

Factors Associated With Hyperopic Shift After Phacoemulsification Combined With Intraocular Lens Implantation in Patients With Primary Angle-Closure Glaucoma

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AIM: To investigate the factors associated with hyperopic shift (HS) after phacoemulsification (PE) combined with intraocular lens (IOL) implantation in patients with primary angle-closure glaucoma (PACG).

METHODS: A total of 167 eyes with PACG that underwent PE+IOL were retrospectively included. Postoperative refractive prediction error (RPE) was calculated as the actual postoperative spherical equivalent minus the Barrett-predicted postoperative spherical equivalent. HS (RPE $>+0.50$ D) was the primary outcome. Group comparisons and univariable logistic regression were performed, followed by receiver operating characteristic (ROC) analyses of selected variables and multivariable logistic regression to identify independent factors. **RESULTS:** Postoperative HS occurred in 54 eyes (32.3%). ROC curve analysis showed that axial length/corneal radius (AL/CR) ratio, anterior chamber depth (ACD), and white-to-white distance (WTW) showed moderate discriminative ability for postoperative HS, with areas under the curve (AUCs) of 0.779, 0.764, and 0.730, respectively. Multivariable logistic regression analysis showed that higher relative lens position (RLP), AL/CR, and WTW were associated with a lower likelihood of postoperative HS, whereas capsular tension ring (CTR) implantation was associated with a higher likelihood of postoperative HS.

CONCLUSIONS: Lower RLP, AL/CR, and WTW values and CTR implantation were independently associated with postoperative HS. ROC analyses showed that AL/CR, ACD, and WTW had discriminative ability for HS.

Keywords: primary angle-closure glaucoma; phacoemulsification; intraocular lens implantation; hyperopic shift; refractive prediction error; relative lens position; axial length/corneal radius ratio

Introduction

Glaucoma is an irreversible, sight-threatening ocular disease characterized by progressive optic nerve damage and visual field defects, among which primary angle-closure glaucoma (PACG) imposes a substantial burden in Asian populations [1]. It is estimated that the number of patients with PACG in Asia will increase to 18.47 million by 2050 [1]. The development of PACG is closely related to anterior chamber angle-closure, crowded anterior segment structures, and lens-related factors. Its treatment goals include not only controlling intraocular pressure and preserving optic nerve function, but also improving postoperative visual quality [2,3].

Phacoemulsification (PE) combined with intraocular lens (IOL) implantation is one of the commonly used surgical procedures for patients with PACG and cataract [3]. In these patients, lens extraction can not only improve visual impairment caused by lens opacity, but may also help

control intraocular pressure by increasing anterior chamber space and improving angle opening [4]. However, eyes with PACG are commonly characterized by a crowded anterior segment, a relatively anterior lens position, and marked postoperative anatomical changes, which may increase uncertainty in predicting the effective lens position and result in discrepancies between the actual and predicted postoperative refraction [5,6]. Previous studies have mainly focused on overall or absolute refractive prediction error, which does not preserve the direction of refractive deviation. In contrast, hyperopic shift (HS) specifically reflects a postoperative refractive outcome that is more hyperopic than predicted and may affect uncorrected visual acuity and spectacle dependence; therefore, it should be evaluated as a distinct directional outcome. Evidence regarding HS after PE+IOL in patients with PACG remains limited, particularly concerning the combined assessment of ocular biometric parameters, composite indices, and surgical factors. Therefore, this study aimed to evaluate factors associated with postoperative HS after PE+IOL in patients with PACG.

Methods

Study Design

This was a retrospective study designed to analyze factors associated with the risk of HS within 3–6 months after PE+IOL in patients with PACG. Study data were obtained

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from the electronic medical records of Yiwu Central Hospital from September 2022 to October 2025.

Study Population

The participants were 167 patients with primary angle-closure glaucoma who underwent PE+IOL at Yiwu Central Hospital, involving a total of 167 eyes (Fig. 1). Inclusion criteria were as follows: (1) age >40 years; (2) diagnosis of PACG, with gonioscopy or anterior segment examination showing $\geq 180^\circ$ iridotrabecular contact or angle-closure, accompanied by elevated intraocular pressure and glaucomatous optic nerve damage [2]; (3) underwent PE+IOL with complete clinical data; (4) preoperative intraocular lens power calculated using the Barrett Universal II formula; (5) implantation of a monofocal non-toric IOL; and (6) follow-up duration of 3–6 months. Exclusion criteria were as follows: (1) history of acute angle-closure glaucoma; (2) other ocular diseases that might affect postoperative refraction; (3) loss of capsular support and sulcus fixation of the intraocular lens; and (4) postoperative myopic shift, defined as a refractive prediction error (RPE) < -0.50 D at the 3–6-month postoperative manifest refraction.

All surgeries were performed according to the standard PE+IOL procedure of Yiwu Central Hospital. After routine preoperative pupil dilation and topical or local anesthesia, the anterior chamber was entered through a clear corneal incision, and viscoelastic material was injected to maintain anterior chamber depth. Continuous curvilinear capsulorhexis, phacoemulsification of the lens nucleus, cortical aspiration, and capsular bag polishing were then performed. A monofocal non-toric intraocular lens was selected according to the preoperative intraocular lens power calculation and implanted into the capsular bag. Goniosynechialysis (GSL) was performed in eyes with peripheral anterior synechiae when mechanical separation of the synechially closed angle was considered necessary. A capsular tension ring (CTR) was selectively implanted when zonular weakness or inadequate capsular bag stability was identified during preoperative evaluation or intraoperatively. The decision regarding CTR implantation was based on the operating surgeon's clinical assessment of zonular and capsular bag stability. No standardized grading system or predefined quantitative criteria were used to determine zonular weakness or the indication for CTR implantation. Thus, CTR implantation was based on individual clinical indications rather than being routinely performed. Postoperatively, routine anti-inflammatory, anti-infective, and intraocular pressure-lowering treatments were administered. This retrospective study was approved by the Ethics Committee of Yiwu Central Hospital (Approval No. K2026-IRB-091) and conducted in accordance with the Declaration of Helsinki. The requirement for informed consent was waived by the Ethics Committee of Yiwu Central Hospital because of the retrospective study design and the use of de-identified clinical data.

Definition of Postoperative Hyperopic Shift

In this study, HS was defined based on refractive prediction error after PE+IOL. Postoperative refractive status was assessed 3–6 months after surgery to obtain relatively stable postoperative results and was expressed as the spherical equivalent (SE) measured by manifest refraction. When multiple measurements were available within this period, the latest measurement within the specified window was used for analysis. SE was calculated as the spherical power plus half of the cylindrical power. The preoperatively predicted postoperative refractive status was the predicted postoperative SE calculated by the Barrett Universal II formula based on the final implanted intraocular lens power. Refractive prediction error was calculated as follows:

Refractive prediction error (D) = actual postoperative SE (D) – Barrett-predicted postoperative SE (D).

A positive refractive prediction error indicated that the actual postoperative refractive status was more hyperopic than the postoperative SE predicted by the Barrett Universal II formula, whereas a negative refractive prediction error indicated that the actual postoperative refractive status was more myopic than the predicted value. In this study, refractive prediction error $> +0.50$ D was defined as postoperative HS [7]. A refractive prediction error between -0.50 D and $+0.50$ D was considered a postoperative refractive outcome essentially within the target range and was defined as target.

Data Collection

Data were obtained from patients' electronic medical records, including demographic characteristics, medical history, ocular parameters, refractive data, and surgical-related variables. Demographic characteristics included age, sex, and body mass index (BMI). Medical history included hypertension, diabetes, and previous glaucoma surgery. Ocular parameters included axial length (AL), corneal radius (CR), AL/CR, anterior chamber depth (ACD), lens thickness (LT), relative lens position (RLP), flat keratometry (K1), steep keratometry (K2), mean keratometry (Km), central corneal thickness (CCT), white-to-white distance (WTW), and preoperative best-corrected visual acuity (BCVA). Refractive data included the Barrett-predicted postoperative spherical equivalent (SE), actual postoperative SE at 3–6 months, and refractive prediction error (RPE). The postoperative refraction interval was defined as the number of days from surgery to the postoperative manifest refraction included in the analysis. Surgical-related variables included whether combined goniosynechialysis (GSL) was performed and whether a capsular tension ring (CTR) was implanted. Km was calculated as $(K1 + K2)/2$, and RLP was calculated as $(ACD + LT/2)/AL \times 10$, consistent with the previously published definition [8]; multiplication by 10 was applied as a conventional scaling factor. All patients underwent routine ophthalmic examinations before surgery, including visual acuity, best-corrected visual acuity, intraocular pressure mea-

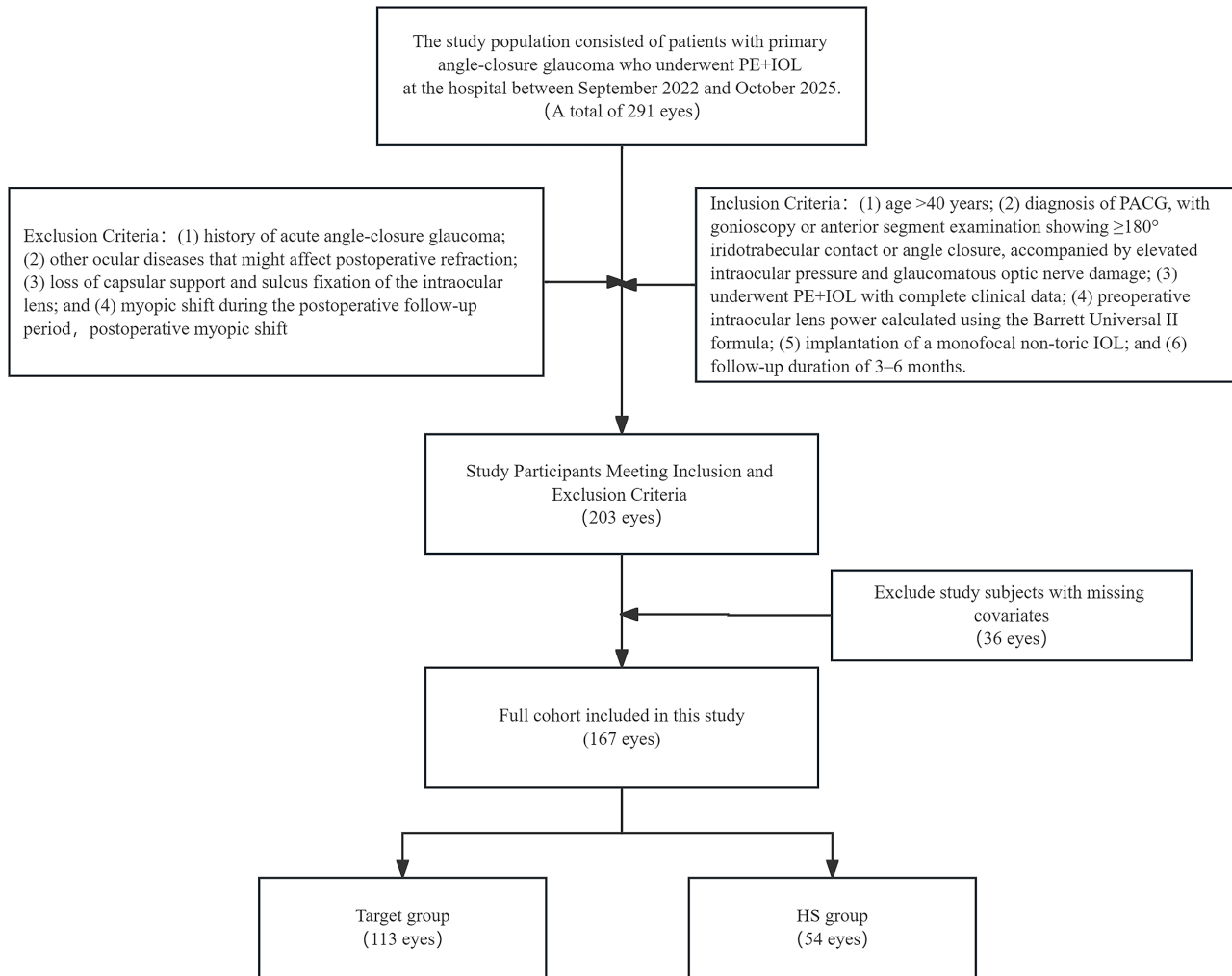


Fig. 1. Study flowchart of inclusion and exclusion. Abbreviations: PE+IOL, phacoemulsification combined with intraocular lens; PACG, primary angle-closure glaucoma; HS, hyperopic shift.

surement, slit-lamp microscopy, fundus examination, and angle-related assessment. Ocular biometric parameters, including AL, K1, K2, ACD, LT, CCT, and WTW, were obtained using an optical biometer. CR was obtained directly from the optical biometer output. Refractive status at 3–6 months postoperatively was recorded based on manifest refraction, and actual postoperative SE was calculated.

Statistical Analysis

Statistical analyses were performed using R software (version 4.4.3; R Foundation for Statistical Computing, Vienna, Austria). Normality was assessed using the Shapiro–Wilk test. Continuous variables are presented as mean $\pm$ standard deviation or median (interquartile range) and were compared using the independent-samples *t* test or Mann–Whitney U test, as appropriate. Categorical variables are presented as *n* (%) and were compared using Pearson’s chi-square test. Refractive prediction error (RPE), the continuous measure underlying the definition of hyperopic shift (HS), was analyzed using Spearman correlation to explore

associations between ocular variables and postoperative refractive deviation. HS, defined according to the prespecified RPE threshold, served as the primary binary clinical outcome for group comparisons and logistic regression analyses. The RPE-based correlation analyses were considered exploratory and supplementary. Univariable and multivariable logistic regression analyses were performed with HS as the dependent variable, and odds ratios (ORs) with 95% CIs were reported. Continuous predictors were standardized before regression. Variables significant in both the group comparisons and univariable analyses were evaluated using individual receiver operating characteristic (ROC) curves to assess their standalone discriminatory ability for postoperative HS and determine optimal cutoff values. These analyses were not intended to develop or validate a multivariable prediction model. The area under the curve (AUC), 95% CI, optimal cutoff, sensitivity, and specificity were calculated, with the cutoff determined by the maximum Youden index. The multivariable model adjusted for age and sex and included RLP, AL/CR, WTW,

Table 1. Baseline characteristics.

Variables	Overall
Age, years	67.97 ± 7.26
Sex	
Female	99 (59.28%)
Male	68 (40.72%)
Study eye	
OD	84 (50.30%)
OS	83 (49.70%)
BMI, kg/m ²	23.98 ± 2.89
AL, mm	22.59 ± 0.45
CR, mm	7.81 ± 0.27
AL/CR	2.90 ± 0.12
ACD, mm	2.41 ± 0.31
LT, mm	4.54 ± 0.25
RLP	2.07 ± 0.14
K1, D	42.77 ± 1.31
K2, D	43.59 ± 1.36
Km, D	43.18 ± 1.33
CCT, μm	537.31 ± 28.84
WTW, mm	11.45 ± 0.34
Preoperative BCVA, logMAR	0.41 (0.31, 0.55)
Barrett-predicted postoperative SE, D	−0.38 ± 0.23
Actual postoperative SE, D	−0.06 (−0.39, 0.31)
RPE, D	0.25 (0.00, 0.63)
Hypertension	
Yes	44 (26.35%)
No	123 (73.65%)
Diabetes	
Yes	16 (9.58%)
No	151 (90.42%)
Previous glaucoma surgery	
Yes	16 (9.58%)
No	151 (90.42%)
Combined GSL	
Yes	49 (29.34%)
No	118 (70.66%)
CTR implantation	
Yes	51 (30.54%)
No	116 (69.46%)
Postoperative HS	
Yes	54 (32.34%)
No	113 (67.66%)
Postoperative refraction interval, days	116.00 (103.00, 145.00)

Note: Data are presented as mean ± standard deviation, median (interquartile range), or n (%), as appropriate. The postoperative refraction interval ranged from 93 to 178 days.

Abbreviations: BMI, body mass index; AL, axial length; CR, corneal radius; ACD, anterior chamber depth; LT, lens thickness; RLP, relative lens position; K1, flat keratometry; K2, steep keratometry; Km, mean keratometry; CCT, central corneal thickness; WTW, white-to-white distance; BCVA, best-corrected visual acuity; SE, spherical equivalent; RPE, refractive prediction error; OD, right eye; OS, left eye; GSL, goniosynechialysis; CTR, capsular tension ring; HS, hyperopic shift; MAR, minimum angle of resolution.

Table 2. Comparisons of clinical and ocular parameters between the target and HS groups.

Variables	Target (n = 113)	HS (n = 54)	<i>p</i> value
Age, years	68.38 ± 7.24	67.11 ± 7.30	0.294
Sex			0.177
Female	71 (62.8%)	28 (51.9%)	
Male	42 (37.2%)	26 (48.1%)	
Study eye			0.543
OD	55 (48.7%)	29 (53.7%)	
OS	58 (51.3%)	25 (46.3%)	
BMI, kg/m ²	24.14 ± 3.12	23.64 ± 2.32	0.243
AL, mm	22.65 ± 0.44	22.45 ± 0.44	0.007
CR, mm	7.73 ± 0.24	7.98 ± 0.24	<0.001
AL/CR	2.93 ± 0.11	2.82 ± 0.10	<0.001
ACD, mm	2.50 ± 0.29	2.22 ± 0.26	<0.001
LT, mm	4.51 ± 0.24	4.60 ± 0.27	0.041
RLP	2.10 ± 0.14	2.01 ± 0.12	<0.001
K1, D	42.70 ± 1.30	42.91 ± 1.34	0.358
K2, D	43.52 ± 1.38	43.73 ± 1.31	0.326
Km, D	43.11 ± 1.33	43.32 ± 1.31	0.337
CCT, µm	537.29 ± 30.96	537.33 ± 24.07	0.992
WTW, mm	11.53 ± 0.34	11.27 ± 0.29	<0.001
Preoperative BCVA, logMAR	0.40 (0.29, 0.54)	0.41 (0.32, 0.56)	0.318
RPE, D	0.13 (0.00, 0.26)	0.75 (0.62, 0.88)	<0.001
Hypertension			0.932
Yes	30 (26.54%)	14 (25.93%)	
No	83 (73.45%)	40 (74.07%)	
Diabetes			0.112
Yes	8 (7.08%)	8 (14.81%)	
No	105 (92.92%)	46 (85.19%)	
Previous glaucoma surgery			0.032
Yes	7 (6.19%)	9 (16.67%)	
No	106 (93.81%)	45 (83.33%)	
Combined GSL			0.675
Yes	32 (28.32%)	17 (31.48%)	
No	81 (71.68%)	37 (68.52%)	
CTR implantation			0.007
Yes	27 (23.89%)	24 (44.44%)	
No	86 (76.11%)	30 (55.56%)	
Postoperative refraction interval, days	116.00 (109.00, 137.00)	126.50 (99.00, 158.00)	0.507

Note: Apparent identical standard deviations between groups reflect rounding to two decimal places; all statistical analyses were performed using unrounded data. Pearson's chi-square test was used for all categorical comparisons because all expected cell frequencies were ≥5.

and CTR implantation. Multicollinearity was assessed using variance inflation factors (VIFs), with VIF <5 indicating no substantial multicollinearity. Patients with missing data required for the analyses were excluded during cohort selection. Consequently, the final analytical dataset contained no missing values, and no missing-data imputation was performed. All tests were two-sided, with $p < 0.05$ considered statistically significant.

Results

Baseline Characteristics

A total of 167 patients with PACG, involving 167 eyes, were included in this study. Among them, 84 eyes were right eyes (50.3%), and 83 were left eyes (49.7%). The mean age of the patients was 67.97 ± 7.26 years. Of the 167 eyes included in the analysis, 54 were classified as having postoperative HS, whereas the remaining 113 eyes had target refractive outcomes (Table 1).

Table 3. Univariable logistic regression analyses for factors associated with postoperative HS.

Variables	OR	95% CI	p value
Age, years	0.837	0.601–1.165	0.291
Sex	0.637	0.331–1.228	0.178
BMI, kg/m ²	0.837	0.602–1.164	0.290
Hypertension	0.968	0.463–2.026	0.932
Diabetes	2.283	0.807–6.455	0.120
Previous glaucoma surgery	3.029	1.062–8.633	0.038
AL, mm	0.625	0.441–0.884	0.008
ACD, mm	0.323	0.208–0.502	<0.001
LT, mm	1.442	1.029–2.021	0.034
RLP	0.510	0.354–0.736	<0.001
AL/CR	0.294	0.188–0.462	<0.001
Km, D	1.174	0.846–1.629	0.337
CCT, μ m	1.001	0.723–1.386	0.993
WTW, mm	0.419	0.283–0.621	<0.001
Preoperative BCVA, logMAR	1.202	0.863–1.674	0.276
Combined GSL	1.163	0.575–2.354	0.675
CTR implantation	2.548	1.279–5.076	0.008

Abbreviation: OR, odds ratio; MAR, minimum angle of resolution.

Comparisons Between the HS and Target Groups

Table 2 shows the comparisons between the HS and target groups. Compared with the target group, the HS group had significantly lower AL, AL/CR, ACD, RLP, and WTW, and higher LT (all $p < 0.05$). Among surgical-related factors, CTR implantation ($p = 0.007$) was more frequent in the HS group than in the target group.

Exploratory analysis showed that RPE was positively associated with LT and negatively associated with ACD, AL, WTW, RLP, and AL/CR (Supplementary Table 1). The correlation matrix showed a strong correlation between ACD and RLP (Supplementary Fig. 1).

Univariable Logistic Regression Analysis

Based on the comparisons between the HS and target groups and the clinical relevance of the variables, univariate logistic regression analysis was further performed to evaluate the associations between candidate variables and postoperative HS. Univariate logistic regression analysis showed that AL (OR = 0.625, 95% CI: 0.441–0.884), ACD (OR = 0.323, 95% CI: 0.208–0.502), RLP (OR = 0.510, 95% CI: 0.354–0.736), AL/CR (OR = 0.294, 95% CI: 0.188–0.462), WTW (OR = 0.419, 95% CI: 0.283–0.621), LT (OR = 1.442, 95% CI: 1.029–2.021), previous glaucoma surgery (OR = 3.029, 95% CI: 1.062–8.633), and CTR implantation (OR = 2.548, 95% CI: 1.279–5.076) were significantly associated with postoperative HS (Table 3).

ROC Curve Analysis and Multivariable Logistic Regression Analysis

Based on the consistently significant findings from the intergroup comparisons and univariable logistic regression

analyses, AL, ACD, LT, RLP, AL/CR, WTW, and CTR implantation were selected for ROC curve analysis to compare the discriminative ability of individual indicators (Fig. 2, Table 4). The results showed that the AUCs of AL/CR, ACD, and WTW were 0.779 (95% CI: 0.699–0.851), 0.764 (95% CI: 0.688–0.836), and 0.730 (95% CI: 0.646–0.805), respectively.

Multivariable logistic regression analysis was further performed to evaluate independent factors associated with postoperative HS (Table 5). The results showed that higher RLP (OR = 0.400, 95% CI: 0.247–0.646), higher AL/CR (OR = 0.237, 95% CI: 0.134–0.418), and higher WTW (OR = 0.478, 95% CI: 0.295–0.775) were associated with a lower likelihood of postoperative HS, whereas CTR implantation was associated with a higher likelihood of postoperative HS (OR = 4.068, 95% CI: 1.582–10.460). All variables included in the final multivariable model had VIF values below 5, indicating no substantial multicollinearity (Supplementary Table 2).

Discussion

The results of this study showed that AL, ACD, LT, RLP, AL/CR, WTW, and CTR implantation were associated with postoperative HS in the univariable analyses and demonstrated varying degrees of standalone discriminative ability in the individual ROC analyses, with AL/CR, ACD, and WTW showing relatively better discrimination. Multivariable logistic regression further showed that lower RLP, AL/CR, and WTW, as well as CTR implantation, were independently associated with postoperative HS.

Liu et al. [7] found that AL, LT, and WTW were important factors associated with postoperative refractive prediction error and the direction of refractive shift after PE+IOL in patients with PACG, and that shorter AL and smaller WTW were associated with HS. Shin et al. [9] also reported that shallower ACD was associated with hyperopic shift after combined cataract surgery and trabeculectomy. From an anatomical perspective, eyes with shorter AL have a shorter anteroposterior dimension and require a higher intraocular lens power. Because short eyes are more susceptible to refractive prediction errors, inaccuracies in estimating the effective lens position and AL-related biometric changes may have a greater impact on postoperative refractive outcomes [9,10]. Shallower ACD reflects crowded anterior segment structures and a relatively anterior lens-iris diaphragm. Because ACD is closely related to the postoperative effective intraocular lens position and refractive error, postoperative deepening of the anterior chamber and changes in the actual position of the IOL within the capsular bag may be difficult to fully predict using preoperative formulas [11,12]. Greater LT indicates more prominent lens-related factors, and anterior segment changes after lens extraction may be more pronounced [13]. WTW reflects the transverse anatomical dimension of the anterior segment, and a smaller WTW may indicate a more compact anterior

Table 4. ROC curve analysis of individual predictors for postoperative HS.

Variables	AUC	95% CI	Optimal cutoff	Sensitivity	Specificity
AL/CR	0.779	0.699–0.851	2.910	0.833	0.602
ACD, mm	0.764	0.688–0.836	2.354	0.759	0.681
WTW, mm	0.730	0.646–0.805	11.570	0.870	0.504
RLP	0.681	0.587–0.771	2.024	0.593	0.735
AL, mm	0.626	0.518–0.721	22.466	0.593	0.681
LT, mm	0.609	0.512–0.709	4.705	0.463	0.805
CTR implantation	0.603	0.522–0.682	1.000	0.444	0.761

Abbreviations: ROC, receiver operating characteristic; AUC, area under the curve.

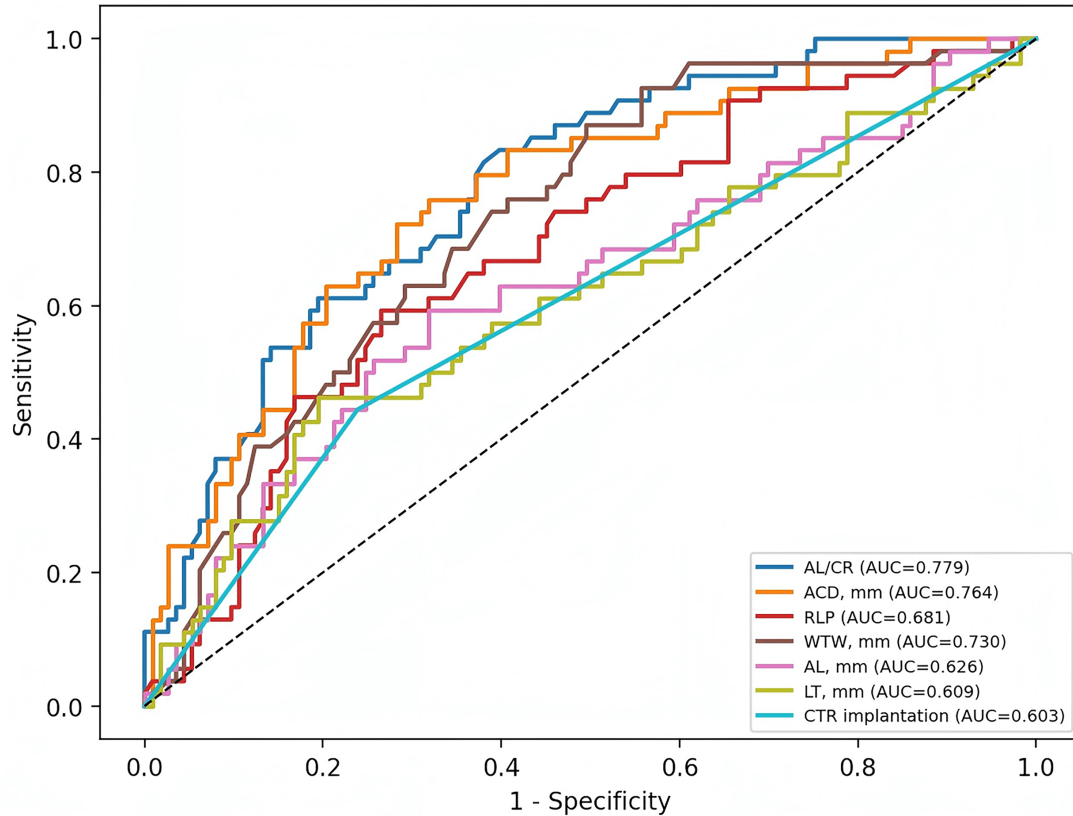


Fig. 2. ROC curves of individual predictors for postoperative HS. Abbreviations: AL, axial length; CR, corneal radius; ACD, anterior chamber depth; RLP, relative lens position; WTW, white-to-white distance; LT, lens thickness; CTR, capsular tension ring; ROC, receiver operating characteristic; AUC, area under the curve.

Table 5. Multivariable logistic regression analyses for factors associated with postoperative HS.

Variables	OR	95% CI	p value
Age, years	0.803	0.515–1.252	0.333
Sex	1.241	0.512–3.006	0.632
RLP	0.400	0.247–0.646	<0.001
AL/CR	0.237	0.134–0.418	<0.001
WTW, mm	0.478	0.295–0.775	0.003
CTR implantation	4.068	1.582–10.460	0.004

segment configuration. Previous research in patients with PACG has also shown that a smaller WTW is associated with postoperative HS [7].

The AL/CR ratio integrates AL and CR and more closely reflects the overall refractive configuration of the eye. Pathak-Ray [14] suggested that using AL alone to assess the risk of angle-closure may be insufficient, and that the interrelationships among AL, lens position, corneal characteristics, and anterior segment structures are also important. In the present study, eyes with lower AL/CR were more likely to develop HS. From the perspective of refractive configuration, lower AL/CR often indicates a relatively shorter AL or a hyperopic structural tendency in the relationship between AL and corneal curvature. Such eyes may be more sensitive to errors in the effective IOL position, slight postoperative changes in AL, or anterior segment remodeling. The study by Liu et al. [7] also suggested that

AL/CR was associated with the direction of postoperative refractive shift, with a higher AL/CR tending to indicate a risk of myopic shift. In contrast, the present study observed that lower AL/CR was associated with HS. Together, these findings suggest that AL/CR may help explain the directionality of postoperative refractive shift.

Notably, this study showed that lower RLP was associated with a higher likelihood of postoperative HS, suggesting that eyes with a more anterior relative lens position are more prone to hyperopic deviation after surgery. RLP is calculated from ACD, LT, and AL, and can reflect relative lens position in the context of AL. Chen et al. [15] reported that PACG eyes may still exhibit a relatively anterior lens position across different AL backgrounds, suggesting that relative lens position can partly characterize the crowded anterior segment features of some PACG eyes. Lower RLP reflects a relatively anterior lens position and is associated with angle-closure in narrow-angle eyes [16]. Lens extraction can substantially deepen the anterior chamber in eyes with primary angle-closure [17]. Therefore, in eyes with lower RLP, the actual postoperative IOL position may be more posterior than that predicted by the Barrett Universal II formula, resulting in a hyperopic prediction error, as posterior IOL displacement is associated with a hyperopic refractive change [18].

CTR was also associated with an increased risk of HS in this study, consistent with the findings of Xu et al. [19], who revealed that, compared with IOL implantation alone, combined CTR implantation was more likely to result in a hyperopic refractive shift in non-myopic cataract patients. CTR may participate in refractive shift by affecting capsular bag tension, the axial position of the IOL, and capsular bag stability [20]. CTR is generally used in eyes with zonular weakness or compromised capsular support; therefore, the association between CTR implantation and HS may partly reflect the underlying ocular conditions that prompted its use [21].

From a clinical perspective, in the preoperative evaluation of patients with PACG undergoing PE+IOL, AL/CR and RLP may provide additional information beyond conventional biometric parameters such as AL, ACD, LT, and WTW. For patients with lower RLP, AL/CR, or WTW, as well as those who may require CTR implantation during surgery, preoperative counseling regarding refractive expectations should be strengthened, and postoperative refractive follow-up should be emphasized. Several limitations should be acknowledged. First, this was a single-center retrospective study with a relatively limited sample size, and selection bias may exist. Second, eyes with postoperative myopic shift were excluded, which may have resulted in the selection of a study population with more stable or hyperopic refractive outcomes. Therefore, the findings are primarily applicable to distinguishing HS from target refractive outcomes and should not be generalized to predictors of postoperative refractive shifts in all directions.

Finally, the association between CTR implantation and HS may be affected by confounding by indication, as CTR is generally used in eyes with zonular weakness or capsular instability. Therefore, this finding should be interpreted cautiously and validated in prospective studies.

Conclusions

This study evaluated the factors associated with postoperative HS after PE+IOL. Multivariable analysis suggested that lower RLP, AL/CR, and WTW, as well as CTR implantation, were associated with postoperative HS. RLP and AL/CR may serve as supplementary parameters to conventional ocular biometry and help identify the risk of postoperative HS from the perspectives of relative lens position and overall ocular refractive configuration.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

JXF and JMY contributed to the study design. JXF conducted the literature search. JMY acquired the data. JXF wrote the article. JMY performed data analysis. Both authors have been involved in revising the manuscript critically for important intellectual content. Both authors gave final approval of the version to be published. Both authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was carried out in strict accordance with the ethical guidelines of the Declaration of Helsinki. It has been reviewed and approved by the Ethics Committee of Yiwu Central Hospital (Approval No. K2026-IRB-091). The requirement for informed consent was waived by the Ethics Committee of Yiwu Central Hospital because of the retrospective study design and the use of de-identified clinical data.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at <https://doi.org/10.62713/aic.4816>.

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