IOP>21 mm Hg. The mean VCDR was 0.61 in the affected eyes and 0.47 in the fellow eyes. The average retinal nerve fiber layer (RNFL) thickness was 75 μm in affected eyes and 87 μm in fellow eyes. Twelve (31.6%) affected eyes showed early glaucomatous loss (MD≤6 dB), while 15 (39.5%) had advanced loss (MD>12 dB). In the fellow eyes, 7 (35.0%) exhibited early loss (MD≤6 dB), and 5 (25.0%) demonstrated advanced loss (MD>12 dB).

Nine affected eyes (23.7%) and 1 fellow eye (4.5%) were found to have GON. Eleven affected eyes (28.9%) were blind, with glaucoma being the most common cause. During this follow-up, new interventions were recommended on 6 eyes: in the affected group, 4 of 33 previously untreated eyes were recommended to use topical glaucoma medications; in the fellow eye group, 1 eye (4.5%) were recommended for LPI and another eye (4.5%) were recommended for LE surgery. Additionally, 6 affected eyes (15.4%) and 2 fellow eyes (9.1%) showed suspicious glaucomatous progression, and they were recommended for regular follow-up.

The results of univariate and multivariate linear regression analyses for potential predictors of BCVA and VF are presented in Table 3. In the univariable analysis, occupation as a factory worker (B=0.489, P=0.011), worse VA at attack (B=0.401, P=0.080) and at early postoperative time (B=0.748, P<0.001), longer duration of elevated IOP (B=0.568, P=0.003), longer follow-up time after APAC attack (B=0.548, P=0.003) and after LE surgery (B=0.524, P=0.004), lower RNFL thickness (B=-0.551, P=0.004), and higher VF-MD (B=0.505, P=0.007) were associated with worse BCVA outcomes. Occupation as a factory worker (B=0.591, P=0.001) or farmer (B=0.371, P=0.025), worse BCVA at attack (B=0.502, P=0.020), at early postoperative time (B=0.482, P=0.007) and during this examination (B=0.505, P=0.007), longer duration of elevated IOP (B=0.510, P=0.007), larger ACDR (B=0.563, P=0.002), larger VCDR (B=0.576, P=0.001), and lower RNFL thickness (B=-0.617, P<0.001) were associated with worse VF outcomes. Follow-up time was not significantly associated with VF loss.

In the multivariate analysis, longer duration of elevated IOP (B=0.961, P=0.004) and worse early postoperative BCVA (B=0.398, P=0.009) remained significant predictors of worse BCVA. Considering collinearity between ACDR and VCDR, only VCDR was included in the multivariate analysis of VF. Occupation as a factory worker (B=0.603, P=0.010) and VCDR (B=0.369, P=0.022) remained significant predictors of VF progression.

DISCUSSION

In this longitudinal study, we reported the long-term outcomes of 39 affected eyes of 31 patients with APAC who underwent LE surgery. After an average follow-up period of 6.7y, 23.7% eyes were blind due to glaucoma, which was higher than the rates reported in previous studies, such as Jeong *et al*[5] (6.2%), Hamid *et al*[6] (15%), Li *et al*[4] (12.54%) and Andreatta *et al*[7] (6%). Additionally, 23.7% of affected eyes exhibited GON despite not being blind. First, this may be attributed to the poorer prognosis of Asians[3,6]. Moreover, this may be associated with the longer average follow-up period of this study. These findings highlight the substantial long-term visual morbidity associated with APAC, even after LE surgery.

Table 2 Basic ophthalmic characteristics at final follow-up in individuals after acute primary angle closure and lens extraction surgery

mean±SD (range) or *n* (%)

Parameters	*n*	Affected eye	*n*	Fellow eye
VA, logMAR	35	0.24±0.48 (-0.08-1.90)	20	0.14±0.14 (0.00-0.40)
Snellen BCVA	35		20	
Normal vision: ≥6/6		13 (37.1)		5 (25.0)
Mild visual impairment: <6/6 and ≥6/18		19 (54.3)		15 (75.0)
Moderate visual impairment: <6/18 and ≥3/60		1 (2.9)		0
Severe visual impairment: <3/60		2 (5.7)		0
IOP	39	14.9±2.6 (10.0-24.0)	22	14.9±2.7(10.0-20.0)
>21 mm Hg		1 (2.5)		0
15-21 mm Hg		18 (46.2)		13 (59.1)
<15 mm Hg		18 (46.2)		9 (40.9)
Missing		2 (5.1)		0
Optical coherence tomography	37		20	
ACDR		0.61±0.18 (0.17-0.91)		0.53±0.17 (0.09-0.75)
VCDR		0.61±0.18 (0.06-0.95)		0.47±0.17 (0.08-0.74)
Average RNFL		75±20 (26-121)		87±16 (52-111)
VF staging	38	11.8±8.0 (1.8-26.5)	20	8.8±5.6 (0.2-20.7)
Early glaucomatous loss: MD≤6 dB		12 (31.6)		7 (35.0)
Moderate glaucomatous loss: 6<MD≤12 dB		11 (28.9)		8 (40.0)
Advanced glaucomatous loss: MD>12 dB		15 (39.5)		5 (25.0)
GON classification	38		22	
Non GON		18 (47.4)		20 (90.9)
GON		9 (23.7)		1 (4.5)
Blindness		11 (28.9)		1 (4.5)
Development of blindness	11		1	
BCVA≤6/60 only		0		0
VF≤20° only		8 (21.1)		1 (15.0)
Both		3 (7.9)		0
Reasons for blindness	11		1	
Glaucoma		9 (23.7)		1 (15.0)
Age-related macular degeneration		1 (2.6)		0
Choroidal coloboma		1 (2.6)		0
Medications for IOP control	39		22	
No treatment		33 (84.6)		22 (100.0)
1 topical agent		5 (12.8)		0
2 topical agents		1 (2.6)		0
Further medical treatment required	39		22	
Topical glaucoma medications		4 among 33 no treatment		NA
LPI of the fellow eye		NA		1/22 (4.5)
Cataract surgery of the fellow eye		NA		1/22 (4.5)
Suspicious progression: regular follow-up is recommended		6/39 (15.4)		2/22 (9.1)

SD: Standard deviation; VA: Visual acuity; BCVA: Best-corrected visual acuity; IOP: Intraocular pressure; ACDR: Average cup-to-disc ratio; VCDR: Vertical cup-to-disc ratio; RNFL: Retinal nerve fiber layer; VF: Visual field; MD: Mean defect; dB: Decibel; GON: Glaucomatous optic neuropathy; LPI: Laser peripheral iridotomy; NA: Not analysed.

Table 3 Univariate and multivariate linear regression of potential predictive factors of logMAR VA and MD

Parameters	VA, logMAR						MD					
	Univariate regression			Multivariate regression			Univariate regression			Multivariate regression		
	UC	SC	*P*	UC	SC	*P*	UC	SC	*P*	UC	SC	*P*
Age	0.017	0.268	0.168	NA	NA	NA	0.228	0.236	0.209	NA	NA	NA
Gender	-0.047	-0.035	0.859	NA	NA	NA	-3.383	-0.15	0.429	NA	NA	NA
Educational level	-0.140	-0.184	0.358	NA	NA	NA	-3.281	-0.287	0.124	NA	NA	NA
Occupation												
Factory worker	0.610	0.489	0.011[a]	0.140	0.120	0.543	10.706	0.591	0.001[a]	13.046	0.603	0.010[a]
Farmer	-0.030	-0.022	0.901	-0.060	-0.058	0.701	7.638	0.371	0.025[a]	5.33	0.274	0.132
Office worker	Ref	Ref	Ref	NA	NA	NA	Ref	Ref	Ref	NA	NA	NA
Family history of glaucoma	0.426	0.257	0.195	NA	NA	NA	-2.728	-0.133	0.485	NA	NA	NA
Hypertension	-0.056	-0.053	0.793	NA	NA	NA	-4.210	-0.272	0.146	NA	NA	NA
Thyroid disease	-0.240	-0.211	0.292	NA	NA	NA	-5.117	-0.306	0.100	NA	NA	NA
History of tobacco or alcohol	-0.203	-0.102	0.613	NA	NA	NA	7.775	0.253	0.177	NA	NA	NA
VA at attack, logMAR	0.227	0.401	0.080[a]	-0.013	-0.021	0.884	5.295	0.502	0.020[a]	0.183	0.015	0.928
IOP at attack (mm Hg)	-0.013	-0.400	0.100	NA	NA	NA	-0.106	-0.194	0.440	NA	NA	NA
Duration of elevated IOP (d)	0.080	0.568	0.003[a]	0.095	0.961	0.004[a]	1.075	0.510	0.007[a]	1.001	0.545	0.226
Repeated attack history	-0.107	-0.103	0.608	NA	NA	NA	4.293	0.275	0.148	NA	NA	NA
Surgery timing (days after attack)	<0.001	0.271	0.163	NA	NA	NA	<0.001	-0.022	0.910	NA	NA	NA
Early postop. VA, logMAR	0.732	0.748	<0.001[a]	0.327	0.398	0.009[a]	7.135	0.482	0.007[a]	3.112	0.203	0.357
Early postop. IOP (mm Hg)	-0.006	-0.045	0.826	NA	NA	NA	0.294	0.153	0.430	NA	NA	NA
Repeated postop. IOP fluctuations	-0.289	-0.198	0.313	NA	NA	NA	1.421	0.063	0.741	NA	NA	NA
Follow-up after APAC attack (y)	0.070	0.548	0.003[a]	<0.001	-0.001	0.997	0.348	0.189	0.317	NA	NA	NA
Follow-up after LE surgery (y)	0.090	0.524	0.004[a]	-0.047	-0.206	0.536	0.771	0.291	0.119	NA	NA	NA
VA at the final follow-up, logMAR	NA	NA	NA	NA	NA	NA	7.712	0.505	0.007[a]	-10.730	-0.576	0.260
IOP at the final follow-up	-0.056	-0.299	0.122	NA	NA	NA	-0.164	-0.057	0.770	NA	NA	NA
ACDR at the final follow-up	0.643	0.251	0.216	NA	NA	NA	23.956	0.563	0.002[a]	NA	NA	NA
VCDR at the final follow-up	0.612	0.218	0.285	NA	NA	NA	24.383	0.576	0.001[a]	21.764	0.369	0.022[a]
RNFL at the final follow-up	-0.015	-0.551	0.004[a]	0.005	0.196	0.267	-0.248	-0.617	<0.001[a]	-0.023	-0.049	0.814
MD at the final follow-up	0.033	0.505	0.007[a]	-0.001	-0.027	0.898	NA	NA	NA	NA	NA	NA

VA: Visual acuity; MD: Mean defect; UC: Unstandardized coefficient; SC: Standardized coefficient; NA: Not analyzed; Ref: Reference; APAC: Acute primary angle closure; LE: Lens extraction; IOP: Intraocular pressure; ACDR: Average cup-to-disc ratio; VCDR: Vertical cup-to-disc ratio; RNFL: Retinal nerve fiber layer. [a]*P*<0.05.

The optimal timing of LE for APAC remains a subject of ongoing debate. While numerous studies have demonstrated clear advantages of early LE surgery–including more effective IOP control, a wider angle with no residual angle closure, and more sustainable improvements in anterior segment parameters[6,20-21,26-28]–emerging evidence suggests that delayed LE performed weeks to months after LPI may yield comparable results[29]. Notably, our study found no significant correlation between surgical timing and long-term visual prognosis. This observation implies that although early LE is recommended as first-line therapy for APAC, delayed intervention may represent a viable alternative in certain clinical scenarios. Further large-scale studies are needed to better define optimal timing for individualized decision-making.

In our study, occupation was a significant risk factor of blindness and poor VF, with farmers and factory workers having higher likelihood of blindness compared to office workers. This may be attributed to the distinct working environments, health awareness, and accessibility to medical resources associated with these occupational groups. We postulate that blindness may be caused by a combination of multiple factors in long-term follow-up. Previous studies have shown that lower education level, delayed treatment, and higher initial IOP may collectively increase the risk of blindness[4]. However, the relatively small sample size of our study may have limited our ability to detect subtle effects of the variables assessed. Regardless, our study emphasizes the necessity of improving compliance and follow-up of factory workers and farmers. Enhancing their awareness of follow up

may be crucial in reducing the risk of blindness.

In terms of VA, the rate of severe visual impairment in our cohort was 5.7% in the affected eyes, which is much lower than the previous studies. Aung *et al*[3] reported that 6.3±1.5y after the APAC attack, 11% of the affected eyes had a VA of less than 6/60. Similarly, Andreatta *et al*[30] reported that after 31.4±18.1mo, 12% of the affected eyes had severe visual impairment with one-third of them attributed to GON. Another study in a Caucasian population had 15% of severe visual impairment, with glaucoma responsible for 47% cases[6]. This discrepancy may be explained by the LE surgery performed in our cohort, eliminating the impact of cataracts on visual outcomes[6]. This aligns with the findings of Suzuki *et al*[20], who demonstrated that phacoemulsification in APAC eyes significantly improved BCVA postoperatively and maintained stable visual outcomes over a 3-year follow-up period. Notably, our study revealed that both acute-phase and early postoperative VA emerged as strong predictors of long-term visual outcomes. This suggests that patients with severe initial visual impairment may have sustained greater optic nerve damage during the acute attack, resulting in poorer long-term prognosis despite surgical intervention. These findings emphasize the importance of close monitoring of early postoperative visual recovery patterns and implementing individualized follow-up strategies based on both acute-phase presentation and initial surgical outcomes.

Our study further demonstrated that longer duration of elevated IOP correlates with increased blindness rates and worse visual outcomes. These findings are consistent with previous reports demonstrating that a longer duration of symptoms is significantly associated with progression from APAC to primary angle-closure glaucoma (PACG)[7], indicating that timely IOP reduction is crucial for a favorable prognosis. The patients in our cohort showed effective postoperative IOP control, with only 2.5% of operated eyes showing IOP above 21 mm Hg, consistent with existing literature[5-6]. This confirms LE surgery's efficacy in IOP reduction. However, while LE surgery effectively addresses the anatomical angle closure, damage to the trabecular meshwork from the acute attack may compromise long-term IOP control in some cases[31-32]. Some patients may require further continuous follow-up and treatment.

Our study demonstrated significant visual impairment in APAC patients after LE surgery, with a high prevalence of blindness (28.9%) and GON (23.7%). The mean MD of 11.8±8.0 dB in affected eyes, consistent with historical data[3], reflects significant VF impairment -28.9% showed moderate glaucomatous loss (6<MD≤12 dB) while 39.5% had advanced loss (MD>12 dB). These findings align with a study on the East Asian populations, where 27.8% of APAC patients experienced VF deterioration despite achieving normal long-term IOP control[5], underscoring the necessity of lifelong follow-up. These observations may be explained by persistent retinal microvascular abnormalities following the acute APAC episode, which can persist even after successful surgical intervention, as demonstrated in previous studies[33].

Clinical management challenges are evident in our findings. Nearly half of our cohort lacked prior VF testing and most eyes lacked long-term treatment before this study. During this follow-up, 15.4% affected eyes and 9.1% fellow eyes showed signs of suspicious progression, 4 among 33 no previous treatment affected eyes were recommended for additional anti-glaucoma eyedrops, and 2 fellow eyes were recommended for LPI or LE surgery. While LE surgery effectively resolves angle closure, postoperative reduction of IOP may lead clinicians to underestimate the need for ongoing monitoring, particularly in patients with preserved central vision. Notably, the fellow eyes also exhibited substantial VF loss (25% with MD>12 dB), consistent with a long-term observation in Caucasian populations[9], suggesting a predisposition to chronic angle closure glaucoma of the fellow eye. However, the absence of postoperative VF assessment may lead to undetected glaucomatous progression. Our findings highlight the critical need for systematic postoperative glaucoma surveillance in APAC patients after LE surgery.

This study has several limitations. First, the relatively small cohort size may reduce statistical power for detecting subtle associations. The generalizability of our findings may be further constrained by the relatively low response rate of 15.5%, potentially introducing selection bias as non-responders likely differed systematically from participants in terms of healthcare engagement and disease severity. The retrospective design, while providing valuable long-term data, introduced variability in follow-up intervals that could affect outcome assessments. Additionally, the study's design did not permit an analysis of visual outcomes at different time points following APAC onset, potentially introducing bias in the final data interpretation. Nevertheless, the ophthalmic examinations at the final follow-up were comprehensive, which enabled the identification of clinical issues that require urgent attention and management.

In summary, we conducted a long-term follow-up study on patients who underwent LE surgery after an APAC attack, and revealed that despite LE surgery, the long-term outcomes of some eyes were not optimal, with a tendency for continued deterioration in visual function. This suggests that LE surgery alone cannot completely resolve the functional sequelae associated with glaucoma, and highlights the importance of lifelong regular follow-ups to monitor GON and manage it actively, particularly in high-risk patients with poor acute-

phase VA, suboptimal early postoperative VA, or prolonged IOP elevation. Target IOP and progression rates should be regularly re-evaluated during follow-up. Future research should focus on identifying populations at high risk for sustained deterioration. With the possibility of risk prediction, we may be able to optimize follow-up protocols and implement personalized management strategies, ultimately improving treatment outcomes.

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Data Availability: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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