Am J Transl Res 2026;18(4):2826-2845
www.ajtr.org /ISSN:1943-8141/AJTR0170760

Original Article

Nomogram-based risk stratification for postoperative dry eye in diabetic cataract patients and its application in tiered nursing care

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Received December 15, 2025; Accepted February 6, 2026; Epub April 15, 2026; Published April 30, 2026

Abstract: Objective: To identify risk factors for postoperative dry eye in diabetic cataract patients, develop a nomogram prediction model, and establish a tiered nursing intervention protocol. Methods: A retrospective cohort study was conducted involving 678 diabetic patients who underwent phacoemulsification with intraocular lens implantation between January 2024 and January 2025. Patients were divided into a dry eye group (n=132) and a non-dry eye group (n=546). Least absolute shrinkage and selection operator (LASSO) regression and multivariate logistic regression were used to identify independent risk factors. A nomogram was constructed, and patients were stratified into low-, moderate-, and high-risk groups based on tertile cutoffs. Model performance was validated using receiver operating characteristic (ROC) curves, calibration curves, and decision curve analysis. Results: Postoperative dry eye occurred in 19.5% (132/678) of patients. Independent risk factors included: preoperative tear breakup time (odds ratio [OR]=0.715), Schirmer test value (OR=0.868), age ≥65 years (OR=1.975), diabetes duration ≥10 years (OR=8.511), glycated hemoglobin (HbA1c) ≥7% (OR=1.907), diabetic retinopathy (OR=0.090), glaucoma (OR=2.530), corneal comorbidities (OR=4.074), operative time ≥20 minutes (OR=2.327), and preservative-free artificial tear use (OR=0.407). The model demonstrated good discrimination (area under the curve [AUC]=0.877), calibration (Brier score = 0.1035), and clinical utility. Conclusion: The nomogram effectively identifies high-risk patients. Risk stratification combined with tiered nursing enables rational resource allocation and targeted intervention for diabetic cataract patients.

Keywords: Diabetes mellitus, cataract, postoperative dry eye, risk factors, risk stratification, nomogram, nursing intervention

Introduction

Diabetes mellitus (DM) represents one of the most significant global public health burdens, with prevalence continuing to rise and age of onset increasingly younger [1]. According to the latest data from the International Diabetes Federation, global DM prevalence is projected to increase from 10.5% in 2021 to 12.2% by 2045 [2]. Chronic hyperglycemia causes multisystem damage, including metabolic changes in the eye. Diabetic patients develop cataracts earlier and experience faster progression. In patients under 65 years, cataract incidence is 3 to 4 times higher in diabetic individuals compared with the general population, making it a major contributor to visual impairment [3]. Phacoemulsification with intraocular lens (IOL) implantation has become the primary surgical approach to restore vision in this population. However, diabetic patients are more susceptible to postoperative complications, particularly ocular surface damage, tear film dysfunction, and progression of diabetic retinopathy (DR) [4]. Among these, postoperative dry eye has attracted considerable attention due to its high incidence, persistent nature, and significant impact on visual quality.

Previous research suggests that DM itself can reduce tear secretion and impair tear film stability through mechanisms involving neuropathy and lacrimal gland microangiopathy [5]. Dry eye prevalence is significantly higher in diabetic

https://doi.org/10.62347/OOIG4924

patients than in non-diabetic individuals and correlates closely with diabetes duration, glycated hemoglobin (HbA1c) levels, and the severity of peripheral neuropathy [6, 7]. Cataract surgery further disrupts ocular surface homeostasis. Studies indicate that approximately 19.5% of patients without preexisting dry eye develop new-onset dry eye after cataract surgery, placing diabetic patients at even greater risk for symptomatic dry eye postoperatively [8]. Postoperative dry eye not only affects the patient's visual recovery experience but may also delay corneal epithelial healing, predispose patients to infection, and increase healthcare utilization. Therefore, effective perioperative risk assessment and nursing intervention for diabetic cataract patients are essential for improving postoperative ocular surface status and visual quality.

Although mechanisms and interventions for post-cataract dry eye have been extensively studied, most literature focuses on general cataract populations. Relatively few studies specifically address diabetic patients with cataracts [9]. Existing research often examines single factors such as tear break-up time (BUT) or postoperative eye drop use. Comprehensive investigation of the interplay among systemic metabolic factors (e.g., diabetes duration, HbA1c), ocular comorbidities (e.g., DR, glaucoma, corneal disease), preoperative tear function, intraoperative time, and postoperative artificial tear management remains limited in this population [10]. Furthermore, nursing interventions typically follow standardized pathways which lack risk-stratified and precision-based management tools. Such approaches fail to address the clinical heterogeneity of characteristics in diabetic patients. In clinical practice, it remains unclear which diabetic cataract patients are truly at high risk for postoperative dry eye. Quantitative prediction-based tiered nursing pathways are also lacking [11]. Current nursing models often apply uniform follow-up schedules and ocular surface management to all patients, leading to resource waste for low-risk individuals while denying adequate preventive intervention to high-risk patients. Therefore there is a clear need for large-sample, multifactorial analysis to establish a scientific risk identification system that can serve as a foundation for precision nursing of postoperative dry eyes.

Building on these considerations, we integrated patient demographics, diabetes-related indicators, preoperative ocular surface status, surgical parameters, and postoperative nursing behaviors in this study. We employed correlation analysis, least absolute shrinkage and selection operator (LASSO) regression, and multivariate logistic regression to screen and validate key factors influencing postoperative dry eye in diabetic cataract patients. Our aims were to identify major risk factors, construct a practical risk stratification model, and develop targeted nursing protocols. We hope these findings will provide evidence-based guidance for clinical practice and contribute to comprehensive improvement in visual rehabilitation outcomes.

Materials and methods

Sample size calculation

Momin et al. [8] reported that the incidence of tear film dysfunction after cataract surgery in diabetic patients was approximately 19.5%. We therefore assumed a postoperative dry eye incidence (P) of 20% for this study. With a two-sided α of 0.05 and an allowable margin of error (E) of 5%, we calculated the required sample size using the single-proportion estimation formula: $N = Z^2 \times [P \times (1\text{-}P)]/E^2$, where $Z_{0.05/2} = 1.96$. Substituting these values: $N = 1.96^2 \times [0.20 \times (1\text{-}0.20)]/0.05^2 = 3.8416 \times 0.16/0.0025 \approx 246$ cases. Allowing for an approximate 10% dropout rate, the minimum required sample size was 274 patients. We ultimately enrolled 678 patients who completed follow-up, which exceeded this requirement and ensured adequate statistical power.

General information

This was a single-center retrospective cohort study. We collected clinical data from diabetic patients who underwent phacoemulsification with intraocular lens implantation (Phaco + IOL) at the ophthalmology department of our hospital between January 2024 and January 2025. The study was approved by Xi'an People's Hospital (Xi'an Fourth Hospital) Ethics Committee. The requirement for informed consent was waived by the Ethics Committee due to the retrospective nature of the study and the use of de-identified data. The study adhered to the principles of the Declaration of Helsinki [12].

Inclusion and exclusion criteria

Inclusion criteria: (1) Confirmed diagnosis of type 1 or type 2 DM according to the World Health Organization (WHO) 1999 diagnostic criteria [13]; (2) Age ≥18 years; (3) Diagnosis of age-related cataract with surgical indications; (4) Underwent phacoemulsification combined with IOL implantation; (5) Complete follow-up data with a minimum follow-up period of one month; (6) Complete clinical records.

Exclusion criteria: (1) Preoperative diagnosis of dry eye according to the Tear Film & Ocular Surface Society Dry Eye Workshop II (TFOS DEWS II) 2017 criteria [14]; (2) History of prior ocular surgery, including refractive surgery or vitreoretinal surgery; (3) Active ocular infection or inflammatory disease; (4) Severe blepharitis or meibomian gland dysfunction (MGD) grade III or higher; (5) Long-term wearing of contact lens (≥3 months); (6) Severe systemic disease precluding examination or follow-up compliance; (7) Severe intraoperative complications such as posterior capsule rupture with vitreous prolapse requiring vitrectomy; (8) Pregnancy or lactation.

Clinical data collection

Patient information was collected from the hospital's electronic medical record system and outpatient follow-up records. The demographic data included age, sex, and body mass index (BMI). Systemic diseases and medical history encompassed hypertension, coronary artery disease (CAD), chronic renal insufficiency, and smoking status (categorized as current smoker, former smoker, or never smoked). Diabetes-related parameters comprised diabetes mellitus (DM) type (either type 1 or type 2), disease duration, HbA1c level, diabetic nephropathy (DN), and diabetic peripheral neuropathy (DPN). Preoperative ocular status included diabetic retinopathy (DR) grade, glaucoma, corneal comorbidities, high myopia (defined as a refractive error of ≤-6.00 D or an axial length of ≥26 mm), pterygium, preoperative dry eye symptoms (as indicated by an Ocular Surface Disease Index [OSDI] score >12), preoperative tear break-up time (BUT), and preoperative Schirmer test results. Surgery-related factors involved surgical technique (either phacoemulsification or manual small-incision cataract surgery), operative time (measured from skin incision to completion of the procedure), and intraoperative complications (such as posterior capsule rupture, iris prolapse, corneal edema, etc.). Postoperative nursing factors included adherence to artificial tear usage (defined as compliant if used according to physician instructions) and the use of preservative-free artificial tears (PF-AT).

Measurement methods

Laboratory parameters: (1) HbA1c measurement: Fasting venous blood (2 mL) was collected in the morning. High-performance liquid chromatography (HPLC) was performed using the Bio-Rad D-10 Hemoglobin A1c Analyzer (Bio-Rad Laboratories, USA). Reagent kits were purchased from Shanghai Enzyme-linked Biotechnology Co., Ltd. HbA1c ≥7% was defined as poor glycemic control. (2) Fasting glucose and renal function: Fasting glucose, serum creatinine, and blood urea nitrogen were measured using an automated biochemical analyzer (Hitachi 7600 series, Japan) to assist in diagnosing DN.

Ophthalmic examination parameters: BUT was examined using a slit-lamp microscope (Topcon SL-D7, Japan). A fluorescein sodium strip (Tianjin Jingming New Technology Development Co., Ltd.) was gently touched to the lower conjunctival fornix. Patients were instructed to blink three times and then keep their eyes open while looking straight ahead. Time was measured from the last complete blink to the appearance of the first dry spot on the cornea. Three consecutive measurements were averaged, and BUT <10 seconds was considered abnormal. For the Schirmer test (without anesthesia), standard Schirmer test strips (5 mm × 35 mm; Tianjin Jingming New Technology Development Co., Ltd.) were used. The strip was folded 5 mm from one end and placed in the conjunctival fornix at the junction of the middle and outer thirds of the lower eyelid. Patients were instructed to gently close both eyes for 5 minutes, after which the length of tear wetting was recorded. A Schirmer value <10 mm/5 min indicated reduced tear secretion. For DR grading, dilated fundus examination was performed preoperatively. Fundus color photographs were obtained using a non-mydriatic fundus camera (Canon CR-2, Japan). Two experienced retinal specialists graded DR according to the International Clinical Diabetic Retinopathy Severity

Scale: no DR, mild nonproliferative diabetic retinopathy (NPDR), moderate NPDR, severe NPDR, and proliferative diabetic retinopathy (PDR). For this study, DR was dichotomized as "present" or "absent".

DPN diagnosis: Diagnosis followed the Chinese Guidelines for the Prevention and Treatment of Type 2 Diabetes (2024 edition) [15]. Assessment included clinical history (numbness, pain, or sensory abnormalities in the extremities), 10-g monofilament touch sensation testing, 128-Hz tuning fork vibration testing, and ankle reflex examination.

Outcome measures

Primary outcome: Occurrence of dry eye at one month postoperatively. Diagnosis was based on the TFOS DEWS II 2017 consensus criteria, requiring both: (1) dry eye-related symptoms (OSDI score >12); and (2) at least one of the following signs: BUT <10 seconds, Schirmer test <10 mm/5 min, or positive corneal fluorescein staining.

Secondary outcomes: (1) Independent risk factors for postoperative dry eye; (2) Nomogram prediction model performance, including discrimination (AUC), calibration (calibration curve, Brier score, Hosmer-Lemeshow test), and clinical utility (decision curve analysis net benefit); (3) Patient distribution across risk strata based on the risk score model; (4) Differences in postoperative dry eye incidence among low-risk, moderate-risk, and high-risk groups.

Statistical analysis

Data analysis was conducted using R version 4.5.1 and SPSS version 27.0. Continuous variables that were normally distributed were presented as mean ± standard deviation ($\bar{x} \pm s$), while group comparisons were made using independent-sample t-tests. Non-normally distributed continuous variables were reported as median with interquartile range [$M(Q_1, Q_3)$], and group comparisons were performed using the Mann-Whitney U test. Categorical variables were expressed as frequency (percentage) [n(%)], with group comparisons executed through chi-square tests or Fisher's exact test. Spearman correlation analysis was employed to evaluate associations among candidate variables, and a correlation heatmap was generated. Correlation coefficients were interpreted as follows: $|r|<0.3$ indicated weak correlation, $0.3\leq|r|<0.5$ indicated moderate correlation, $0.5\leq|r|<0.7$ indicated strong correlation, and $|r|\geq0.7$ indicated very strong correlation. LASSO regression was utilized for variable selection. Ten-fold cross-validation was applied to determine the optimal penalty parameter λ, with the one standard error (1-SE) rule adopted to select a more parsimonious and robust model. The variance inflation factor (VIF) was calculated for each variable, where VIF<5 indicated no severe multicollinearity. The occurrence of postoperative dry eye (yes =1, no =0) served as the dependent variable. Variables with non-zero coefficients following LASSO selection were included in both univariate and multivariate logistic regression models, and odds ratios (OR) along with 95% confidence intervals (CI) were calculated.

Based on the results of multivariate logistic regression, a nomogram was constructed utilizing the rms package in R software. The regression coefficients were transformed into a weighted scoring system for visualization, facilitating individualized predictions of postoperative dry eye risk. Furthermore, an interactive web-based dynamic nomogram tool was developed using the shiny package; upon entering patient-specific parameters, the system automatically calculates the predicted probability for convenient clinical application. Internal validation was conducted to assess model performance. For discrimination assessment, receiver operating characteristic (ROC) curves were plotted, and the area under the curve (AUC) along with its 95% confidence interval (CI) was calculated; an AUC greater than 0.7 was deemed acceptable, greater than 0.8 good, and greater than 0.9 excellent. For calibration assessment, Bootstrap resampling (B=1000) was employed to generate calibration curves to evaluate the agreement between predicted probabilities and observed outcomes; Brier scores were computed to assess overall prediction accuracy (ranging from 0 to 1, with values closer to 0 indicating better accuracy). Additionally, the Hosmer-Lemeshow goodness-of-fit test was applied, with a *P*-value greater than 0.05 indicating a good model fit without significant deviation. For clinical utility assessment, decision curve analysis (DCA) evaluated net benefit across varying threshold probabili-

ties and compared the model with 'treat-all' and 'treat-none' strategies to determine clinical applicability. A risk score (RiskScore) was constructed using the β-coefficient weighted sum method, and patients were stratified into low-risk, moderate-risk, and high-risk groups according to RiskScore tertiles (33rd and 67th percentiles). The incidence of postoperative dry eye was compared among these groups. All statistical tests were two-sided, with a *P*-value of less than 0.05 considered statistically significant.

Results

Comparison of baseline characteristics

For demographic variables, age was significantly higher in the Dry Eye Group (P=0.013), whereas sex and BMI showed no significant differences between groups (P>0.05). Regarding systemic diseases, the proportion of patients with hypertension was higher in the Dry Eye Group (P=0.051). CAD, chronic renal insufficiency, and smoking history did not differ significantly (P>0.05). Among diabetes-related factors, longer disease duration (P<0.001), higher HbA1c levels (P<0.001), and presence of DPN (P=0.006) were all associated with complication occurrence. DM type and DN showed no significant differences (P>0.05). For preoperative ocular status, significant differences were observed for DR (P<0.001), glaucoma (P=0.038), corneal comorbidities (P=0.002), preoperative dry eye symptoms (P <0.001), preoperative BUT (P<0.001), and Schirmer test values (P=0.001). High myopia and other factors showed no significant differences (P>0.05). Among surgery-related factors, longer operative time was significantly associated with complication occurrence (P<0.001). Surgical technique and intraoperative complications did not differ significantly (P>0.05). For postoperative nursing factors, significant differences were found for artificial tear use compliance (P<0.001) and PF-AT use (P=0.002). Pterygium also showed statistical significance (P=0.026) (**Table 1**).

Correlation analysis results

After uniform variable coding, a correlation matrix was constructed and a heatmap was generated (**Figure 1**; **Table 2**). Overall, correlations were concentrated among diabetes complication and duration-related indicators, as well as between preoperative tear function and symptom measures. Most other variable pairs showed weak or non-significant correlations. The strongest correlation appeared between diabetic complications: DN and DPN demonstrated very strong positive correlation (r=0.803, P<0.001). Strong correlations mainly involved diabetes duration and tear function indicators. DM_Duration showed significant negative correlation with DPN (r=-0.708, P<0.001). Pre_BUT_s and Pre_DES also showed significant negative correlation (r=-0.674, P<0.001). Moderate correlations included: DM_Duration with DN (r=-0.568, P<0.001), with HbA1c (r=0.527, P<0.001), and with DR (r=-0.438, P<0.001). AT_StdUse and AT_PF were positively correlated (r=0.510, P<0.001). Weak correlations were observed between HbA1c and DPN (r=-0.369, P<0.001), DPN and DR (r=0.310, P<0.001), Pre_BUT_s and Pre_Schirmer_mm (r=0.335, P<0.001), and Pre_Schirmer_mm and Pre_DES (r=-0.270, P< 0.001). DN and DR (r=0.249, P<0.001), HbA1c and DN (r=-0.214, P<0.001), and HbA1c and DR (r=-0.206, P<0.001) also showed weak correlations. Beyond these relationships, most correlation coefficients were very weak or near zero. Although some reached statistical significance (e.g., r≈0.10-0.15, P<0.05), the correlation strength was limited and clinical relevance may be minimal. Many variable pairs showed no significant correlation (P>0.05), indicating the absence of a pervasive strong correlation structure.

LASSO regression and multicollinearity analysis results

LASSO regression was used to screen candidate variables. The coefficient path plot showed that as the penalty parameter λ increased, most variable coefficients shrank toward zero. Only a few variables retained non-zero coefficients under stronger penalization (**Figure 2A**). Ten-fold cross-validation was performed. Following the 1-SE rule to select a more parsimonious and robust model, the optimal penalty parameter was λ_1se=0.0203 (**Figure 2B**). At this λ_1se value, 12 variables with non-zero coefficients were retained: Pre_BUT_s, Pre_Schirmer_mm, Age, DM_Duration, HbA1c, DR, Glaucoma, CornealDz, OpTime_ge20, AT_StdUse, AT_PF, and Pterygium (**Table 3**). These findings suggest that these factors have rela-

Table 1. Comparison of general characteristics and perioperative factors

Variable	Total (n=678)	Dry Eye Group (n=132)	Non-Dry Eye Group (n=546)	Statistic	*P* value	95% CI
Age				6.15	0.013	
<65 years	312 (46.0%)	48 (36.4%)	264 (48.4%)			
≥65 years	366 (54.0%)	84 (63.6%)	282 (51.6%)			1.638 (1.107-2.425)
Sex				0.698	0.403	
Male	358 (52.8%)	74 (56.1%)	284 (52.0%)			
Female	320 (47.2%)	58 (43.9%)	262 (48.0%)			0.850 (0.580-1.246)
BMI (kg/m^2)				3.527	0.06	
<25	368 (54.3%)	62 (47.0%)	306 (56.0%)			
≥25	310 (45.7%)	70 (53.0%)	240 (44.0%)			1.440 (0.983-2.108)
Hypertension				3.822	0.051	
Yes	308 (45.4%)	70 (53.0%)	238 (43.6%)			
No	370 (54.6%)	62 (47.0%)	308 (56.4%)			0.684 (0.467-1.002)
CAD				3.416	0.065	
Yes	108 (15.9%)	28 (21.2%)	80 (14.7%)			
No	570 (84.1%)	104 (78.8%)	466 (85.3%)			0.638 (0.395-1.030)
Chronic renal insufficiency				0.627	0.428	
Yes	60 (8.8%)	14 (10.6%)	46 (8.4%)			
No	618 (91.2%)	118 (89.4%)	500 (91.6%)			0.775 (0.413-1.457)
Smoking history				2.866	0.09	
Yes (current/former)	186 (27.4%)	44 (33.3%)	142 (26.0%)			
No	492 (72.6%)	88 (66.7%)	404 (74.0%)			0.703 (0.467-1.059)
DM type				1.204	0.273	
Type 1	38 (5.6%)	10 (7.6%)	28 (5.1%)			
Type 2	640 (94.4%)	122 (92.4%)	518 (94.9%)			0.659 (0.312-1.394)
DM duration				26.278	<0.001	
<10 years	438 (64.6%)	60 (45.5%)	378 (69.2%)			
≥10 years	240 (35.4%)	72 (54.5%)	168 (30.8%)			2.700 (1.832-3.979)
HbA1c				16.494	<0.001	
<7%	460 (67.8%)	70 (53.0%)	390 (71.4%)			
≥7%	218 (32.2%)	62 (47.0%)	156 (28.6%)			2.214 (1.501-3.267)
Diabetic nephropathy				2.776	0.096	
Yes	102 (15.0%)	26 (19.7%)	76 (13.9%)			
No	576 (85.0%)	106 (80.3%)	470 (86.1%)			0.659 (0.403-1.079)
DPN				7.46	0.006	
Yes	146 (21.5%)	40 (30.3%)	106 (19.4%)			
No	532 (78.5%)	92 (69.7%)	440 (80.6%)			0.554 (0.361-0.850)
DR				15.394	<0.001	
No	502 (74.0%)	80 (60.6%)	422 (77.3%)			
Yes	176 (26.0%)	52 (39.4%)	124 (22.7%)			2.212 (1.479-3.308)
Glaucoma				4.29	0.038	
Yes	78 (11.5%)	22 (16.7%)	56 (10.3%)			
No	600 (88.5%)	110 (83.3%)	490 (89.7%)			0.571 (0.335-0.975)
Corneal comorbidities				9.907	0.002	
Yes	42 (6.2%)	16 (12.1%)	26 (4.8%)			
No	636 (93.8%)	116 (87.9%)	520 (95.2%)			0.362 (0.188-0.698)
High myopia				2.559	0.11	
Yes	76 (11.2%)	20 (15.2%)	56 (10.3%)			
No	602 (88.8%)	112 (84.8%)	490 (89.7%)			0.640 (0.369-1.110)
Preoperative dry eye symptoms				32.22	<0.001	
Yes	152 (22.4%)	54 (40.9%)	98 (17.9%)			
No	526 (77.6%)	78 (59.1%)	448 (82.1%)			0.316 (0.210-0.476)
Preoperative BUT (s)	7.93±2.59	6.02±2.06	8.39±2.49	10.082	<0.001	0.014 (0.005-0.037)
Preoperative Schirmer (mm)	12.20 (10.00, 14.50)	10.60 (7.18, 12.30)	12.70 (10.50, 15.00)	7.547	<0.001	0.107 (0.060-0.191)

Phacoemulsification				2.665	0.103	
Yes	620 (91.4%)	116 (87.9%)	504 (92.3%)			
No	58 (8.6%)	16 (12.1%)	42 (7.7%)			1.655 (0.899-3.047)
Operative time ≥20 min				14.016	<0.001	
Yes	162 (23.9%)	48 (36.4%)	114 (20.9%)			
No	516 (76.1%)	84 (63.6%)	432 (79.1%)			0.462 (0.306-0.696)
Intraoperative complications				2.202	0.138	
Yes	26 (3.8%)	8 (6.1%)	18 (3.3%)			
No	652 (96.2%)	124 (93.9%)	528 (96.7%)			0.528 (0.225-1.243)
Compliant artificial tear use				27.382	<0.001	
Yes	510 (75.2%)	76 (57.6%)	434 (79.5%)			
No	168 (24.8%)	56 (42.4%)	112 (20.5%)			2.855 (1.908-4.272)
Preservative-free artificial tears				9.754	0.002	
Yes	380 (56.0%)	58 (43.9%)	322 (59.0%)			
No	298 (44.0%)	74 (56.1%)	224 (41.0%)			1.834 (1.250-2.692)
Pterygium				4.984	0.026	
Yes	51 (7.5%)	16 (12.1%)	35 (6.4%)			
No	627 (92.5%)	116 (87.9%)	511 (93.6%)			0.497 (0.266-0.928)

Note: HbA1c, hemoglobin A1c; DR, diabetic retinopathy; DPN, diabetic peripheral neuropathy; BUT, tear break-up time; CAD, coronary artery disease; DM, diabetes mellitus; BMI, body mass index.

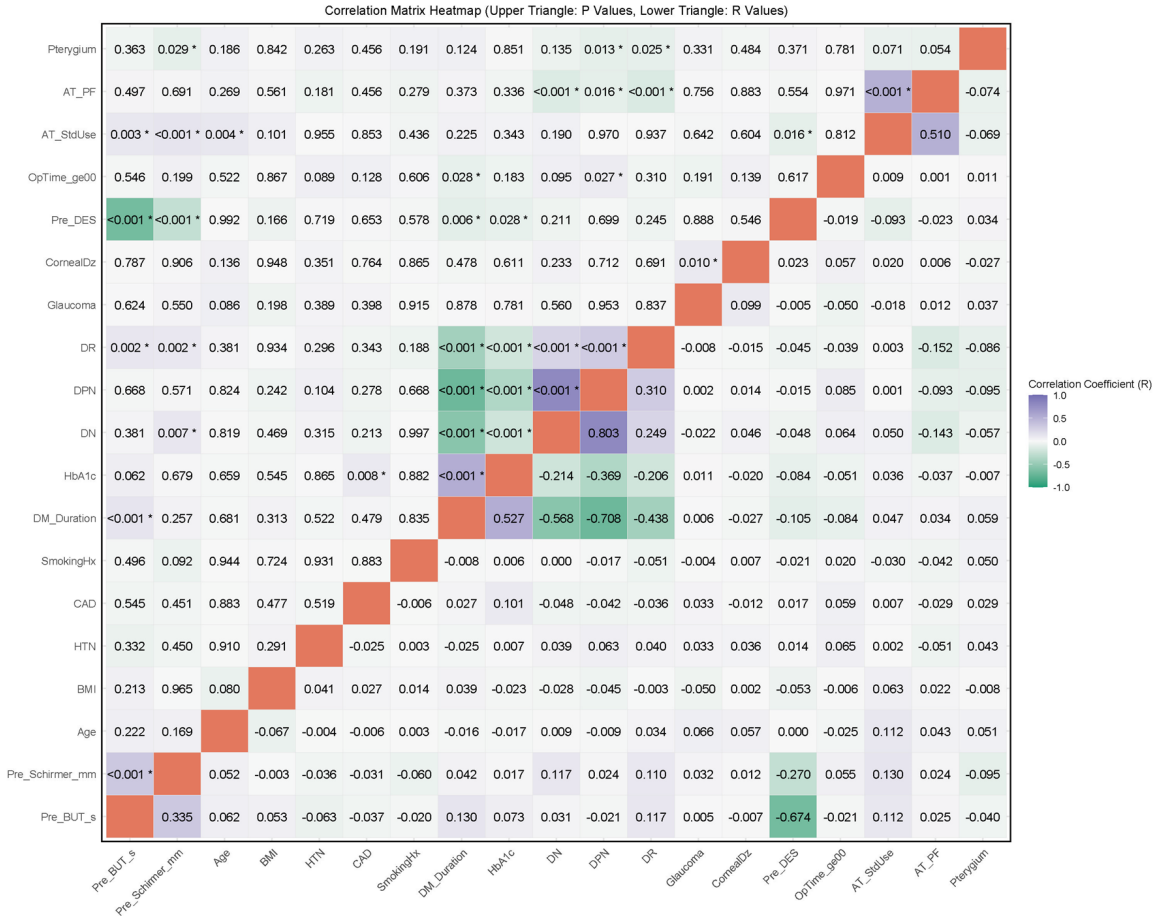

Figure 1. Correlation analysis heatmap. Note: Pre_BUT_s, preoperative tear break-up time; Pre_Schirmer_mm, preoperative Schirmer test; Age, patient age; BMI, body mass index; HTN, hypertension; CAD, coronary artery disease; SmokingHx, smoking history; DM_Duration, diabetes mellitus duration; HbA1c, hemoglobin A1c; DN, diabetic nephropathy; DPN, diabetic peripheral neuropathy; DR, diabetic retinopathy; Glaucoma, glaucoma; CornealDz, corneal disease; Pre_DES, preoperative dry eye symptoms; OpTime_ge20, operative time ≥20 minutes; AT_StdUse, artificial tears standardized use; AT_PF, preservative-free artificial tears; Pterygium, pterygium.

Table 2. Variable coding scheme

Variable	Coding	Variable Type
Preoperative BUT (s)	Original data	Continuous
Preoperative Schirmer (mm)	Original data	Continuous
Age	<65 years =0, ≥65 years =1	Categorical
BMI	<25 =1, ≥25=0	Categorical
Hypertension	Yes =1, No =0	Categorical
CAD	Yes =1, No =0	Categorical
Smoking history	Yes (current/former) =1, No =0	Categorical
DM duration	<10 years =0, ≥10 years =1	Categorical
HbA1c	<7% =0, ≥7% =1	Categorical
Diabetic nephropathy	Yes =1, No =0	Categorical
DPN	Yes =1, No =0	Categorical
DR	Yes =1, No =0	Categorical
Glaucoma	Yes =1, No =0	Categorical
Corneal comorbidities	Yes =1, No =0	Categorical
Preoperative dry eye symptoms	Yes =1, No =0	Categorical
Operative time ≥20 min	Yes =1, No =0	Categorical
Compliant artificial tear use	Yes =1, No =0	Categorical
Preservative-free artificial tears	Yes =1, No =0	Categorical
Pterygium	Yes =1, No =0	Categorical

Note: BUT, tear break-up time; DR, diabetic retinopathy; HbA1c, hemoglobin A1c; DPN, diabetic peripheral neuropathy; CAD, coronary artery disease; DM, diabetes mellitus; BMI, body mass index.

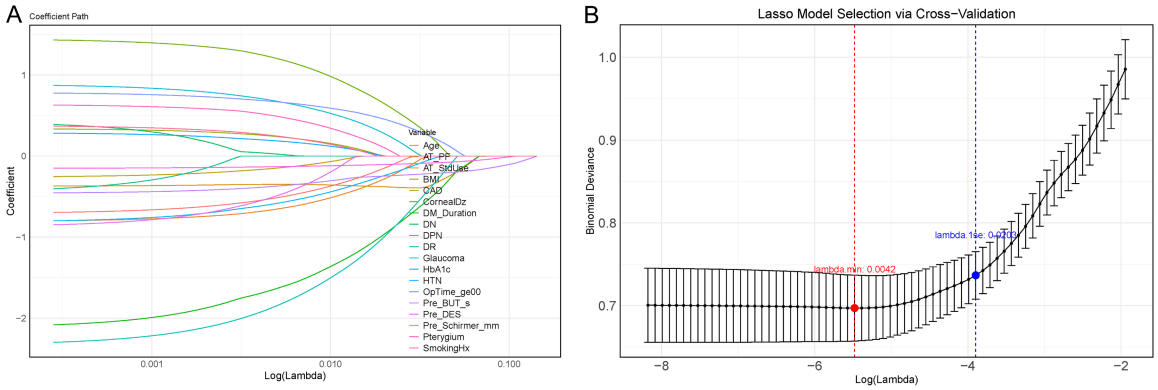

Figure 2. LASSO regression variable selection process. A. Coefficient path plot. B. LASSO cross-validation curve. Note: LASSO, least absolute shrinkage and selection operator; SE, standard error.

tively stable associations with postoperative dry eye occurrence. Multicollinearity testing showed that all candidate variables had VIF values within acceptable ranges (1.030-4.170), with no evidence of severe multicollinearity (**Table 3**). The LASSO selection results therefore demonstrated good stability.

Logistic regression analysis results

Integrating correlation analysis and LASSO (1-SE, λ=0.0203) selection results, and considering that multicollinearity tests were within acceptable ranges, we entered LASSO-retained variables into the multivariate logistic regression model. These included Pre_BUT_s, Pre_Schirmer_mm, Age, DM_Duration, HbA1c, DR, Glaucoma, CornealDz, OpTime_ge20, AT_StdUse, AT_PF, and Pterygium. Univariate logistic regression showed that all 12 variables were significantly associated with postoperative dry eye occurrence (all P<0.05). Multivariate logistic regression confirmed that the following remained independent factors: Pre_BUT_s (OR

Table 3. Multicollinearity (VIF) and LASSO regression selection results

Variable	VIF	Interpretation	Lasso (λ=1se)
Pre_BUT_s	2.248	Low multicollinearity	-0.246
Pre_Schirmer_mm	1.269	Low multicollinearity	-0.104
Age	1.106	Low multicollinearity	-0.144
BMI	1.053	Low multicollinearity	
HTN	1.064	Low multicollinearity	
CAD	1.046	Low multicollinearity	
SmokingHx	1.030	Low multicollinearity	
DM_Duration	4.170	Low multicollinearity	-0.955
HbA1c	1.574	Low multicollinearity	-0.236
DN	3.015	Low multicollinearity	
DPN	3.480	Low multicollinearity	
DR	3.175	Low multicollinearity	-0.983
Glaucoma	1.057	Low multicollinearity	0.272
CornealDz	1.087	Low multicollinearity	0.640
Pre_DES	2.099	Low multicollinearity	
OpTime_ge20	1.071	Low multicollinearity	0.452
AT_StdUse	1.637	Low multicollinearity	-0.379
AT_PF	1.776	Low multicollinearity	-0.277
Pterygium	1.077	Low multicollinearity	0.097

Note: Pre_BUT_s, preoperative tear break-up time; Pre_Schirmer_mm, preoperative Schirmer test; Age, patient age; BMI, body mass index; HTN, hypertension; CAD, coronary artery disease; SmokingHx, smoking history; DM_Duration, diabetes mellitus duration; HbA1c, hemoglobin A1c; DN, diabetic nephropathy; DPN, diabetic peripheral neuropathy; DR, diabetic retinopathy; CornealDz, corneal disease; Pre_DES, preoperative dry eye symptoms; OpTime_ge20, operative time ≥20 minutes; AT_StdUse, artificial tears standardized use; AT_PF, preservative-free artificial tears; VIF, variance inflation factor; LASSO, least absolute shrinkage and selection operator; SE, standard error.

=0.715), Pre_Schirmer_mm (OR=0.868), Age (OR=1.975), DM_Duration (OR=8.511), HbA1c (OR=1.907), DR (OR=0.090), Glaucoma (OR=2.530), CornealDz (OR=4.074), OpTime_ge20 (OR=2.327), and AT_PF (OR=0.407). All associations were statistically significant (P<0.05). AT_StdUse and Pterygium were no longer significant after adjustment (P>0.05) (**Figure 3**).

Distribution of postoperative dry eye risk factors

Visualization of postoperative dry eye risk factors is shown in **Figure 4**. Box plots revealed that preoperative Pre_BUT_s and Pre_Schirmer_mm values were lower in the Dry Eye Group compared with the non-Dry Eye Group. This suggests that patients with poorer preoperative tear film stability and tear secretion function are more prone to postoperative dry eye (**Figure 4A**). Comparison of major risk factor proportions showed higher rates in the Dry Eye Group for diabetes duration above threshold, HbA1c ≥7%, DR, corneal comorbidities, glaucoma, and operative time ≥20 minutes. AT_PF was more common in the non-Dry Eye Group, indicating a protective trend (**Figure 4B**). Within the Dry Eye Group, we further analyzed the distribution of major risk factors (**Figure 4C**). The proportions shown in the ring chart represent the percentage of patients with each risk factor within the Dry Eye Group. This visualization aimed to demonstrate the distribution of risk characteristics rather than variable weights or contributions in the model. Notably, since AT_PF was identified as a protective factor in multivariate regression, the ring chart displays the proportion of patients who did not use preservative-free artificial tears (AT_PF=0). This is clarified in the figure legend to avoid directional misinterpretation.

Construction of the nomogram

Based on the multivariate logistic regression model, a nomogram was constructed to provide individualized prediction of postoperative dry eye in diabetic cataract patients. The final

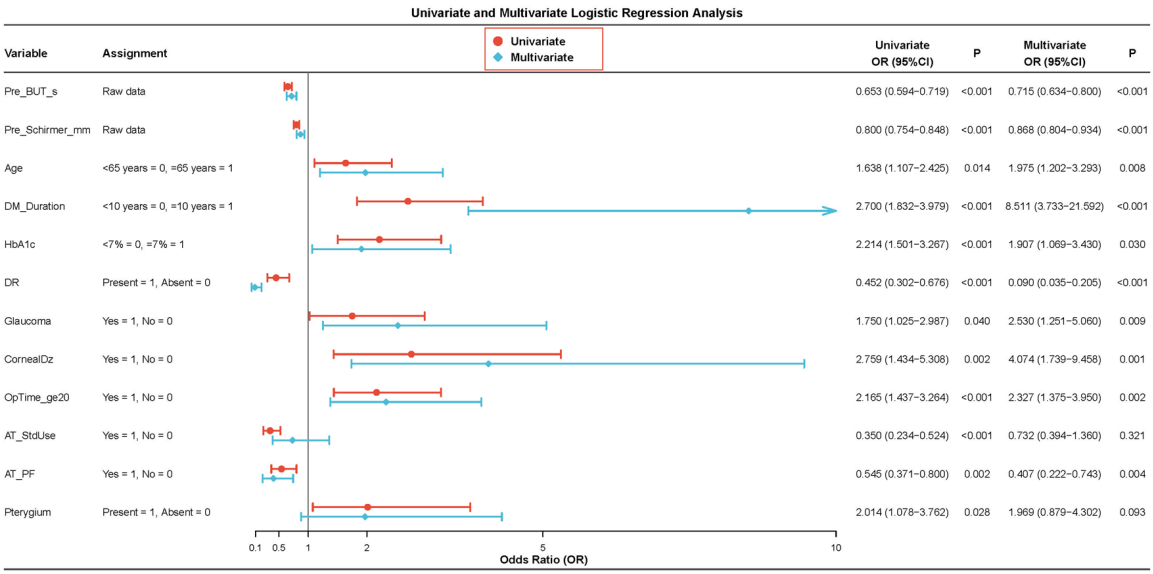

Figure 3. Logistic regression analysis results. Forest plot showing odds ratios and 95% confidence intervals for univariate and multivariate logistic regression analyses. Note: Pre_BUT_s, preoperative tear break-up time; Age, patient age; HTN, hypertension; CAD, coronary artery disease; SmokingHx, smoking history; DM_Duration, diabetes mellitus duration; HbA1c, hemoglobin A1c; DR, diabetic retinopathy; Glaucoma, glaucoma; CornealDz, corneal disease; OpTime_ge20, operative time ≥20 minutes; AT_StdUse, artificial tears standardized use; Pterygium, pterygium.

model incorporated ten independent predictors identified in the regression analysis: Pre_BUT_s, Pre_Schirmer_mm, Age, DM_Duration, HbA1c, DR, Glaucoma, CornealDz, Operative time ≥20 min, and AT_PF. **Figure 5A** shows the static nomogram, in which each variable is assigned a score proportional to its regression coefficient. The total point score corresponds to the predicted risk of postoperative dry eye at the bottom scale. To facilitate clinical implementation, an interactive dynamic nomogram was also developed (**Figure 5B**). This web-based interface automatically calculates the predicted probability after entering patient-specific parameters, allowing rapid estimation of postoperative dry eye risk. The example shown in **Figure 5B** demonstrates a predicted risk of 57.4% for a representative patient. The nomogram therefore provides a user-friendly, quantitative tool for risk stratification prior to cataract surgery. Based on the multivariate logistic regression model, a nomogram was constructed to provide individualized prediction of postoperative dry eye in diabetic cataract patients. The final model incorporated ten independent predictors: Pre_BUT_s (β=-0.335), Pre_Schirmer_mm (β=-0.142), Age ≥65 years (β=0.681), DM_Duration ≥10 years (β=2.141), HbA1c ≥7% (β=0.646), DR (β=-2.408), Glaucoma (β=0.928), CornealDz (β=1.404), Operative time ≥20 min (β=0.845), and AT_PF (β=-0.899). The risk score was calculated as the linear combination of these coefficients, and the predicted probability was derived using the logistic function: P = 1/(1 + e^-RiskScore).

Internal validation of the predictive model

Internal validation demonstrated that the predictive model possessed strong performance in discrimination, calibration, and clinical utility. The ROC curve (**Figure 6A**) showed an AUC of 0.877 with a 95% CI of 0.848-0.906, indicating excellent ability to distinguish between patients who did and did not develop postoperative dry eye. Calibration assessment using a bootstrap-corrected calibration plot (**Figure 6B**) revealed close agreement between predicted and observed probabilities across risk levels. The Brier score was 0.1035, and the Hosmer-Lemeshow test yielded χ^2=8.342 (df=8) with P=0.4008, confirming good model calibration without significant misfit. Decision curve analysis (**Figure 6C**) further demonstrated that the model provided positive net clinical benefit across a wide range of threshold probabilities (0-99%), with a maximum net benefit of 19.77%, outperforming the treat-all and treat-none strategies. Collectively, these results support the robustness, accuracy, and clinical applicability of the predictive model.

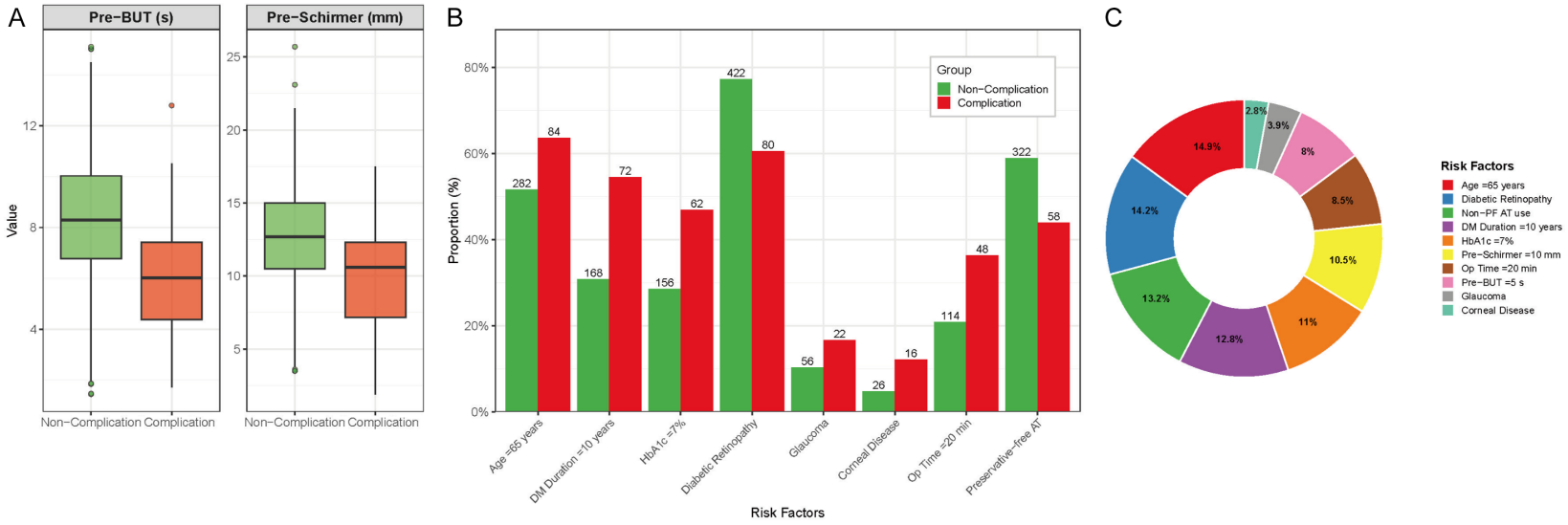

Figure 4. Visualization of postoperative dry eye risk factors. A. Box plot of preoperative tear break-up time and Schirmer test values comparing complication and non-Dry Eye Groups. B. Comparison of major risk factor proportions between groups. C. Ring chart showing risk factor composition within the Dry Eye Group. Note: BUT, tear break-up time; DR, diabetic retinopathy; DM_Duration, diabetes mellitus duration; AT_StdUse, artificial tears standardized use; CornealDz, corneal disease.

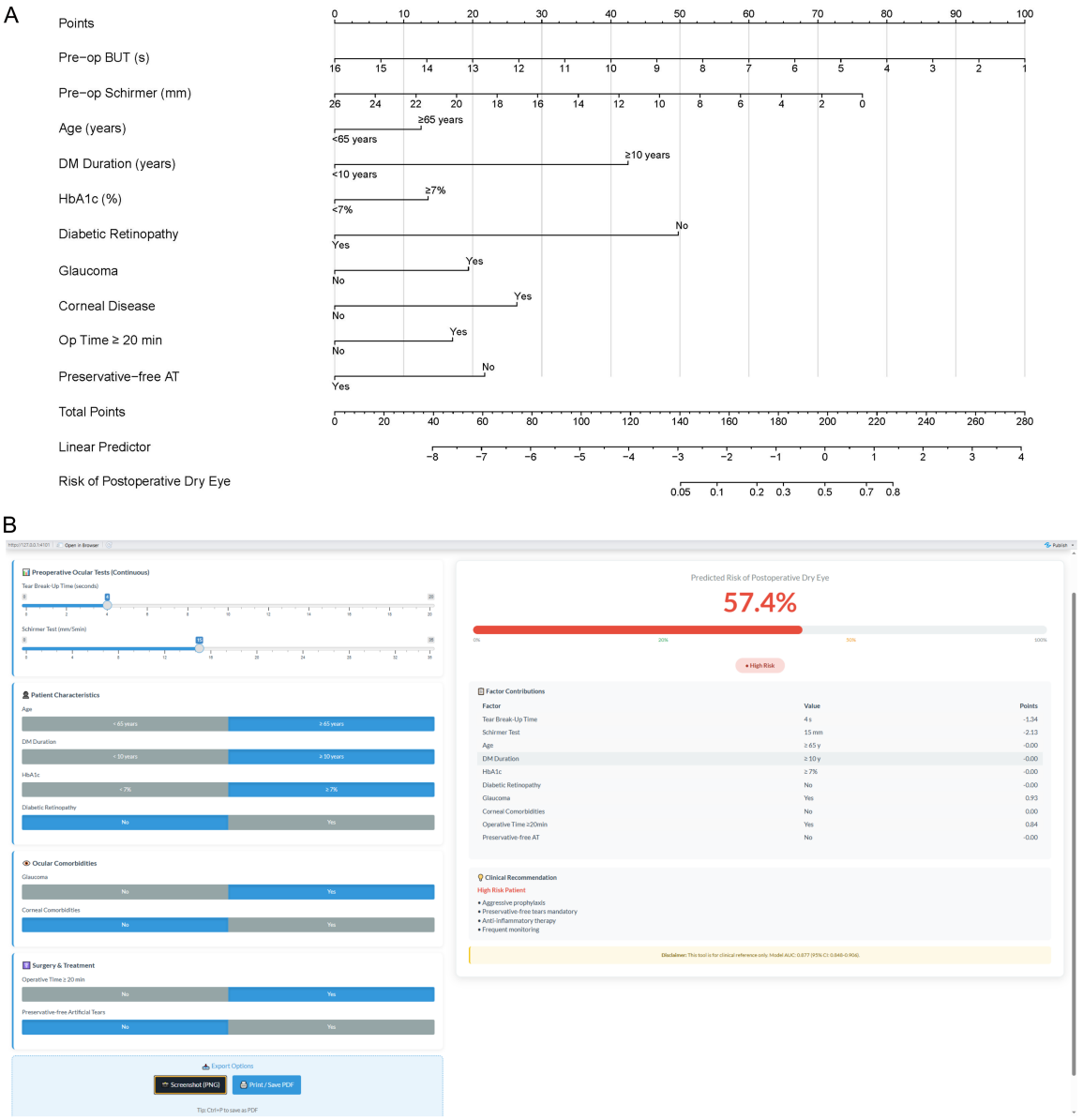

Figure 5. Construction of the predictive nomogram for postoperative dry eye. A. Static nomogram integrating ten independent predictors including preoperative BUT, Schirmer test value, age, diabetes duration, HbA1c level, diabetic retinopathy, glaucoma, corneal disease, operative time ≥20 minutes, and use of preservative-free artificial tears. Each predictor contributes a weighted point value, and the total points correspond to the predicted probability of postoperative dry eye. B. Interactive web-based dynamic nomogram showing individualized prediction results. After entering patient-specific variables, the system automatically calculates the predicted postoperative dry eye risk, illustrated here with an example prediction of 57.4%. Note: BUT, Tear break-up time; HbA1c, glycated hemoglobin; DR, diabetic retinopathy; AT, artificial tears; PF, preservative-free; Op Time, operative time.

Risk stratification analysis results

Based on the multivariate logistic regression results, we constructed a postoperative dry eye risk score model using linear predictors (β-coefficient weighted sum). The model incorporated 10 independent factors: Pre_BUT_s, Pre_Schirmer_mm, Age, DM_Duration, HbA1c, DR, Glaucoma, CornealDz, OpTime_ge20, and AT_PF. Each patient's RiskScore was calculated accordingly. Patients were stratified into three groups based on RiskScore tertile cutoffs (33rd percentile: -9.425; 67th percentile: -7.389). Sample distribution across strata was relatively balanced: low-risk group 224 patients (33.0%), moderate-risk group 230 patients (33.9%),

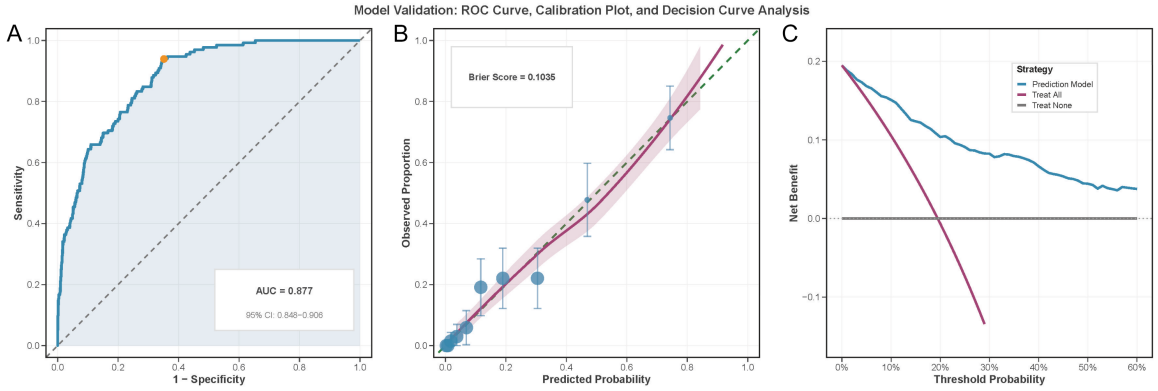

Figure 6. Internal validation of the predictive model. A. Receiver operating characteristic (ROC) curve demonstrating strong discrimination of the predictive model, with an AUC of 0.877 (95% CI: 0.848-0.906). B. Bootstrap-corrected calibration plot showing close agreement between predicted and observed postoperative dry eye probabilities. The Brier score was 0.1035, and the Hosmer-Lemeshow test indicated good calibration (χ^2=8.342, df=8, P=0.4008). C. Decision curve analysis (DCA) showing positive net clinical benefit of the predictive model across threshold probabilities from 0% to 99%, with a maximum net benefit of 19.77%, indicating superior utility compared with treat-all or treat-none strategies. Note: ROC, Receiver operating characteristic; AUC, area under the curve; DCA, decision curve analysis; CI, confidence interval.

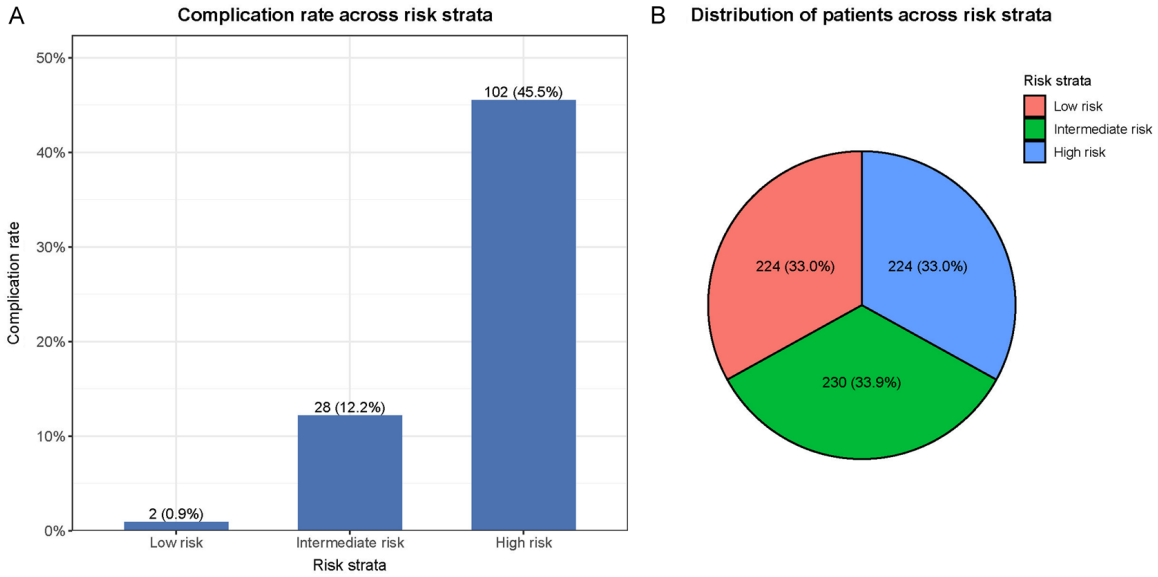

Figure 7. Risk score-based postoperative dry eye risk stratification visualization. A. Bar chart showing complication incidence by risk stratum: low-risk 0.9%, moderate-risk 12.2%, high-risk 45.5%. B. Pie chart showing patient distribution across risk strata: low-risk 33.0% (n=224), moderate-risk 33.9% (n=230), high-risk 33.0% (n=224). Note: Risk strata, risk level; RS, risk score.

and high-risk group 224 patients (33.0%) (**Figure 7B**). Postoperative dry eye incidence showed a significant increasing trend across risk strata. The low-risk group had an incidence of 0.9% (2/224), the moderate-risk group 12.2% (28/230), and the high-risk group 45.5% (102/224) (**Figure 7A**). These findings indicate that the risk stratification model can effectively identify patients at high risk for postoperative dry eye, providing a basis for individualized prevention and follow-up in clinical practice.

Construction of risk stratification-based nursing intervention protocol for postoperative dry eye

Building on the risk stratification model, we developed a tiered nursing intervention proto-

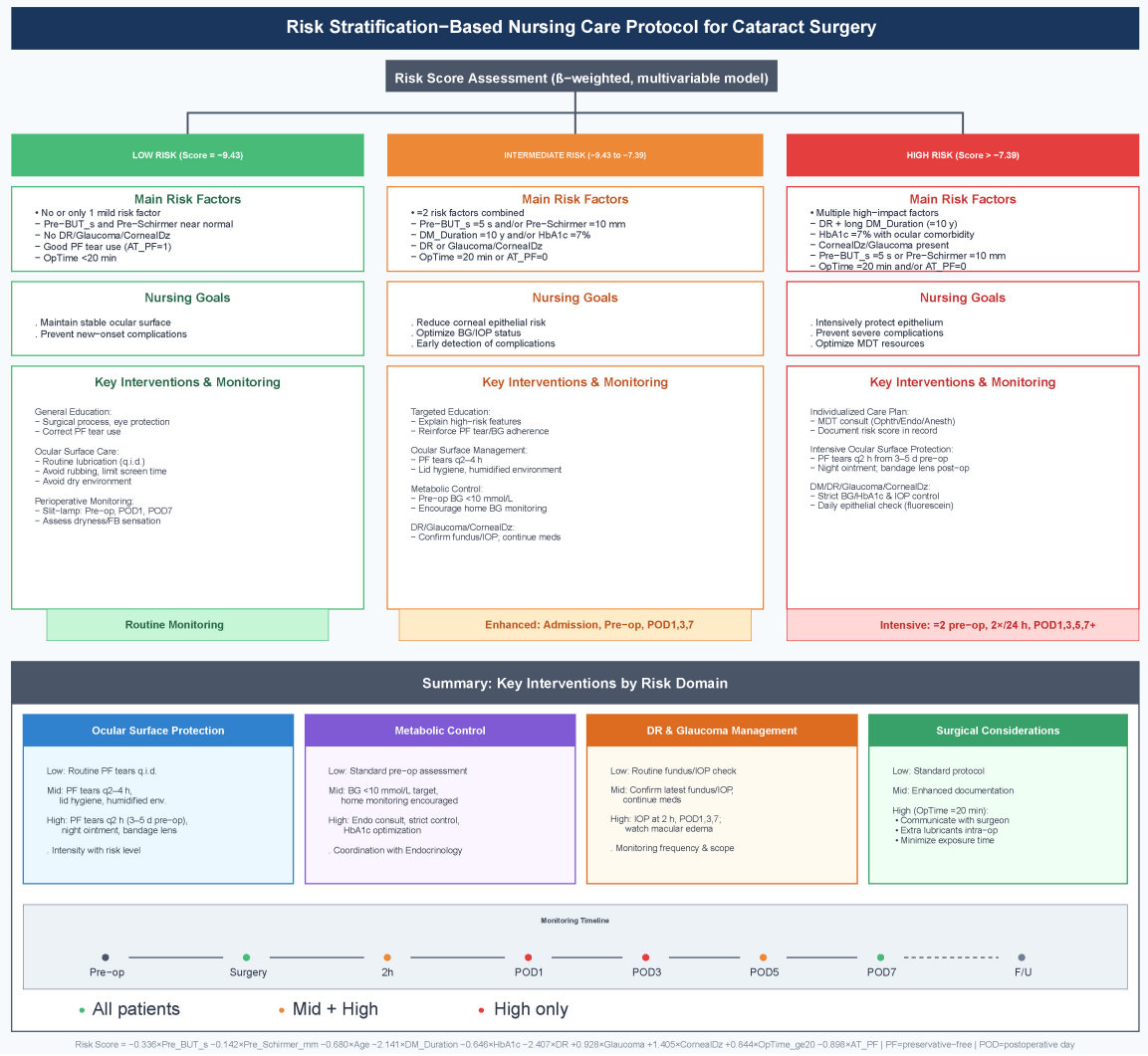

Figure 8. Flowchart of risk stratification-based cataract surgery nursing protocol. This flowchart illustrates the framework for tiered nursing care based on risk scoring. The top section shows the risk score assessment entry point. The middle section displays three risk tiers: low-risk (green), moderate-risk (orange), and high-risk (red). Each tier lists the main risk factors, nursing objectives, and key intervention measures. The bottom section summarizes intervention points organized by nursing domain (ocular surface protection, metabolic control, DR and glaucoma management, and surgery-related considerations) along with a monitoring timeline from preoperative through follow-up phases. Arrows indicate the direction of the nursing workflow, and color intensity reflects increasing intervention intensity. Note: This flowchart was constructed based on 10 independent risk factors identified through multivariate logistic regression. Risk scores were calculated using the β-coefficient weighted method and stratified into three tiers according to tertile cutoffs. The green area represents the low-risk group (routine care), the orange area represents the moderate-risk group (enhanced care), and the red area represents the high-risk group (intensive care). The timeline at the bottom shows key monitoring points from preoperative (Pre-op) through follow-up (F/U) phases. Abbreviations: BUT, tear break-up time; DR, diabetic retinopathy; IOP, intraocular pressure; POD, postoperative day.

col (**Figure 8**; Table S1). This protocol incorporated the 10 independent factors identified by multivariate logistic regression (Pre_BUT_s, Pre_Schirmer_mm, Age, DM_Duration, HbA1c, DR, Glaucoma, CornealDz, OpTime_ge20, and AT_PF). Patients were stratified according to risk score tertile cutoffs into low-risk (RiskScore ≤-9.43), moderate-risk (-9.43 to -7.39), and high-risk (>-7.39) groups. Corresponding nursing objectives and intervention strategies were developed for each tier. The low-risk group received routine nursing care, emphasizing health education and basic ocular surface monitoring. The moderate-risk group received enhanced care on top of routine measures. This includes strengthened preoperative and

postoperative tear film and tear function assessment, guidance on proper use of preservative-free artificial tears, glycemic and metabolic status management, and environmental stimulus control. The high-risk group received refined, individualized nursing care. Interventions included enhanced ocular surface protection and lubrication protocols, multidisciplinary collaborative management involving ophthalmology, endocrinology, and nursing, early postoperative high-frequency monitoring of symptoms and corneal epithelium, one-on-one bedside education with caregiver involvement, and targeted protective measures for patients with prolonged operative time or ocular surface comorbidities. The intervention protocol was organized into four modules by nursing domain: ocular surface protection, metabolic control, DR and glaucoma management, and surgery-related factors. A dynamic monitoring timeline spanning preoperative through follow-up phases ensured continuity and systematization of nursing measures.

Discussion

Postoperative dry eye represents a significant complication affecting visual rehabilitation quality and patient satisfaction in diabetic cataract patients. In this study, we retrospectively analyzed clinical data from 678 diabetic patients who underwent cataract surgery. Using LASSO regression and multivariate logistic regression, we identified 10 independent influencing factors. We then constructed a risk stratification model based on tertile cutoffs and developed a tiered nursing intervention protocol accordingly. These findings provide evidence-based guidance for precision nursing in clinical practice.

Postoperative dry eye incidence and overview of influencing factors

Our study showed that postoperative dry eye occurred in 19.5% (132/678) of diabetic cataract patients one month after surgery. This rate is lower than the 37.4% reported in a systematic review by Miura et al. [16] for the general cataract population. Several factors may explain this discrepancy. Most importantly, our strict exclusion of patients with preoperatively diagnosed dry eye is likely the primary reason for the lower incidence rate. Many previous studies, including the meta-analysis by Miura et al. [16], included patients with subclinical or undiagnosed dry eye at baseline, which would inevitably inflate postoperative dry eye rates. By excluding these patients, our study specifically captured true “new-onset” postoperative dry eye cases. Additionally, differences in diagnostic criteria may also contribute; we applied the TFOS DEWS II criteria requiring concurrent presence of both symptoms and signs [17]. The choice of our follow-up time point (one month) may also play a role, as dry eye incidence is typically higher in the early postoperative period, and by one month, most patients have achieved partial ocular surface recovery [18]. Interestingly, our incidence rate closely matches the 19.5% dry eye prevalence in diabetic populations reported by Pan et al. [19]. This similarity suggests that even diabetic patients without preoperative dry eye diagnosis may already have compromised ocular surface reserve function. Surgical trauma can further tip the balance toward decompensation.

Mechanisms of preoperative tear function and diabetic metabolic factors

We found that preoperative BUT and Schirmer test values independently predicted postoperative dry eye. This finding aligns with previous studies [16, 20]. Poor preoperative tear film stability reflects insufficient ocular surface reserve. When surgical trauma disrupts corneal nerves and ocular surface homeostasis, patients with limited compensatory capacity become more susceptible to postoperative dry eye. Diabetes duration ≥10 years and HbA1c ≥7% emerged as independent risk factors. These findings indicate that poor metabolic control accelerates ocular surface damage progression. A meta-analysis by Kuo et al. [21] confirmed that diabetic patients have significantly reduced tear secretion and impaired tear film stability compared with non-diabetic individuals. Chronic hyperglycemia damages the lacrimal functional unit through multiple mechanisms. On the one hand, hyperglycemic conditions cause lacrimal gland microangiopathy and autonomic neuropathy, reducing both basal and reflex tear secretion. On the other hand, accumulation of advanced glycation end products (AGEs) damages corneal nerve terminal density, further diminishing corneal sensitivity and reflex tear production [22]. Mangoli

et al. [23] reported that 77.35% of diabetic patients with HbA1c ≥6.5% had moderate to severe dry eye, confirming a positive correlation between glycemic control and dry eye severity. DR serves as a marker of microvascular damage. Its presence indicates more severe systemic and ocular involvement. Mansuri et al. [24] demonstrated that dry eye prevalence was significantly higher in DR patients compared with those without DR. Patients with DR often exhibit more pronounced corneal nerve density reduction and tear film dysfunction. This may reflect shared microvascular and neuropathic mechanisms underlying both retinal and ocular surface pathology.

Analysis of ocular comorbidities and surgery-related factors

Glaucoma and corneal comorbidities emerged as independent risk factors in our study. Glaucoma patients often use intraocular pressure-lowering eye drops containing preservatives such as benzalkonium chloride (BAK) for extended periods. BAK exerts significant cytotoxic effects on the ocular surface [25]. Studies have shown that BAK disrupts tear film lipid layer stability, induces conjunctival goblet cell apoptosis, and causes meibomian gland dysfunction. Long-term users may have meibomian gland dropout rates reaching 82% [26]. Patients with corneal comorbidities already have compromised corneal epithelial barrier function. Their healing capacity is reduced, and they show heightened sensitivity to surgical stress. Operative time ≥20 minutes was another important risk factor, consistent with findings by Sahu et al. [20]. Prolonged surgery means extended corneal exposure, greater cumulative ultrasound energy (increased CDE), and more microscope light damage. A meta-analysis by Lu et al. [27] demonstrated that phacoemulsification affects tear film stability and corneal sensitivity through several mechanisms: incision-related corneal nerve injury, free radical generation from ultrasound energy, and inflammatory mediator release. The cornea has the highest nerve terminal density of any tissue in the human body. Even a 2.8 mm clear corneal incision can transect local nerves. Corneal nerve integrity is essential for maintaining normal blink reflex and tear secretion. Full recovery typically requires 3 to 6 months [28].

Protective effect of preservative-free artificial tears

Our study showed that regular use of preservative-free artificial tears protected against postoperative dry eye (OR=0.407). This finding carries important clinical implications. Preservatives such as BAK have direct toxic effects on corneal epithelial cells. They disrupt the tear film lipid layer, provoke ocular surface inflammation, accelerate goblet cell apoptosis, and may impair corneal nerve regeneration [29]. Lee et al. [30] conducted a retrospective cohort study and confirmed that patients using hyaluronic acid-containing preservative-free artificial tears after surgery had significantly lower rates of corneal punctate staining and dry eye symptoms compared with those using preserved formulations. Jensen et al. [31] performed a prospective randomized controlled trial showing that preservative-free treatment regimens (including dexamethasone, nonsteroidal anti-inflammatory drugs, and hyaluronic acid/trehalose artificial tears) were superior to preserved formulations in reducing postoperative ocular surface damage. The benefit was particularly pronounced in patients with preexisting dry eye signs. For diabetic patients, the ocular surface is already in a vulnerable state. The cumulative toxicity from preservatives in multiple eye drops may be even more significant. Regular postoperative use of preservative-free artificial tears is therefore especially important for this population.

Construction and validation of the nomogram prediction model

Based on the multivariate logistic regression results, we constructed a nomogram model incorporating 10 independent predictors, transforming a complex regression equation into an intuitive visual scoring tool for clinicians to rapidly assess postoperative dry eye risk preoperatively. As a graphical prediction tool, nomograms have been widely applied in tumor prognosis and cardiovascular risk assessment, with the advantage of presenting multifactorial model predictions in an intuitive, quantitative manner without complex calculations to obtain individualized risk predictions [32]. We also developed a shiny package-based dynamic interactive web nomogram; after entering patient parameters, the system automatically

calculates predicted probabilities, further enhancing clinical applicability. This study's reporting follows the TRIPOD (Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis) statement requirements [33] to ensure transparency and reproducibility of research results. Internal validation demonstrated that our predictive model had good discrimination, calibration, and clinical utility. ROC curve analysis showed an AUC of 0.877 (95% CI: 0.848-0.906), indicating excellent discriminative ability. Bootstrap-corrected calibration curves showed close agreement between predicted and observed probabilities, with a Brier score of 0.1035 and Hosmer-Lemeshow test P= 0.4008, confirming good calibration without significant deviation. DCA showed positive net clinical benefit across threshold probabilities from 0% to 99%, with maximum net benefit reaching 19.77%, superior to "treat-all" and "treat-none" strategies, indicating good clinical decision support value.

Clinical value of the risk stratification model and tiered nursing strategy

The risk stratification model we constructed demonstrated good performance in distinguishing patients at different risk levels. Postoperative dry eye incidence rates were 0.9%, 12.2%, and 45.5% in the low-risk, moderate-risk, and high-risk groups, respectively. This significant increasing trend was statistically meaningful. The model incorporates 10 variables that are routinely collected in clinical practice. No specialized equipment is required, calculation is straightforward, and rapid risk assessment can be completed during preoperative outpatient visits. Unlike previous studies, our research specifically focused on the diabetic population. We comprehensively included metabolic factors (disease duration, HbA1c, DR), ocular surface factors (preoperative BUT, Schirmer test, glaucoma, corneal disease), surgical factors (operative time), and nursing factors (preservative-free artificial tear use). This approach established a multidimensional risk assessment system. The "precision nursing" concept based on risk stratification breaks from traditional one-size-fits-all nursing models. High-risk patients receive more intensive monitoring and intervention, such as preoperative ocular surface optimization, enhanced intraoperative corneal protection, high-frequency postoperative follow-up, and one-on-one health education. Meanwhile, low-risk patients avoid overtreatment. This approach facilitates optimal allocation of nursing resources [34]. The tiered nursing protocol emphasizes multidisciplinary collaboration among ophthalmology, endocrinology, and nursing. Glycemic management is integrated throughout the perioperative nursing process, reflecting a holistic management philosophy for diabetic patients. However, several challenges may arise during the implementation of this tiered nursing approach. First, regarding nursing resource allocation, high-risk patients require more intensive monitoring and one-on-one education, which may increase nursing workload and staffing demands. Healthcare institutions need to balance resource distribution between high-risk and low-risk patients to ensure efficiency without compromising care quality. Second, patient compliance management remains a concern, particularly for elderly diabetic patients who may have difficulty adhering to complex eye drop regimens or follow-up schedules. Strategies such as simplified instructions, family caregiver involvement, and reminder systems may help improve compliance. Third, effective multidisciplinary collaboration requires clear communication pathways and defined responsibilities among ophthalmologists, endocrinologists, and nursing staff. Establishing standardized referral protocols and regular case conferences can facilitate seamless coordination. Future studies should evaluate these implementation challenges and develop practical solutions to optimize the clinical application of risk-stratified nursing protocols.

Study innovations

This study offers several innovations. First, regarding study population specificity, we systematically investigated multidimensional risk factors for postoperative dry eye in diabetic cataract patients for the first time. This fills a gap in the existing literature. Second, regarding methodological rigor, we employed LASSO regression for variable selection. This approach effectively addressed multicollinearity and improved model robustness and interpretability. Third, regarding practical applicability, we translated the risk model directly into action-

able nursing pathways. The "risk stratification plus precision nursing" management strategy provides differentiated nursing protocols for low-, moderate-, and high-risk groups. This has strong clinical guidance value and potential for broader implementation. Fourth, regarding a comprehensive perspective, we incorporated nursing factors (preservative-free artificial tear use) into our analytical framework. This goes beyond prior studies that focused primarily on clinical factors and provides evidence-based support for nursing interventions.

Study limitations and future research directions

This study presents several limitations. As a single-center retrospective analysis, the sample source was relatively homogeneous, which may introduce selection bias. Therefore, the generalizability of our conclusions should be interpreted with caution. The follow-up duration was limited to one month, preventing us from observing long-term dry eye outcomes or dynamic changes over time. Furthermore, the tiered nursing protocol was developed based on retrospective data and has yet to be validated through prospective intervention studies. Aspects such as nursing compliance, patient satisfaction, and cost-effectiveness analysis require further investigation. Additionally, we did not include newer ocular surface examination parameters, such as meibomian gland morphological assessment using infrared meibography or tear osmolarity testing, which may have resulted in the omission of important information. Future research should explore several directions. Conducting multicenter prospective cohort studies is essential to validate the external validity of the risk model. Extending the follow-up duration to 6 to 12 months will allow for a better understanding of the natural course of dry eye and recovery patterns. Moreover, randomized controlled trials should be designed to evaluate the effectiveness of tiered nursing interventions. Incorporating advanced detection technologies, including meibomian gland imaging, tear osmolarity measurement, and corneal confocal microscopy, will enhance the assessment system [35]. Lastly, exploring artificial intelligence-assisted risk prediction systems could improve clinical application efficiency. Health economics evaluations should also be performed to inform healthcare resource allocation decisions.

Conclusion

In summary, postoperative dry eye in diabetic cataract patients is closely associated with multiple factors. These include preoperative tear function (BUT, Schirmer test), diabetes-related factors (disease duration, HbA1c, DR), ocular comorbidities (glaucoma, corneal disease), surgical factors (operative time), and nursing factors (preservative-free artificial tear use). The nomogram model constructed from β-coefficient weighted scoring demonstrated good predictive performance upon internal validation and can effectively identify high-risk individuals. Postoperative dry eye incidence showed a significant stepwise increase across low-, moderate-, and high-risk groups. A management strategy that combines risk stratification with precision nursing facilitates rational allocation of nursing resources. High-risk patients receive targeted, intensive interventions. This approach provides evidence-based nursing guidance for improving postoperative ocular surface health and visual rehabilitation quality in diabetic cataract patients.

Disclosure of conflict of interest

None.

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Table S1. Risk stratification-based nursing intervention summary

Risk factor	Risk definition (cut-off)	Low-risk: routine care	Intermediate-risk: enhanced care	High-risk: intensive care
Pre_BUT_s (short tear break-up time)	Pre_BUT_s ≤5 s	Routine ocular surface assessment once per shift; standard education on eye protection and tear use	Tear-film evaluation at admission/pre-op/POD1; reinforce PF tear use; avoid air-conditioning, strong light, dust	Individualized lubrication plan (higher PF tear frequency); warm compress/lid hygiene as ordered; close symptom monitoring q4-6h early post-op
Pre_Schirmer_mm (low tear secretion)	Pre_Schirmer_mm ≤10 mm	Routine Schirmer/BUT follow-up if symptomatic	Pre- and postoperative tear-secretion monitoring; reinforce hydration and PF tear adherence	Intensified tear-supplement regimen, consider gel/ointment at night; daily epithelial assessment early post-op
Age (elderly patients)	Age ≥65 years	Assess self-care ability; written + verbal instructions	Simplified materials, repeat-back teaching, family involvement; fall-risk assessment	One-to-one bedside education; assisted instillation; comprehensive safety management
DM_Duration (long disease course)	DM duration ≥10 years	Basic diabetes education; routine fasting BG checks	Coordinate endocrine plan; capillary BG checks before meals/bedtime	MDT management; strict perioperative glucose control; rapid response to abnormal BG
HbA1c (poor glycemic control)	HbA1c ≥7%	Routine pre-op metabolic review	Target BG <10 mmol/L pre-op; reinforce self-monitoring	Endocrine consult; intensive HbA1c/BG optimization before surgery; tighter peri-op monitoring
DR (diabetic retinopathy)	DR = 1	Confirm latest fundus results; routine visual assessment	Explain DR-related surgical risk; observe visual complaints	Daily early post-op visual checks; timely ophthalmology contact for deterioration; psychological support
Glaucoma	Glaucoma = 1	Confirm meds and adherence	Teach drop sequence/spacing; observe for IOP-related symptoms	Strict IOP monitoring schedule; coordinate regimen adjustment; emergency response for acute IOP rise
CornealDz (pre-existing corneal disease)	CornealDz = 1	Ask corneal history; avoid mechanical irritation	Pre-op corneal protection consult; protective shield use	Strict ocular surface protection; more frequent slit-lamp checks; early recognition of PED/infection
OpTime_ge20 (prolonged operation time)	Operation time ≥20 min	Standard intra-op cooperation	Ensure adequate lubrication intra-op; post-op corneal staining check	Pre-op briefing with surgeon; enhanced pain/photophobia monitoring first 24h; targeted surface care
AT_PF (non-PF artificial tears)	Not using PF artificial tears post-op (AT_PF = 0)	Standard tear education	Reinforce PF tear advantage and adherence	PF tears q2h early post-op; check adherence at each contact; solve barriers (cost/technique/cognition)

Note: Pre_BUT_s, preoperative tear break-up time; Pre_Schirmer_mm, preoperative Schirmer test; DM_Duration, diabetes duration; DR, diabetic retinopathy; HbA1c, hemoglobin A1c; CornealDz, corneal disease; OpTime_ge20, operation time ≥20 min; AT_PF, preservative-free artificial tears; POD, postoperative day. Nursing intensity is step-up across strata.