Analysis of Risk Factors and Model Construction for Recurrence Following Surgery for Primary Retinal Detachment

Ann. Ital. Chir., 2025 96, 8: 1047–1056
https://doi.org/10.62713/aic.4176

Xinru Jia[1], Dongwei Yao[1], Yan Shi[1], Chengfei Lin[1]

[1]Department of Ophthalmology, The First Affiliated Hospital of Ningbo University, 315000 Ningbo, Zhejiang, China

AIM: To investigate the risk factors for recurrent retinal detachment (re-RD) and to develop a predictive model to provide a basis for clinical evaluation.

METHODS: A retrospective analysis was conducted on clinical data from 432 patients who underwent primary retinal detachment (RD) surgery at our institution between January 2021 and December 2023. Univariate and multivariate logistic regression analyses were used to identify independent risk factors for re-RD. A predictive model was constructed based on significant variables, and its performance was evaluated.

RESULTS: Independent risk factors for re-RD included previous ocular surgery, increased axial length, larger retinal tear diameter, and surgical methods ($p < 0.05$). Younger age was associated with a higher incidence of re-RD, while moderate preoperative best-corrected visual acuity (BCVA, $0.1 \leq \text{BCVA} < 0.5$) was associated with a reduced incidence. The predictive model demonstrated satisfactory performance, with an area under the receiver operating characteristic (ROC) curve of 0.789. The calibration curve indicated good agreement between predicted probabilities and observed outcomes.

CONCLUSIONS: This study identified significant risk factors for re-RD and developed a predictive model with robust clinical relevance. These findings contribute to individualized risk assessment and optimized surgical decision-making in patients undergoing primary RD surgery.

Keywords: recurrent retinal detachment; risk factors; logistic regression; predictive model

Introduction

Retinal detachment (RD) is a prevalent ophthalmic condition that can result in permanent vision loss if not promptly treated. Its global incidence is estimated to range from 6.3 to 17.9 cases per 100,000 individuals annually, with notable variations based on age, ethnicity, and geographic region [1,2]. RD imposes a significant disease burden, not only due to its potential to cause blindness but also because of the associated healthcare costs and psychosocial impact on patients. Timely surgical intervention remains the primary treatment for RD; however, postoperative recurrence continues to pose a significant clinical challenge [3,4].

Recurrent retinal detachment (re-RD) is a severe complication following primary RD surgery. It increases the economic burden on patients and leads to poor visual outcomes, especially when unresolved or requiring repeated surgical interventions. The underlying pathophysiology of re-RD is multifactorial, involving a combination of patient-specific characteristics, surgical techniques, and disease-related factors. Despite advances in surgical methods, recurrence rates following primary RD repair have been reported to range between 5% and 15%, depending on the patient population studied and surgical approach used [5,6]. Effectively addressing re-RD is essential for enhancing both clinical outcomes and quality of life in these patients.

Previous studies have identified several risk factors associated with re-RD, including axial length, the size and location of retinal tears, and the type of surgical procedure performed. For example, increased axial length, larger retinal tears, and specific surgical approaches such as pars plana vitrectomy (PPV) have been implicated in a higher risk of recurrence [7,8]. However, inconsistencies in findings across studies have limited the generalizability of these results. Furthermore, few comprehensive predictive models exist that integrate multiple risk factors to enable individualized recurrence risk assessment [9].

The primary objective of this study was to address these gaps by conducting a retrospective analysis to identify independent risk factors for re-RD and to construct a predictive model based on these variables. By integrating multiple preoperative and intraoperative variables, this study aimed to establish a robust framework for clinical risk evaluation and personalized intervention. Such a model may assist clinicians in optimizing surgical planning, enhancing postoperative monitoring, and ultimately lowering the incidence of re-RD.

Submitted: 22 May 2025 Revised: 13 June 2025 Accepted: 3 July 2025 Published: 10 August 2025
Correspondence to: Chengfei Lin, Department of Ophthalmology, The First Affiliated Hospital of Ningbo University, 315000 Ningbo, Zhejiang, China (e-mail: linchengfeidyyy@163.com).

Materials and Methods

Study Population

This retrospective study included 432 patients who underwent primary RD surgery at The First Affiliated Hospital of Ningbo University between January 2021 and December 2023. Inclusion criteria comprised patients diagnosed with primary RD who had not undergone previous retinal surgery. Exclusion criteria included patients with proliferative vitreoretinopathy (PVR) grade C or higher, traumatic retinal detachment, concurrent ocular infections, or incomplete medical records. Patients with PVR grade C or higher were specifically excluded, as this advanced stage of PVR represents a distinct clinical entity in which PVR itself frequently becomes the dominant factor affecting surgical outcomes and recurrence risk, potentially confounding the identification of other relevant risk factors in primary RD cases without severe pre-existing PVR. This exclusion was intended to ensure a more homogeneous study population for analyzing predictors in uncomplicated primary RD repairs.

Comprehensive clinical data were collected, including baseline demographics (e.g., age, gender, systemic medical history), ocular characteristics (e.g., axial length, retinal tear diameter and location, categorized, though the number of tears was not separately analyzed in the model), status of the contralateral eye, surgical details (e.g., surgical method, preoperative best-corrected visual acuity [BCVA]), and follow-up outcomes (e.g., recurrence of RD).

Surgical Procedures

All procedures were performed by experienced vitreoretinal surgeons following standardized protocols. Surgical techniques included scleral buckling (SB), PPV with gas tamponade (PPV + Gas), PPV with silicone oil tamponade (PPV + Silicone oil), and combined procedures tailored to individual patient characteristics. Combined surgeries included interventions such as phacoemulsification with intraocular lens (IOL) implantation (Phaco + IOL implantation), primarily used to address coexisting cataracts or other lens-related concerns, thereby optimizing visual outcomes for patients during RD repair.

In PPV procedures, a 23- or 25-gauge vitrectomy system was used. The choice of tamponade agent (e.g., C_3F_8 gas or silicone oil) was based on the location and extent of the detachment. Endolaser photocoagulation or cryotherapy was applied as needed to seal retinal tears.

Follow-up

Patients were followed for a minimum of 12 months postoperatively. Follow-up assessments included comprehensive ophthalmic examinations, such as BCVA measurement, intraocular pressure monitoring, and fundus examination via indirect ophthalmoscopy. Recurrence of RD was defined as a new-onset retinal detachment occurring after initial surgical repair, confirmed through clinical examination and imaging.

Statistical Analysis

Statistical analyses were conducted using SPSS (version 26.0, IBM Corp., Armonk, NY, USA). While general statistical testing was performed using SPSS, the nomogram model, receiver operating characteristic (ROC) curve, and calibration curve were constructed and plotted using R software (version 4.3.2; R Foundation for Statistical Computing, Vienna, Austria). Normality of continuous variables was tested using the Shapiro-Wilk test. Non-normally distributed variables were expressed as medians with interquartile ranges (IQR) and compared using the Mann-Whitney U test. Categorical variables were expressed as frequencies and percentages, and analyzed using the chi-square or Fisher's exact test, as appropriate. A p-value < 0.05 was considered statistically significant.

Univariate logistic regression analysis was first performed to identify potential risk factors for re-RD. Variables with a p-value < 0.05 in the univariate analysis were subsequently included in multivariate logistic regression to determine independent predictors of re-RD. A nomogram model was constructed using the significant predictors identified in the multivariate analysis. The predictive performance of the model was evaluated using the ROC curve, with the area under the curve (AUC) used to assess discrimination ability. To further assess the stability of the model and minimize overfitting, 10-fold cross-validation was performed, and the average AUC from the cross-validation was reported. Calibration of the model was evaluated through calibration curves, and the Hosmer-Lemeshow goodness-of-fit test was applied to assess model fit.

Results

Baseline Characteristics of Patients

A total of 432 patients who underwent primary retinal detachment (RD) surgery were included in this study, among whom 60 cases (13.9%) experienced re-RD. Significant differences were observed between the re-RD group and the non-recurrent group in terms of age, surgical history, axial length, retinal tear diameter, contralateral retinal status, best-corrected visual acuity (BCVA), and surgical method ($p < 0.05$, Table 1).

Notably, patients in the re-RD group had a younger median age (52.0 years [39.50, 63.75]) compared to the non-recurrent group (57.0 years [49.0, 64.0], $p = 0.027$). The proportion of patients with a history of ocular surgery was significantly higher in the re-RD group (25.0%) than in the non-recurrent group (11.02%, $p = 0.006$). Similarly, axial length was greater in the re-RD group (26.72 mm [24.28, 29.50]) compared to the non-recurrent group (24.42 mm [23.48, 26.52], $p < 0.001$). Additionally, the retinal tear diameter was larger in the re-RD group (1.00 mm [0.50, 3.88]) than in the non-recurrent group (1.00 mm [0.30, 2.00], $p = 0.014$).

Regarding the contralateral retinal status, the frequencies of peripheral retinopathy (20.0% vs. 9.14%) and high myopia-related lesions (21.67% vs. 12.37%) were significantly higher in the re-RD group ($p = 0.008$). For BCVA, the proportion of patients presenting with moderately impaired vision ($0.1 \leq$ BCVA < 0.5) was lower in the re-RD group (15.0%) compared to the non-recurrent group (35.48%, $p = 0.009$). In terms of surgical methods, patients in the re-RD group were more likely to have undergone PPV with gas tamponade (PPV + Gas) (26.67% vs. 11.29%, $p = 0.012$).
In contrast, no statistically significant differences were observed between the two groups in terms of gender, history of hypertension or diabetes, history of ocular trauma, intraocular pressure, laterality, lens status, duration from onset to surgery, extent of retinal detachment, or macular status ($p > 0.05$, Table 1).
These findings suggest that several baseline characteristics, including age, axial length, and surgical factors, are associated with re-RD, whereas systemic comorbidities and macular involvement appear unrelated to recurrence risk.

Univariate and Multivariate Logistic Regression Analysis

Univariate logistic regression analysis was performed to identify potential factors associated with re-RD, and the results are summarized in Table 2. Significant variables associated with re-RD included age, surgical history, axial length, retinal tear diameter, contralateral peripheral retinal pathology, BCVA ($0.1 \leq$ BCVA < 0.5), and the PPV + Gas surgical method ($p < 0.05$).
Multivariate logistic regression analysis identified the following independent predictors of re-RD: age (odds ratio (OR) = 0.972, 95% CI: 0.948–0.996, $p = 0.022$), indicating that increasing age served as a protective factor against re-RD; surgical history (OR = 3.007, 95% CI: 1.337–6.767, $p = 0.008$), showing that patients with a history of ocular surgery had an elevated recurrence risk; axial length (OR = 1.160, 95% CI: 1.028–1.310, $p = 0.016$), where longer axial length was associated with a higher risk of re-RD; retinal tear diameter (OR = 1.187, 95% CI: 1.049–1.343, $p = 0.007$), with larger tear diameters serving as a significant risk factor; contralateral peripheral retinal pathology (OR = 2.798, 95% CI: 1.141–6.864, $p = 0.025$), indicating that pathology in the contralateral eye significantly increased the risk of recurrence. However, the overall contralateral retinal status variable did not reach statistical significance ($p = 0.163$). Therefore, although contralateral peripheral retinal pathology was an independent risk factor for re-RD, it was not included in the final model construction; BCVA ($0.1 \leq$ BCVA < 0.5) (OR = 0.236, 95% CI: 0.081–0.688, $p = 0.008$) was associated with a lower recurrence risk of re-RD compared to BCVA ≥ 0.5; and PPV + Gas surgical method (OR = 14.096, 95% CI: 1.472–134.947, $p = 0.022$), demonstrated a strong association with increased risk of re-RD.
Among these variables, age was identified as a protective factor, with recurrence risk decreasing as age increased. Conversely, surgical history, axial length, retinal tear diameter, contralateral peripheral retinal pathology, moderate BCVA, and the PPV + Gas procedure were determined to be independent risk factors for re-RD. These findings highlight the multifactorial nature of re-RD and underscore the relevance of these variables in predicting recurrence following primary surgery.

Construction of the Nomogram Model

A nomogram model was constructed to estimate the risk of re-RD based on the results of the multivariate logistic regression analysis. Six significant predictors were included in the model: age, surgical history, axial length, retinal tear diameter, BCVA, and surgical method (Fig. 1). Each variable in the nomogram was assigned a point value proportional to its contribution to the recurrence risk. The total score, derived by summing the scores from all predictors, was then mapped to a linear predictor and a corresponding probability of recurrence. This framework enables quantitative and individualized risk assessment.
The nomogram illustrates the relative impact of each risk factor. Variables such as younger age, a history of ocular surgery, greater axial length, larger retinal tear diameter, lower BCVA values (e.g., $0.1 \leq$ BCVA < 0.5), and surgical methods like PPV + Gas are strongly associated with increased re-RD risk. This model serves as a practical clinical tool for the stratification of patients based on their recurrence risk. By integrating these six variables, the nomogram offers a robust and clinically relevant approach to predicting re-RD, thereby supporting improved patient management and surgical decision-making.

Illustrative Case Example of Nomogram Application

To demonstrate the clinical utility of the nomogram, we present an illustrative example based on data from a patient treated at our institution. We considered a 65-year-old male patient diagnosed with a primary retinal detachment. He had no history of ocular surgery, which corresponds to a value of '0' on the 'surgical history' axis of the nomogram (Fig. 1), contributing approximately 0 points. His preoperative BCVA was 0.2. Assuming this falls within the category '$0.1 \leq$ BCVA < 0.5' and corresponds to label '1' on the nomogram's BCVA scale (representing the lowest risk points for this protective factor), this likewise contributes approximately 0 points.
Further assessment revealed an axial length of 28 mm. Locating this value on the 'axial length' axis of the nomogram yields approximately 45 points. The diameter of the retinal tear was 4 mm, which, when referenced on the 'retinal tear diameter' axis, adds approximately 25 points. The patient underwent PPV + Gas for the repair. Assuming this surgical approach corresponds to label '2' on the 'surgical methods' axis, representing the highest risk category for this variable, it contributes approximately 100 points. His age of 65 years corresponds to approximately 27 points on the 'age' axis.
Summing the scores for this patient: 27 (age) + 0 (surgi-

Table 1. Baseline characteristics of patients with and without re-RD.

Variable	Overall (n = 432)	No recurrence (n = 372)	Recurrence (n = 60)	Chi-square value/ *Z* value	*p*-value
Gender, n (%)				0.112	0.738
Female	193.00 (44.68)	165.00 (44.35)	28.00 (46.67)		
Male	239.00 (55.32)	207.00 (55.65)	32.00 (53.33)		
Age (years), median (P_{25}, P_{75})	57.0 (48.0, 64.0)	57.0 (49.0, 64.0)	52.0 (39.50, 63.75)	–2.209	0.027
Hypertension, n (%)	125.00 (28.94)	109.00 (29.30)	16.00 (26.67)	0.174	0.676
Diabetes, n (%)	55.00 (12.73)	49.00 (13.17)	6.00 (10.00)	0.468	0.494
History of eye trauma, n (%)	18.00 (4.17)	13.00 (3.49)	5.00 (8.33)		0.089[a]
Surgical history, n (%)	56.00 (12.96)	41.00 (11.02)	15.00 (25.00)	8.948	0.006
Intraocular pressure (mmHg), median (P_{25}, P_{75})	13.00 (12.00, 16.00)	13.00 (12.00, 16.00)	13.00 (10.50, 16.00)	–0.364	0.716
Axial length (mm), median (P_{25}, P_{75})	24.46 (23.54, 27.45)	24.42 (23.48, 26.52)	26.72 (24.28, 29.50)	–4.345	<0.001
Retinal tear diameter (mm), median (P_{25}, P_{75})	1.00 (0.30, 2.00)	1.00 (0.30, 2.00)	1.00 (0.50, 3.88)	–2.459	0.014
Laterality, n (%)				2.941	0.086
Right	244.00 (56.48)	204.00 (54.84)	40.00 (66.67)		
Left	188.00 (43.52)	168.00 (45.16)	20.00 (33.33%)		
Lens status, n (%)				3.006	0.222
Phakic	386 (89.35)	335 (90.05)	51 (85.00)		
Pseudophakic	44 (10.19)	36 (9.68)	8 (13.33)		
Aphakic	2 (0.46)	1 (0.27)	1 (1.67)		
Contralateral retinal status, n (%)				11.815	0.008
Normal	311 (71.99)	278 (74.73)	33 (55.00)		
Peripheral retinopathy	46 (10.65)	34 (9.14)	12 (20.00)		
High myopia-related lesions	59 (13.66)	46 (12.37)	13 (21.67)		
Retinal detachment	16 (3.70)	14 (3.76%)	2 (3.33)		
Time from onset to surgery, n (%)				1.942	0.585
≤5 days	128.00 (29.63)	111.00 (29.84)	17.00 (28.33)		
6–10 days	100.00 (23.15)	82.00 (22.04)	18.00 (30.00)		
11–30 days	126.00 (29.17)	111.00 (29.84)	15.00 (25.00)		
>30 days	78.00 (18.06)	68.00 (18.28)	10.00 (16.67)		
BCVA, n (%)				11.546	0.009
≥0.5	57.00 (13.19)	46.00 (12.37)	11.00 (18.33)		
$0.1 \leq$ BCVA < 0.5	141.00 (32.64)	132.00 (35.48)	9.00 (15.00)		
$0.01 \leq$ BCVA < 0.1	70.00 (16.20)	61.00 (16.40)	9.00 (15.00)		
Severe visual loss (CF/HM/LP/NLP)	164.00 (37.96)	133.00 (35.75)	31.00 (51.67)		
Retinal tear location, n (%)					0.102[a]
Macular hole	31.00 (7.18)	30.00 (8.06)	1.00 (1.67)		
Peripheral retina	401.00 (92.82)	342.00 (91.94)	59.00 (98.33)		
Retinal detachment extent, n (%)				4.185	0.382
Macular region only	31 (7.18)	30 (8.06)	1 (1.67)		
One quadrant	353 (81.71)	302 (81.18)	51 (85.00)		
Two quadrants	5 (1.16)	4 (1.08)	1 (1.67)		
Three quadrants	3 (0.69)	2 (0.54)	1 (1.67)		
Four quadrants	40 (9.26)	34 (9.14)	6 (10)		
Macular status, n (%)				0.029	0.864
On	90.00 (20.83)	78.00 (20.97)	12.00 (20.00)		
Off	342.00 (79.17)	294.00 (79.03)	48.00 (80.00)		
Surgical method, n (%)				12.789	0.012
Scleral buckling (SB), n (%)	26 (6.02)	25 (6.72)	1 (1.67)		
PPV + Gas	58 (13.43)	42 (11.29)	16 (26.67)		
PPV + C_3F_8	67.00 (15.51)	60 (16.13)	7 (11.67)		
PPV + Silicone oil	116 (26.85)	99 (26.61)	17 (28.33)		
PPV + Complex combined	165 (38.19)	146 (39.25)	19 (31.67)		

Note: [a] Fisher's exact test. re-RD, recurrent retinal detachment; BCVA, best-corrected visual acuity; PPV, pars plana vitrectomy; CF, counting fingers; HM, hand motion; LP, light perception; NLP, no light perception.

Table 2. Univariate and multivariate logistic regression analysis of risk factors for re-RD.

Variable	Univariate regression analysis		Multivariate regression analysis	
	OR (95% CI)	*p*-value	OR (95% CI)	*p*-value
Gender (male vs. female)	0.911 (0.527–1.581)	0.738		
Age (years)	0.980 (0.962–0.998)	0.027	0.972 (0.948–0.996)	0.022
Hypertension (yes vs. no)	0.877 (0.463–1.592)	0.676		
Diabetes (yes vs. no)	0.732 (0.271–1.673)	0.495		
History of eye trauma (yes vs. no)	2.510 (0.781–6.947)	0.092		
Surgical history (yes vs. no)	2.691 (1.348–5.174)	0.004	3.007 (1.337–6.767)	0.008
Intraocular pressure (mmHg)	0.987 (0.912–1.065)	0.735		
Axial length (mm)	1.228 (1.122–1.345)	<0.001	1.160 (1.028–1.310)	0.016
Retinal tear diameter (mm)	1.205 (1.083–1.340)	0.001	1.187 (1.049–1.343)	0.007
Laterality (left vs. right)	0.607 (0.336–1.066)	0.089		
Lens status				
Phakic	Ref			
Pseudophakic	1.460 (0.642–3.317)	0.366		
Aphakic	6.569 (0.404–106.668)	0.186		
Contralateral retinal status				0.163
Normal	Ref			
Peripheral retinopathy	2.973 (1.364–6.190)	0.004	2.798 (1.141–6.864)	0.025
High myopia-related lesions	2.381 (1.135–4.777)	0.017	1.242 (0.472–3.268)	0.661
Retinal detachment	1.203 (0.184–4.564)	0.812	1.117 (0.221–5.644)	0.894
Time from onset to surgery				
≤5 days	Ref			
6–10 days	1.433 (0.695–2.970)	0.328		
11–30 days	0.882 (0.416–1.856)	0.741		
>30 days	0.960 (0.403–2.187)	0.924		
Preoperative BCVA				0.023
≥0.5	Ref			
0.1 ≤ BCVA < 0.5	0.285 (0.108–0.731)	0.009	0.236 (0.081–0.688)	0.008
0.01 ≤ BCVA < 0.1	0.617 (0.231–1.612)	0.324	0.556 (0.187–1.654)	0.291
Severe visual loss (CF/HM/LP/NLP)	0.975 (0.464–2.171)	0.948	0.796 (0.310–2.040)	0.634
Retinal tear location (peripheral retina vs macular hole)	5.175 (1.076–93.040)	0.109		
Retinal detachment extent				
Macular region	Ref			
One quadrant	5.066 (0.676–37.975)	0.114		
Two quadrants	7.500 (0.388–144.973)	0.182		
Three quadrants	15.000 (0.663–339.548)	0.089		
Four quadrants	5.294 (0.603–46.515)	0.133		
Macular status (off vs. on)	1.061 (0.553–2.180)	0.864		
Surgical method				0.038
SB	Ref			
PPV + Gas	9.524 (1.190–76.238)	0.034	14.096 (1.472–134.947)	0.022
PPV + C_3F_8	2.917 (0.341–24.954)	0.328	4.854 (0.485–48.580)	0.179
PPV + Silicone oil	4.293 (0.545–33.815)	0.166	4.458 (0.467–42.561)	0.194
PPV + Complex combined	3.253 (0.417–25.403)	0.261	8.874 (0.884–89.068)	0.064

Note: Ref, reference category; OR, odds ratio.

cal history) + 0 (BCVA) + 45 (axial length) + 25 (retinal tear diameter) + 100 (surgical method) yields a total of 197 points. Mapping this total on the 'total points' axis of the nomogram and projecting downward, the linear predictor is approximately –1.6, which corresponds to a 'Predicted Value', or an estimated risk of recurrent retinal detachment of approximately 0.16 (16%).

This case illustrates how the nomogram can translate individual patient variables into a quantitative risk score, supporting personalized clinical decision-making and tailored counseling on postoperative expectations and follow-up intensity. Accurate application requires clearly defined categories for variables such as BCVA and surgical method, as specified in the model's development.

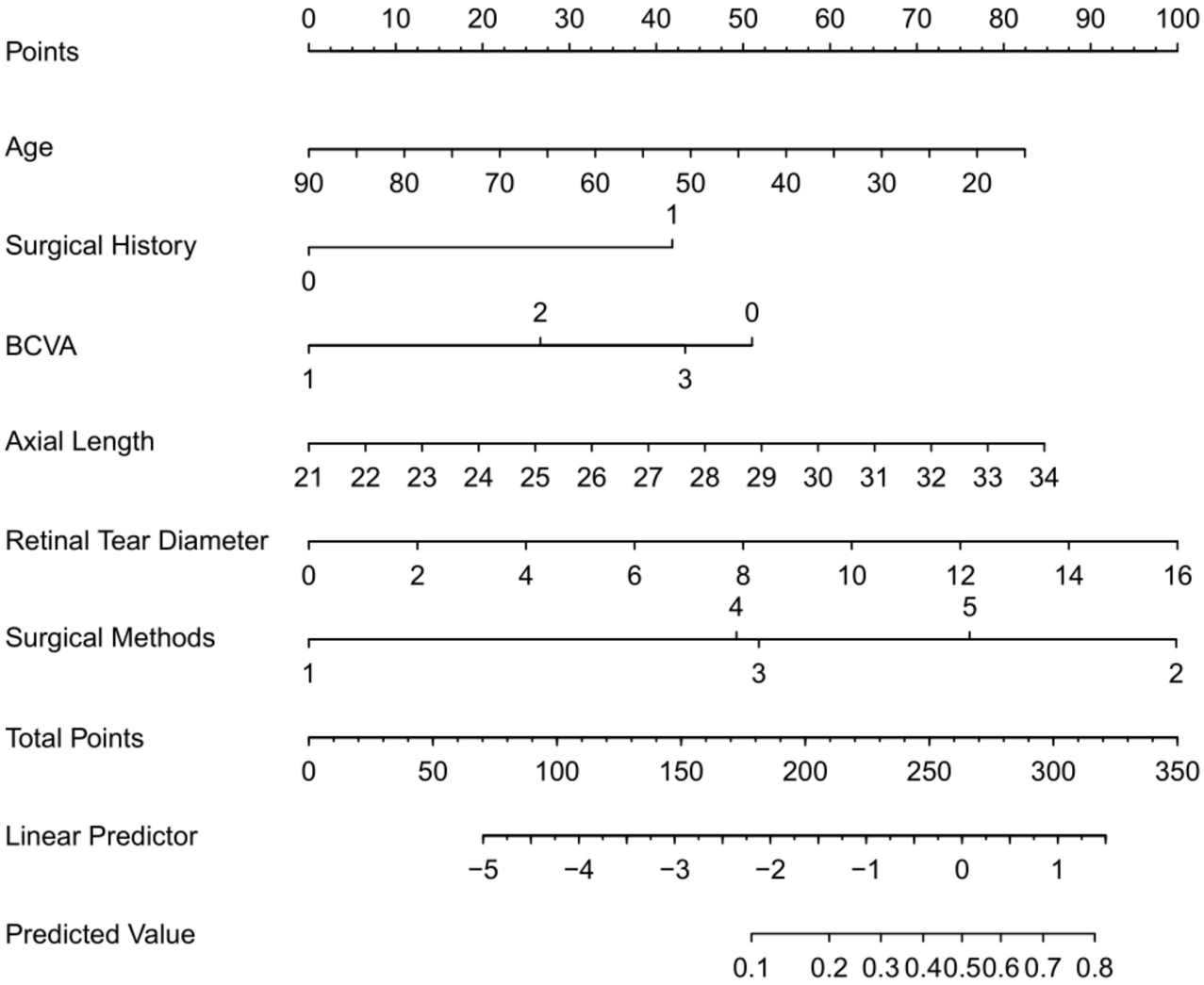

Fig. 1. Nomogram model for predicting the risk of re-RD. The model integrates key preoperative factors to estimate the probability of re-RD. Variables encoding: surgical history: 0 indicates NO; 1 indicates Yes. BCVA: 0 indicates $\geq$0.5; 1 indicates 0.1 $\leq$ BCVA $<$ 0.5; 2 indicates 0.01 $\leq$ BCVA $<$ 0.1; 3 indicates severe visual loss (counting fingers/hand motion/light perception/no light perception). Surgical methods: 1 indicates scleral buckling; 2 indicates PPV + Gas; 3 indicates PPV + C_3F_8; 4 indicates PPV + Silicone oil; 5 indicates PPV + Complex combined surgery.

Predictive Performance of the Model

The predictive performance of the nomogram model was evaluated using ROC analysis, 10-fold cross-validation, and calibration assessments. The ROC curve for the complete dataset (Fig. 2) yielded an AUC of 0.789 (95% CI: 0.732–0.846), indicating good discriminative value. The 10-fold cross-validation produced a mean AUC of 0.775 (95% CI: 0.714–0.841), suggesting good stability and performance of the model on unseen data subsets. At the optimal cutoff value of 0.451, the model achieved a sensitivity of 73.3% and a specificity of 71.8%, reflecting strong performance in distinguishing between patients with and without re-RD.

The calibration curve showed close agreement between predicted probabilities and observed recurrence rates (Fig. 3). The apparent and bias-corrected calibration curves closely followed the ideal diagonal line, indicating that the nomogram provided accurate predictions of re-RD risk. The Hosmer-Lemeshow test further confirmed the goodness of fit of the model, with a non-significant *p*-value of 0.874, suggesting no significant deviation between predicted and observed outcomes. Collectively, these findings highlight the strong predictive accuracy, robustness, and clinical applicability in estimating individual risk for recurrent retinal detachment following primary surgery.

Discussion

This study identified multiple factors associated with re-RD, including age, preoperative BCVA, surgical history, axial length, retinal tear diameter, contralateral peripheral retinal pathology, and surgical method. Among these, age was a protective factor, with increasing age associated with

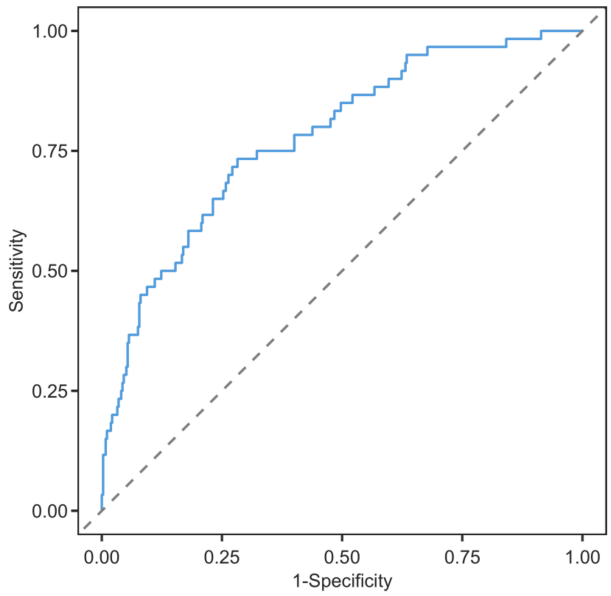

Fig. 2. ROC curve of the nomogram for predicting the risk of re-RD. Abbreviations: ROC, receiver operating characteristic.

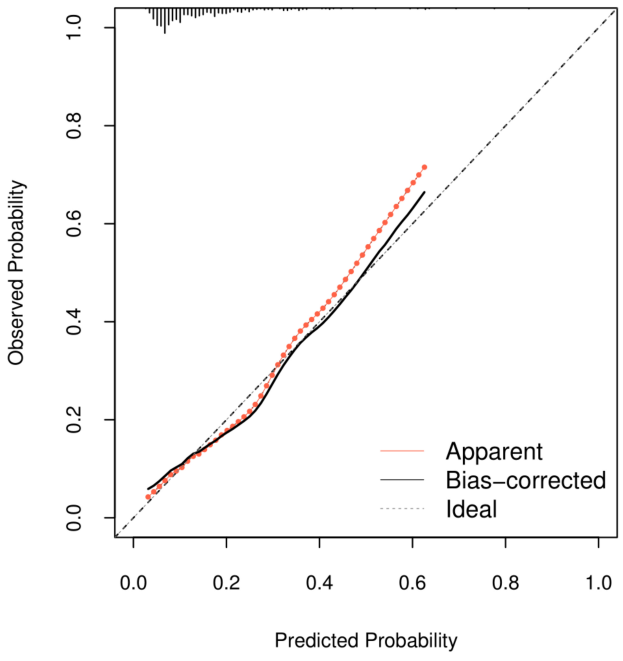

Fig. 3. Calibration curve of the nomogram for predicting re-RD risk.

a reduced risk of recurrence. Conversely, ocular surgical history, greater axial length, lower BCVA, larger retinal tear diameter, the presence of contralateral peripheral retinal pathology, and use of PPV + Gas surgical methods were determined to be independent risk factors for re-RD. These findings align with and extend upon previous research, highlighting the multifactorial etiology and complex pathogenesis of re-RD [10,11]. Given that overall contralateral retinal status was not statistically significant, only contralateral peripheral retinal pathology was analyzed and excluded from the final nomogram construction.

The nomogram model constructed in this study integrates six preoperative risk factors and demonstrated strong predictive performance, with an area under the ROC curve of 0.789. At the optimal cutoff value (0.451), the model exhibited a sensitivity of 73.3% and a specificity of 71.8%, supporting its potential utility in clinical practice. Calibration curve analysis further confirmed the model's reliability, revealing a high degree of concordance between predicted probabilities and observed outcomes. These results underscore the utility of the nomogram as an effective and user-friendly tool for individualized risk stratification and informed clinical decision-making in patients undergoing primary retinal detachment surgery [12].

Age emerged as a protective factor against re-RD. The observed positive association between younger age and high recurrence risk may reflect increased vitreoretinal traction forces or heightened cellular proliferation in younger individuals, which could contribute to more aggressive disease progression and surgical failure [13,14].

In terms of BCVA, patients with BCVA between 0.1 and 0.5 ($0.1 \leq \text{BCVA} < 0.5$) exhibited a lower recurrence risk compared to those with BCVA $\geq$0.5. These findings contrast with previous studies reporting that better BCVA is typically correlated with milder retinal detachment, while poorer preoperative BCVA have been associated with a higher risk of re-RD [15,16]. The discrepancy may be attributed to differences in baseline characteristics, inclusion criteria, and study populations.

Surgical history, axial length, and retinal tear diameter were identified as independent risk factors for re-RD. A history of prior ocular surgery may result in altered vitreous dynamics, adhesions, or compromised anatomical restoration, increasing susceptibility to recurrent detachment [17]. Longer axial length, a hallmark of high myopia, is associated with biomechanical thinning of scleral walls and increased susceptibility to mechanical stress, which predispose the eye to detachment recurrence [18,19]. Larger retinal tear diameters reflect more severe retinal injury, allowing greater subretinal fluid accumulation and posing challenges to long-term surgical success [20].

Additionally, contralateral peripheral retinal pathology, such as lattice degeneration or myopia-related lesions, may reflect systemic or bilateral predispositions to retinal instability. Although this variable was not included in the construction of the nomogram prediction model, these contralateral lesions may still contribute to an increased risk of re-RD [13]. The precise underlying mechanisms warrant further investigation but may involve genetic predispositions affecting vitreoretinal structural integrity or shared bilateral degenerative processes not fully accounted for by other individual risk factors. The identification of contralateral pathology as an independent predictor underscores a potentially novel dimension of re-RD risk assessment, extending beyond exclusively ipsilateral considerations.

A notable finding in this study was the strong association between the PPV + Gas surgical method and an increased risk of re-RD (OR = 14.096). Similarly, Zhou *et al*. [21] reported that, compared to Scleral buckling (SB), PPV + Gas was the most significant risk factor for re-RD (OR = 9.04, 95% CI: 2.02–40.43, $p = 0.004$). Several factors may explain this observation. The "PPV + Gas" group included procedures utilizing short-acting gases such as SF_6 or air, which offer significantly shorter duration of internal tamponade compared to C_3F_8 or silicone oil [22]. This reduced tamponade time may be inadequate for the development of durable chorioretinal adhesions, especially in eyes with larger or multiple retinal tears, or in cases with suboptimal postoperative positioning compliance. Furthermore, short-acting gases may be less effective than silicone oil in suppressing the PVR cascade, which provides a longer and more stable tamponade effect [23]. The wide confidence interval observed for this odds ratio suggests that while the association is statistically significant, further research using larger cohorts is necessary to refine the estimate and validate these mechanistic hypotheses.

When contextualizing our nomogram within the existing literature, it is evident that although numerous studies have investigated risk factors for re-RD, relatively few have resulted in externally validated, comprehensive predictive nomograms tailored for a broad primary RD population, excluding advanced PVR. Zhou *et al*. [21] investigated the risk factors for re-RD in patients with rhegmatogenous retinal detachment who underwent surgery. They analyzed 15 potential variables in 403 patients and identified axial length, inferior retinal breaks, retinal break diameter, and surgical method as independent risk factors for re-RD. Based on these four factors, they constructed a predictive nomogram for re-RD, achieving an AUC of 0.892 [21]. Notably, age and BCVA were not included among the independent predictors in their model. In a separate study, Aleshawi *et al*. [24] identified significant independent predictors of re-RD, including longer symptom duration before surgery, more extensive retinal detachment, and inadequate prophylactic laser retinopexy. Their findings underscore the significance of early symptom recognition, timely surgical intervention, and adequate laser retinopexy to reduce recurrence risk and associated complications [24]. The primary reason for the discrepancy between our findings and those reported in other studies may be attributed to differences in study design, including variations in patient demographics, surgical methods, and the selection of candidate variables. Such heterogeneity can lead to divergence in the identified predictors and model performance.

Despite the strengths of our study, several limitations must be acknowledged. First, the reliance on a single-center, retrospective dataset may introduce selection bias, potentially stemming from specific patient referral patterns or demographic characteristics unique to our institution. This limitation may affect the external validity and generalizability of our findings. Additionally, center-specific practices, including surgeon experience, preferred surgical techniques (e.g., subtle variations in vitrectomy procedures or choice of tamponade for specific RD characteristics not fully captured by the broad procedural categories employed), and perioperative management protocols, could have influenced the observed risk factors and the predictive performance of the model in other settings. Consequently, the reported AUC and optimal cutoff value may vary when applied in different populations. To enhance the applicability of this model, validation through a larger, multicenter prospective study is essential. Such a study would help confirm the performance of the model across diverse populations and account for inter-institutional variability in clinical practice.

Second, our study is subject to limitations inherent in its retrospective design, including the presence of several unmeasured potential confounders. Although the study protocol stipulated that all procedures be performed by experienced vitreoretinal surgeons following standardized protocols, specific measures of surgical experience, such as individual case volume or years in practice, were not quantitatively included as variables. The retrospective collection of such detailed data was not feasible for this analysis. Similarly, intraoperative events such as iatrogenic retinal tears were not systematically recorded as distinct variables and thus were not incorporated into our predictive model [14]. The deliberate exclusion of patients with PVR grade C or higher, while intended to yield a more homogeneous cohort for identifying primary RD risk factors, inherently limits the applicability of the model to more complex cases where advanced PVR is a dominant determinant of re-RD. Consequently, the development of a dedicated predictive model for this higher-risk subgroup is warranted. Although PVR grades were not comprehensively analyzed as distinct variables in this iteration, future prospective studies should aim to develop and validate predictive models that encompass the full spectrum of PVR severity, including grade C and above, to extend clinical applicability to a wider range of RD complexities.

Third, although we employed 10-fold cross-validation to enhance internal validation and model stability, the optimal form of validation would involve application of the nomogram to an independent external cohort. Given the single-center, retrospective design of this study, our findings, including the performance of the nomogram, may not be directly generalizable across different clinical populations or institutional practices without external validation. Multicenter, prospective studies are warranted to confirm the utility of the nomogram and ensure broader clinical relevance.

Fourth, the 'PPV + Complex combined surgery' category, while necessary for grouping procedures involving concurrent interventions such as phacoemulsification with primary RD repair, inherently introduces clinical heterogeneity. Although our main analysis differentiated PPV subtypes based on tamponade agents (e.g., gas, C_3F_8, or silicone oil), further stratification within the 'PPV + Complex combined

surgery' group based on the specific concurrent procedures was not performed due to limited subgroup sample sizes. Future studies with larger cohorts will be valuable in dissecting the impact of individual combined surgical procedures on re-RD risk when performed alongside PPV.

Fifth, the minimum follow-up period of 12 months, while standard for assessing primary RD surgical outcomes, may not capture all re-RD events, as recurrences may manifest beyond this observation window. Consequently, the actual recurrence rate over a longer duration may be underestimated in our cohort. Future prospective studies incorporating extended and uniformly structured follow-up protocols would allow for more comprehensive time-to-event analyses, such as Cox proportional hazards regression, to better characterize the long-term incidence and temporal patterns of re-RD.

Furthermore, certain variables, such as the specific number of retinal tears (despite inclusion diameter and location) and patient adherence to standardized postoperative positioning protocols, which is notably critical following gas tamponade, were not fully incorporated as independent variables in the present model. These unmeasured variables, including surgeon-specific characteristics, select intraoperative events, variations in postoperative compliance, and the number of retinal tears, are known to potentially influence re-RD risk. Their exclusion represents a limitation of this study. Future large-scale, prospective studies should aim to systematically capture these and other dynamic variables to develop more robust and comprehensively adjusted predictive models for re-RD.

Conclusions

In conclusion, this study highlights the significance of age, BCVA, surgical history, axial length, retinal tear diameter, and surgical methods in predicting re-RD. The nomogram model developed herein, demonstrating robust predictive performance and practical clinical applicability, provides a valuable tool for individualized risk assessment and clinical decision-making. However, additional research is needed to address current limitations and to further refine and optimize the model for broader clinical implementation.

Availability of Data and Materials

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

Author Contributions

All authors contributed to this paper. XRJ: methodology, data collection and analysis, writing—original draft. DWY: investigation, data collection and analysis. YS: formal analysis, visualization. CFL: conceptualization, supervision, writing—reviewing. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All 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

The present study followed the Declaration of Helsinki. This study was approved by the Ethics Committee of The First Affiliated Hospital of Ningbo University (2025 research NO.102RS), and written informed consent was obtained from all subjects participating in the trial, and their information was stored and used for research anonymously.

Acknowledgment

Not applicable.

Funding

This study was supported by Zhejiang Province Medical and Health Technology Plan Project (No. 2025KY1320).

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Mitry D, Charteris DG, Fleck BW, Campbell H, Singh J. The epidemiology of rhegmatogenous retinal detachment: geographical variation and clinical associations. The British Journal of Ophthalmology. 2010; 94: 678–684. https://doi.org/10.1136/bjo.2009.157727.

[2] Xu M, Fan X, Huang X, Chen X, Shao Y, Li X. Steroid Drugs as an Adjunct for Reducing the Incidence of Proliferative Vitreoretinopathy after Rhegmatogenous Retinal Detachment Surgery: A Meta-Analysis of Randomized Controlled Studies. Ophthalmic Research. 2023; 66: 599–610. https://doi.org/10.1159/000529451.

[3] Nagpal M, Chaudhary P, Wachasundar S, Eltayib A, Raihan A. Management of recurrent rhegmatogenous retinal detachment. Indian Journal of Ophthalmology. 2018; 66: 1763–1771. https://doi.org/10.4103/ijo.IJO_1212_18.

[4] Jeon BJ, Lee SJ, Kim KL, Huh EA, Kim JY. Long-term evaluation of the effects of vitreous degeneration on cataracts and retinal detachment in dogs. Veterinary Ophthalmology. 2023; 26: 324–330. https://doi.org/10.1111/vop.13078.

[5] Wang T, Moinuddin O, Abuzaitoun R, Hwang M, Besirli C, Wubben TJ, *et al*. Retinal Detachment After Endophthalmitis: Risk Factors and Outcomes. Clinical Ophthalmology (Auckland, N.Z.). 2021; 15: 1529–1537. https://doi.org/10.2147/OPTH.S302757.

[6] Vila N, Rampakakis E, Rezende F. Endoscopy-assisted vitrectomy outcomes during silicone oil removal after complex retinal detachment repair. Journal of VitreoRetinal Diseases. 2019; 3: 445–451. https://doi.org/10.1177/2474126419861850.

[7] Mwaikambo BR, Sennlaub F, Ong H, Chemtob S, Hardy P. Activation of CD36 inhibits and induces regression of inflammatory corneal neovascularization. Investigative Ophthalmology & Visual Science. 2006; 47: 4356–4364. https://doi.org/10.1167/iovs.05-1656.

[8] Guner ME, Guner MK, Cebeci Z, Kır N. Preoperative and Postoperative Factors Affecting Functional Success in Anatomically Successful Retinal Detachment Surgery. Korean Journal of Ophthalmology: KJO. 2022; 36: 477–485. https://doi.org/10.3341/kjo.2022.0057.

[9] Bemme S, Lauermann P, Striebe NA, Khattab MH, Affeldt J, Callizo J, *et al*. Risk of perioperative bleeding complications in rhegmatogenous retinal detachment surgery: a retrospective single-

center study. Graefe's Archive for Clinical and Experimental Ophthalmology = Albrecht Von Graefes Archiv Fur Klinische Und Experimentelle Ophthalmologie. 2020; 258: 961–969. https://doi.org/10.1007/s00417-019-04554-1.

[10] Clayman HM. Intraocular lenses, axial length, and retinal detachment. American Journal of Ophthalmology. 1982; 93: 807. https://doi.org/10.1016/0002-9394(82)90489-5.

[11] Sim R, Cheung G, Ting D, Wong E, Wong TY, Yeo I, *et al*. Retinal microvascular signs in COVID-19. The British Journal of Ophthalmology. 2022; 106: 1308–1312. https://doi.org/10.1136/bjophthalmol-2020-318236.

[12] Lee JE. Two-step surgery for retinal detachment caused by myopic macular hole. Clinical Ophthalmology (Auckland, N.Z.). 2012; 6: 1771–1774. https://doi.org/10.2147/OPTH.S38358.

[13] Iovino C, Caporossi T, Peiretti E. Vitreoretinal surgery tip and tricks in the era of COVID-19. Graefe's Archive for Clinical and Experimental Ophthalmology = Albrecht Von Graefes Archiv Fur Klinische Und Experimentelle Ophthalmologie. 2020; 258: 2869–2870. https://doi.org/10.1007/s00417-020-04800-x.

[14] Yu G, Li M, Dang G. Combined Rhegmatogenous and Tractional Retinal Detachment in Solitary Retinal Capillary Hemangioma. Ophthalmology. Retina. 2023; 7: 531. https://doi.org/10.1016/j.oret.2023.01.020.

[15] Konstantinidis L, Stappler T, Potic J, Roquelaure D, El Wardani M, Wolfensberger TJ. Characteristics of patients with complete visual acuity recovery after vitrectomy for macula-off retinal detachment. Eye (London, England). 2021; 35: 2834–2839. https://doi.org/10.1038/s41433-020-01322-y.

[16] Jia LY, Sun YX, Zhang YP, Ma K. Risk Factors of Recurrent Retinal Detachment Following Surgical Treatment for Rhegmatogenous Retinal Detachment: A Retrospective Study. Risk Management and Healthcare Policy. 2020; 13: 3165–3171. https://doi.org/10.2147/RMHP.S288777.

[17] Li Y, Cheung N, Jia L, Zhang H, Liu N. SURGICAL OUTCOMES OF 25-GAUGE PARS PLANA VITRECTOMY USING AIR AS AN INTERNAL TAMPONADE FOR PRIMARY RHEGMATOGENOUS RETINAL DETACHMENT. Retina (Philadelphia, Pa.). 2020; 40: 2077–2082. https://doi.org/10.1097/IAE.0000000000002744.

[18] Mellen P, Baumal C. Retinal Detachment Present at Birth in an Infant With a Novel CTNNB1 Mutation. Ophthalmic Surgery, Lasers & Imaging Retina. 2022; 53: 403–405. https://doi.org/10.3928/23258160-20220705-01.

[19] CAMBIAGGI A. MYOPIA AND RETINAL DETACHMENT: STATISTICAL STUDY OF SOME OF THEIR RELATIONSHIPS. American Journal of Ophthalmology. 1964; 58: 642–650.

[20] Taylor K, Su M, Richards Z, Mamawalla M, Rao P, Chang E. Outcomes in Retinal Detachment Repair and Laser Prophylaxis for Syndromes with Optically Empty Vitreous. Ophthalmology. Retina. 2023; 7: 848–856. https://doi.org/10.1016/j.oret.2023.06.012.

[21] Zhou Y, Lu Q, Chen Z, Lu P. A Prediction Nomogram for Recurrent Retinal Detachment. Risk Management and Healthcare Policy. 2023; 16: 479–488. https://doi.org/10.2147/RMHP.S403136.

[22] Casini G, Loiudice P, De Cillà S, Radice P, Nardi M. Sulfur hexafluoride (SF_6) versus perfluoropropane (C_3F_8) tamponade and short term face-down position for macular hole repair: a randomized prospective study. International Journal of Retina and Vitreous. 2016; 2: 10. https://doi.org/10.1186/s40942-016-0036-9.

[23] Siwik P, Chudoba T, Cisiecki S. Retinal Displacement Following Vitrectomy for Rhegmatogenous Retinal Detachment: A Systematic Review of Surgical Techniques, Tamponade Agents, and Outcomes. Journal of Clinical Medicine. 2025; 14: 250. https://doi.org/10.3390/jcm14010250.

[24] Aleshawi A, Al-Dwairi R, Saleh OA, Adi S, Al Beiruti S, Alasheh A, *et al*. Recurrent Rhegmatogenous Retinal Detachment: Characteristics, Risk Factors, and Outcomes. Therapeutics and Clinical Risk Management. 2025; 21: 425–440. https://doi.org/10.2147/TCRM.S506037.