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A novel nomogram prediction model for postoperative atrial fibrillation in patients undergoing laparotomy

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Abstract

Background Postoperative atrial fibrillation (POAF) is an ordinary complication of surgery, particularly cardiac surgery. It significantly increases in-hospital mortality and costs. This study aimed to establish a nomogram prediction model for POAF in patients undergoing laparotomy. The model is expected to identify individuals at a high risk of POAF before surgery in clinical practice.

Methods A retrospective observational case–control study involving 230 adult patients (60 patients with POAF, 120 patients in the control group, and 50 patients in the validation group) who underwent laparotomy was retrieved from two hospitals. Independent risk variables for POAF were investigated using logistic regression and the least absolute shrinkage and selection operator (LASSO) regression analysis. Subsequently, a nomogram model for POAF was constructed by multivariate logistic regression equations. The prediction model was internally validated by bootstrap method and externally validated with the validation group data. To assess the discriminative ability of the nomogram model, a receiver operating characteristic (ROC) curve was generated and a calibration curve was employed to assess the concentricity between the model's probability curve and the ideal curve. Subsequently, decision curve analysis (DCA) was performed to assess the clinical effectiveness of the model.

Results C-reactive protein (CRP), lymphocyte-to-monocyte ratio(LMR), blood urea nitrogen (BUN), and Macruz index were independent risk variables for POAF in patients who underwent laparotomy. A user-friendly and efficient prediction nomogram was visualized using R software. This nomogram exhibited strong discrimination, as evidenced by an area under the ROC curve (AUC) of 0.90 (95% CI 0.8509–0.9488) for the training set, 0.86 (95% CI 0.7142–1) for the test set, and 0.9792 (95% CI 0.9293–1) for the validation group data. The C-index of the bootstrap nomogram model was 0.8998. Furthermore, DCA revealed that this model displayed excellent fit and calibration, as well as positive net benefits.

Conclusions A nomogram prediction model was constructed for POAF in patients who underwent abdominal surgery. The nomogram prediction model is expected to identify individuals at high risk of POAF in clinical practice for prophylactic therapeutic intervention prior to surgery.

Keywords Postoperative atrial fibrillation, Abdominal surgery, Risk factors, Nomogram

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Introduction

Atrial fibrillation (AF) is a prevalent type of arrhythmia in clinical practice. It can significantly increase the risks of heart failure, stroke, cognitive dysfunction, and dementia. These disorders can significantly decrease patients' quality of life (Chung et al. 2020; Andrade et al. 2014; Madhavan et al. 2018). The incidence of AF increases with age, with a 1.5- to 1.9-fold higher risk of death than in those without it. This may be due to the combined effects of thromboembolic events, heart failure, and other complications (Du et al. 2021; Benjamin et al. 1998).

Surgical procedures usually increase the risk of AF. Postoperative atrial fibrillation (POAF) is characterized as new-onset AF in patients without a history of AF that occurs within the initial four weeks after surgery. Nevertheless, there is a lack of consensus regarding the precise definition of POAF. POAF is a major complication after cardiovascular and thoracic surgery, with an incidence of up to 40–50% after valve replacement surgery; approximately 30% after aortic surgery, total lung resection, and lung transplantation; approximately 20% after coronary artery bypass grafting; and a lower incidence of 0.4–15% after non-cardiac and non-thoracic surgery (Dobrev et al. 2019; Polanczyk et al. 1998; Batra et al. 2001; Christians et al. 2001; Walsh et al. 2007; Sohn et al. 2009; Bhave et al. 2012; Siontis et al. 2022; Hyun et al. 2021). In a retrospective study from the National Inpatient Sample database, 294,112 patients developed POAF after non-cardiac procedures between 2010 and 2015. Patients who underwent colorectal surgery were found to have the highest risk of developing POAF (Prince-Wright et al. 2022). In clinical practice, it has been observed that patients undergoing laparotomy are prone to comorbidities, such as gastrointestinal bleeding, infection, and bowel obstruction, as well as prolonged periods of water fasting prior to surgery, making them a high-risk group for POAF in patients undergoing non-cardiac surgery.

POAF typically develops within the first four days after surgery and is usually self-limiting. However, its occurrence may affect the hemodynamic stability after surgery, leading to an increased incidence of hypotension, heart failure, and thrombotic events. These events increase postoperative length of stay, hospital costs, and mortality (Bhave et al. 2012; Maesen et al. 2012). Meanwhile, patients with POAF have a significantly higher risk of paroxysmal AF in the years following surgery (Maesen et al. 2012). If POAF persistently fails to convert to sinus rhythm, anticoagulant medication is necessary to prevent thrombotic events. However, in patients who undergo laparotomy, especially in the elderly, anticoagulants may increase the incidence of postoperative gastrointestinal hemorrhage, which in turn may prolong postoperative hospitalization, increase hospital costs, and lead to mortality.

According to the recommendations of the 2020 European Society of Cardiology (ESC) Guidelines for the Diagnosis and Management of AF, β-blockers serve as the cornerstone of prophylaxis against POAF in patients who have undergone cardiac procedures (Class of Recommendation I, Level of Evidence A) (Hindricks et al. 2020). Furthermore, various randomized controlled trials have confirmed the efficacy of drugs such as amiodarone and sotalol in preventing POAF (Mitchell et al. 2005; Burgess et al. 2006). However, the routine prophylactic administration of β-blockers in non-cardiac surgery has been linked to an elevated risk of serious postoperative complications (Class of Recommendation III, Level of Evidence B). Early identification of patients at a high risk of AF before surgery and administration of heart rate control medications, if appropriate, can effectively prevent the incidence of POAF. This approach avoids the adverse events of hypotension and bradycardia associated with routine prophylactic use of β-blockers.

This study aimed to establish a nomogram prediction model for POAF risk in patients who underwent laparotomy by collecting clinical characteristics, surgical information, blood test data, and electrocardiogram data.

Materials and methods

Patients and study design

This retrospective study reviewed the data of 2675 patients admitted to the Surgical Inpatient Unit of the 904th Hospital of Joint Logistics Support Force from June 2017 to June 2023, based on electronic case records using the ICD-10 case coding system. Eligible patients were over 18 years old, underwent laparotomy under general anesthesia, and did not receive preoperative medications affecting heart rate or rhythm. Exclusion criteria included the following: (1) preoperative history of paroxysmal or persistent AF; (2) history of valvular heart disease, rheumatic heart disease, or heart valve surgery; (3) history of hyperthyroidism; and (4) preoperative electrocardiograms confirmed AF rhythm.

Following the exclusion of 341 patients, the remaining 2234 were categorized based on intraoperative and postoperative electrocardiographically confirmed AF rhythms. The POAF group consisted of 60 patients who experienced paroxysmal or persistent AF for the first time during the intraoperative and 4-week postoperative periods. A control group of 120 patients without POAF was matched at a 1:2 ratio, randomly selected from the 2174 patients without POAF using a random number table (Fig. 1).

Patients who were consecutively registered in the surgical inpatient department of Hefei Third People's Hospital

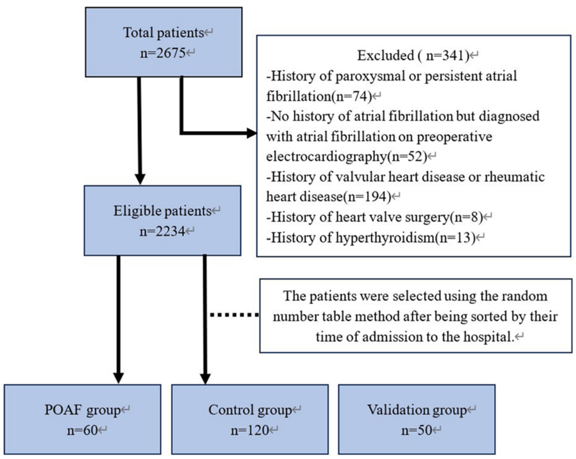

Fig. 1 Study flow chart and patient demographics based on the flow chart. Abbreviation: POAF, postoperative atrial fibrillation

and underwent laparotomy between September 2023 and December 2023 were selected as the validation group, with the same inclusion and exclusion criteria as the two groups of enrolled patients mentioned above.

Basic patient information, disease progression status, surgical details, laboratory test results, and in-hospital electrocardiogram images were extracted from the electronic medical record system and were provided anonymously. The reasonableness of patient enrolment was verified by two independent investigators who were blinded to the study's purpose.

Data collection

Data from 48 variables were collected in this study, including electrocardiogram (ECG), preoperative laboratory tests, and clinical data. The clinical parameters included body mass index (BMI), age, gender, and comorbidities such as obstructive sleep apnea syndrome (OSAS), hypertension, diabetes mellitus, stroke, coronary heart disease (CHD), fever, intestinal obstruction, and sepsis, as defined by the Sepsis 3 Consensus Guidelines (Singer et al. 2016). Additional clinical variables included daily fluid intake, presentation for emergency surgery, type of surgery, type of pathology, and the American Society of Anesthesiologists (ASA) Class. Notably, variables such as fever, sepsis, intestinal obstruction, and daily fluid intake were collected prior to the occurrence of the clinical endpoints. Preoperative laboratory tests were collected within one week prior to surgery, measuring the following parameters: (1) hematological parameters, including white blood cell(WBC) count, hemoglobin, platelet count, neutrophil count, lymphocyte count, monocyte count, and hematocrit value; (2) electrolytes, including Levels of sodium (Na), chloride (Cl), potassium (K), calcium (Ca), phosphorus (P), and magnesium (Mg); (3) renal function and serum proteins, including serum creatinine, blood urea nitrogen (BUN), albumin, prealbumin levels, N-terminal pro-brain natriuretic peptide (NT-pro BNP), and D-dimer; (4) immune-inflammatory markers, including C-reactive protein (CRP), neutrophil-to-lymphocyte ratio (NLR), lymphocyte-to-monocyte ratio (LMR), platelet-to-lymphocyte ratio (PLR), systemic inflammatory response index (SIRI = neutrophil count × monocyte count/lymphocyte count), systemic immunoinflammatory index (SII = neutrophil count × platelet count/lymphocyte count), and systemic inflammation score (SIS). Preoperative ECG parameters included P-wave duration, P-wave amplitude, QRS wave duration, PR interval, Macruz index, and left ventricular hypertrophy (LVH).

Electrocardiograms (ECG)

Electronic ECG images within one week before surgery were obtained from the electronic medical record system, and two independent investigators who were blinded to the purpose of the study measured the ECG data with MedEx ECG Work software. The PR interval was defined as the longest interval between the onsets of the P- and Q-waves in each of the 12 leads. The P-wave duration was characterized by the broadest P-wave span from its onset to its offset, whereas the QRS duration was determined as the longest interval measured from the onset of the Q-wave to the J-point. The P-wave amplitude was determined by the separation between the highest and lowest points of the P-wave in lead II. The distance between the offset of the P-wave and the onset of the Q-wave in lead II represents the PR segment, and the ratio of the P-wave duration to the PR segment duration in lead II represents the Macruz index. LVH was considered to be present if the combined amplitude of the S-wave in lead V1 and the R-wave in leads V5 or V6 was equal to or exceeded 35 mm (Sokolow-Lyon index). In cases where discrepancies greater than 5 ms for interval measurements and 0.5 mm for amplitude measurements arose between the two investigators, resolution was achieved through mutual consensus.

Construction and validation of the nomogram prediction model

Differences in the variables were compared between the POAF and control groups. Univariate and multivariate logistic regression analyses were performed to identify independent variables of POAF in patients undergoing laparotomy. The variables were tested for multicollinearity and screened by the least absolute shrinkage and selection operator (LASSO) regression analysis. The data for each variable in the above groups were divided into training set (85%) and test set (15%). Multivariate logistic regression equations were constructed based on the independent variables identified by the LASSO regression analysis and the training set data. The model was visualized as a nomogram and comprehensively evaluated by receiver operating characteristic (ROC) curves, calibration curves, and clinical decision curves. External validation was performed using data from the validation group.

Statistical analysis

R software (www.r-project.org, version 4.2.1) was applied for statistical analysis. The normality of continuous variables was assessed by the Kolmogorov–Smirnov test. Normally distributed variables were presented as mean ± standard deviation (SD); otherwise, they were presented as median (25th and 75th quartiles). For normally distributed variables, Student's *t*-test or one-way analysis of variance was used to investigate statistical differences in continuous variables; for non-normally distributed variables, the Mann–Whitney *U*-test was utilized. Categorical variables were presented as frequencies with percentages. Fisher's exact test or chi-square test was used to assess the proportions. The variance inflation factor (VIF) was used to test for multicollinearity in the variables, and VIF > 10 was considered to be suggestive of multicollinearity. The independent variables of POAF were identified by LASSO regression analysis with glmnet package of R software. Multivariable logistic regression analysis was performed to construct the regression model. ROC curves, calibration curves, and clinical decision curves were performed by rmda package of R software. All tests were two-tailed, and differences with P-value < 0.05 were considered to be statistically significant.

Results

Patient characteristics

As illustrated in Tables 1 and 3, the mean age of the patients enrolled in the three groups exceeded 65 years. No statistically significant differences ($P > 0.05$) were observed between the POAF and control groups regarding gender, age, BMI, comorbidities (including hypertension, diabetes mellitus, stroke, CHD, and OSAS), daily fluid intake, presentation for emergency surgery, surgical type (stratified into 16 categories based on the affected organ and surgical procedure; detailed results of this analysis are presented in the supplementary file), type of pathology, laboratory test variables (such as platelet count and phosphorus levels), and ECG variables (including P-wave amplitude, QRS wave duration, and LVH).

Screening for independent risk factors of POAF by logistic regression analysis

Univariate logistic regression analysis demonstrated that fever, sepsis, intestinal obstruction, ASA Class (II/III), blood cell count (WBC, neutrophil, lymphocyte, monocyte, and hemoglobin), hematocrit value, electrolytes (Na, K, Ca, and Mg), serum creatinine, BUN, albumin, prealbumin, CRP, NT-pro BNP, D-dimer, NLR, LMR, PLR, SIRI, SII, SIS, P-wave duration, PR interval, and Macruz index were variables that showed statistically significant differences between the two groups ($P < 0.05$, Table 2). The results of the multicollinearity analysis indicated that there was multicollinearity among the following variables: neutrophil count, lymphocyte count, monocyte count, hemoglobin, hematocrit value, NLR, PLR, SIRI, and SII, as their VIF > 10. In addition, multicollinearity of variables was visualized by the corrplot package of R software (Fig. 2). Subsequently, variables with statistical significance in the univariate regression analysis and VIF < 10 were subjected to multivariate regression analysis, which revealed that BUN, CRP, P-wave duration, and PR interval were independent risk factors for POAF in patients who underwent laparotomy ($P < 0.05$, Table 2).

Candidate variables for model selected by LASSO regression analysis

Forty-eight candidate variables obtained preoperatively were screened for candidate predictors by LASSO regression analysis, excluding variable covariates. With the gradual contraction of the penalty parameter λ, the number of candidate variables for the model was 18 when the value of λ with the minimum error in the tenfold cross-validation was selected as the optimal value of the model. When the value of λ within 1 × the standard error of the minimum value was chosen as the optimal value of the model, the number of candidate variables for the model was seven (Fig. 3A, B). The aim of clinical predictive modeling is to keep the model variables as simple as possible while ensuring the predictive validity of the model. Therefore, we chose seven candidate variables (CRP, NT-pro BNP, LMR, Ca, albumin, BUN, and the Macruz index) as candidate variables for the prediction model.

Construction and validation of the nomogram prediction model

The general information of the validation group and the training set is presented in Table 3. Based on the training set data, a logistic regression model with seven

Table 1 Basic clinical characteristics of the POAF group and the control group

Variables	Total ($n=180$)	Control group ($n=120$)	POAF group ($n=60$)	P value [b]
Gender, n (%)				0.868
Female	63 (35)	41 (34)	22 (37)	
Male	117 (65)	79 (66)	38 (63)	
Age (years)	66 (58, 74)	65 (56.75, 72.25)	68 (59.5, 77.25)	0.117
BMI (kg/m^2)	23.69 ± 2.68	23.75 ± 2.87	23.57 ± 2.26	0.641[a]
Hypertension, n (%)	87 (48)	60 (50)	27 (45)	0.635
Diabetes mellitus, n (%)	34 (19)	19 (16)	15 (25)	0.201
Stroke, n (%)	39 (22)	22 (18)	17 (28)	0.179
CHD, n (%)	32 (18)	18 (15)	14 (23)	0.241
OSAS, n (%)	48 (27)	32 (27)	16 (27)	1
Fever, n (%)	57 (32)	26 (22)	31 (52)	< 0.001
Intestinal obstruction, n (%)	50 (28)	27 (22)	23 (38)	0.039
Sepsis, n (%)	26 (14.44)	8 (6.67)	18 (30)	< 0.001
Daily fluid intake (l)	2 (1.68, 2.52)	1.98 (1.65, 2.52)	2.15 (1.77, 2.51)	0.348
Emergency surgery, n (%)	26 (14.44)	13 (10.83)	13 (21.67)	0.051
Type of surgery, n (%)				0.102
Laparoscopic	86 (48)	63 (52)	23 (38)	
Open	94 (52)	57 (48)	37 (62)	
ASA Class, n (%)				0.003
I	65 (36)	52 (43)	13 (22)	
II	73 (41)	47 (39)	26 (43)	
III	36 (20)	16 (13)	20 (33)	
IV	6 (3)	5 (4)	1 (2)	
Pathology, n (%)				
Malignant	98 (81.67)	61 (50.83)	37 (61.67)	0.169
WBC count (10^9/l)	6.82 (5.65, 9.29)	6.36 (5.2, 8.25)	8.57 (6.64, 10.09)	< 0.001
Neutrophil count (10^9/l)	4.53 (3.51, 7.06)	4.09 (3.06, 5.49)	6.13 (4.47, 8.36)	< 0.001
Lymphocyte count (10^9/l)	1.45 ± 0.55	1.56 ± 0.56	1.21 ± 0.42	< 0.001[a]
Monocyte count (10^9/l)	0.54 (0.39, 0.72)	0.5 (0.35, 0.62)	0.68 (0.53, 0.8)	< 0.001
Hemoglobin (g/l)	128.5 (113.75, 142)	133 (119.75, 144)	118.5 (104.5, 132.5)	< 0.001
Hematocrit value	0.37 ± 0.06	0.38 ± 0.05	0.35 ± 0.06	< 0.001[a]
Platelet count (10^9/l)	201.26 ± 70.85	205.32 ± 72.82	193.15 ± 66.59	0.265[a]
Na (mmol/l)	141.6 (138.67, 143)	141.85 (139.6, 143.43)	139.75 (138.17, 142.83)	0.008
Cl (mmol/l)	103.1 (101.05, 105.3)	103.7 (101.92, 105.45)	102.05 (99.6, 103.65)	< 0.001
K (mmol/l)	3.84 ± 0.4	3.9 ± 0.37	3.74 ± 0.44	0.017[a]
Ca (mmol/l)	2.16 (2.04, 2.25)	2.19 (2.11, 2.26)	2.06 (1.95, 2.16)	< 0.001
P (mmol/l)	1.03 (0.92, 1.13)	1.02 (0.92, 1.15)	1.03 (0.92, 1.13)	0.975
Mg (mmol/l)	0.86 (0.8, 0.92)	0.88 (0.82, 0.93)	0.84 (0.78, 0.88)	0.003
Albumin (g/l)	36.77 ± 4.84	38.09 ± 4.44	34.14 ± 4.56	< 0.001[a]
Prealbumin (g/l)	210.22 ± 61.97	216.94 ± 65.73	196.78 ± 51.59	0.026[a]
Serum creatinine (μmol/l)	74 (63, 85.25)	71.5 (62, 82.25)	76.5 (67.75, 88.5)	0.013
BUN (mmol/l)	5.88 (4.59, 7.13)	5.23 (4.36, 6.63)	6.84 (5.88, 8.37)	< 0.001
CRP (mg/l)	11.1 (3.77, 24.12)	6.14 (1.78, 16.74)	20.22 (11.73, 40.96)	< 0.001
NT-pro BNP (pg/ml)	437.3 (184.25, 968.75)	319 (158.25, 744.75)	855 (449.65, 1945.75)	< 0.001
D-dimer (mg/l)	0.68 (0.32, 1.29)	0.51 (0.26, 1.06)	1.14 (0.66, 2.06)	< 0.001
NLR	3.41 (2.15, 5.79)	2.68 (1.9, 4.53)	5.47 (3.51, 7.88)	< 0.001
LMR	2.86 (1.66, 4.05)	3.26 (2.28, 4.38)	1.6 (1.25, 2.85)	< 0.001
PLR	136.64 (104.16, 188.15)	130.74 (97.96, 171.14)	148.75 (117.8, 197.99)	0.015
SIRI	1.84 (0.94, 3.98)	1.15 (0.75, 2.36)	3.66 (1.96, 6.4)	< 0.001

Table 1 (continued)

Variables	Total (*n* = 180)	Control group (*n* = 120)	POAF group (*n* = 60)	*P* value [b]
SII	610.92 (390.15, 1139.89)	526.44 (335.37, 855.02)	922.65 (581.37, 1461.23)	< 0.001
SIS, *n* (%)				< 0.001
0	18 (10)	16 (13)	2 (3)	
1	47 (26)	41 (34)	6 (10)	
2	115 (64)	63 (52)	52 (87)	
P-wave duration (ms)	90 (80, 95)	87 (80, 92)	90 (86, 100)	< 0.001
P-wave amplitude (mv)	1.5 (1.2, 2)	1.5 (1, 2)	1.6 (1.5, 2)	0.082
PR interval (ms)	160 (150, 167)	160 (150, 177)	150 (144.25, 160)	< 0.001
Macruz index	1.25 (1, 1.5)	1.12 (0.99, 1.31)	1.46 (1.29, 1.67)	< 0.001
QRS wave duration (ms)	85 (79, 90)	86 (80, 90)	84 (78.75, 88.5)	0.577
LVH, *n* (%)	29 (16)	17 (14)	12 (20)	0.43

Values are presented as mean ± SD, number (%), or median (interquartile range)

[a] Unpaired Student's *t*-test

[b] Mann–Whitney *U*-test and chi-square test

Abbreviations: BMI body mass index, *CHD* coronary heart disease, *OSAS* obstructive sleep apnea syndrome, *ASA* American Society of Anesthesiologists, WBC white blood cell, *BUN* blood urea nitrogen *CRP* C-reactive protein, *NT-pro BNP* N-terminal pro-brain natriuretic peptide, *NLR* neutrophil-to-lymphocyte ratio, *LMR* lymphocyte-to-monocyte ratio, *PLR* platelet-to-lymphocyte ratio, *SIRI* systemic inflammatory response index, *SII* systemic immunoinflammatory index, *SIS* systemic inflammation score, *LVH* left ventricular hypertrophy

candidate variables was initially constructed. However, three variables (NT-pro BNP, Ca, and albumin) were excluded according to the Wald test ($P > 0.05$) (Table 4). The remaining four variables were CRP, LMR, BUN, and the Macruz index. Based on the outcomes of both univariate and multivariate logistic regression analyses, these four variables were chosen as the basis for constructing the logistic regression model, and all variables were tested by the Wald test ($P < 0.05$) (Table 5). The standardized regression coefficient of the Macruz index was the largest, indicating that it had the greatest influence on the dependent variable, i.e., the risk of POAF.

Based on the results of the regression model, a nomogram was generated using the rms package in the R software (Fig. 3C). The total score was calculated as the sum of the four index scores, with each index corresponding to a score on the upper-point line. To estimate the probability of POAF in patients who underwent laparotomy, the whole score was projected on the bottom scales.

The nomogram model's capacity for discrimination was evaluated by ROC curve analysis after computing each patient's total score with the nomogram prediction model. The area under the ROC curve (AUC) was 0.90 (95% CI 0.8509–0.9488) for the training set and 0.86 (95% CI 0.7142–1) for the test set, which indicates that the nomogram model has good discriminative ability (Fig. 4A, B). The nomogram model was externally validated using the data of the validation group with an AUC of 0.9792 (95% CI 0.9293–1), which was higher than the AUC values of the training and test sets, suggesting that the model had sufficient generalizability (Fig. 4C, D).

The Hosmer–Lemeshow test indicated that there was no statistically significant deviation between the predicted values of the nomogram model and the actual observed values ($\chi^2 = 1.1496$, df = 8, $P = 0.9971$). This suggests that the predictive probabilities of the nomogram model were well-aligned with the actual probabilities. To validate the nomogram model, an internal bootstrap validation was conducted using 1000 sampling repetitions. The C-index of the bootstrap nomogram model was 0.8998, indicating a discrimination ability that was comparable to that of the initial nomogram model. Furthermore, the calibration curve from the internal bootstrap validation illustrated a mean absolute error of 0.022, signifying a high level of agreement between the calibration and ideal curves (Fig. 4E).

The decision curve analysis (DCA) of the nomogram model is depicted in Fig. 4F. It was observed that within the predicted risk range of 0.01–0.9 for POAF in laparotomy patients, implementing preventive measures based on this model yielded significantly higher net benefits compared to the scenario where no treatment was administered (Fig. 4F). Notably, the nomogram model exhibited the most substantial benefit when the predicted risk of POAF in laparotomy patients fell within the range of 0.01 to 0.9.

Discussion

The pathogenesis of AF is complex and several factors may increase the susceptibility to AF, including increasing age, cardiovascular disease, non-cardiovascular diseases (hyperthyroidism, OSAS, chronic obstructive

Table 2 The risk factors of POAF explored by univariate and multivariate logistic regression analysis

	Univariate analysis					**Multivariable analysis**		
	***P* value**	**OR**		**95% CI**	***P* value**		**OR**	**95% CI**
Fever	< 0.001	3.86	1.98	7.53				
Intestinal obstruction	0.027	2.14	1.09	4.20				
Sepsis	< 0.001	6.00	2.43	14.83				
ASA Class II	0.044	2.21	1.02	4.80				
ASA Class III	< 0.001	5.00	2.04	12.24				
WBC count	0.001	1.21	1.08	1.36	0.027	172.31	1.81	16,367.02
Neutrophil count	< 0.001	1.27	1.12	1.43	0.009	0.00	0.00	0.19
Lymphocyte count	< 0.001	0.24	0.12	0.49				
Monocyte count	< 0.001	17.34	4.16	72.22				
Hemoglobin	< 0.001	0.97	0.96	0.99				
Hematocrit value	< 0.001	0.00	0.00	0.01				
Na	0.013	0.88	0.79	0.97				
K	0.012	0.35	0.15	0.79				
Ca	< 0.001	0.02	0.00	0.14				
Mg	0.018	0.02	0.00	0.52				
Albumin	< 0.001	0.82	0.76	0.89				
Prealbumin	0.041	0.99	0.99	1.00	0.042	1.02	1.00	1.05
Serum creatinine	0.015	1.02	1.00	1.03				
BUN	< 0.001	1.54	1.28	1.85	0.006	2.64	1.32	5.28
CRP	< 0.001	1.04	1.02	1.06	0.006	1.07	1.02	1.13
NT-pro BNP	< 0.001	1.00	1.00	1.00				
D-dimer	0.018	1.43	1.06	1.92				
NLR	< 0.001	1.24	1.11	1.38				
LMR	< 0.001	0.44	0.32	0.59				
PLR	0.03	1.00	1.00	1.01				
SIRI	< 0.001	1.34	1.17	1.52				
SII	< 0.001	1.00	1.00	1.00				
SIS 2	0.015	6.60	1.45	30.04				
P-wave duration	0.002	1.06	1.02	1.10	0.003	1.45	1.13	1.85
PR interval	< 0.001	0.96	0.93	0.98	0.001	0.77	0.65	0.90
Macruz index	< 0.001	14.40	4.90	42.36				

pulmonary disease, autoimmune diseases, neoplasms, etc.), unhealthy lifestyle (overweight/obesity, alcohol consumption, tobacco use, excessive/inadequate physical activity, etc.), surgery, and serious medical conditions such as severe infections (Du et al. 2017). Whether cardiac or non-cardiac surgery, the known risk factors associated with POAF include age, gender, comorbidities, and degree of trauma (Hakala and Hedman 2003; Gaudino et al. 2023). Currently, studies related to POAF have focused on patients who underwent cardiac surgery, and fewer studies have been conducted on the risk of POAF in patients who underwent laparotomy.

Madsen et al. reported a prospective, single-center cohort study of patients who underwent emergency abdominal surgery and found that age, previous AF, heart failure, hypertension, diabetes mellitus, chronic kidney disease, and major surgery were risk factors of POAF (Madsen et al. 2023). Patients aged over 60 years with a

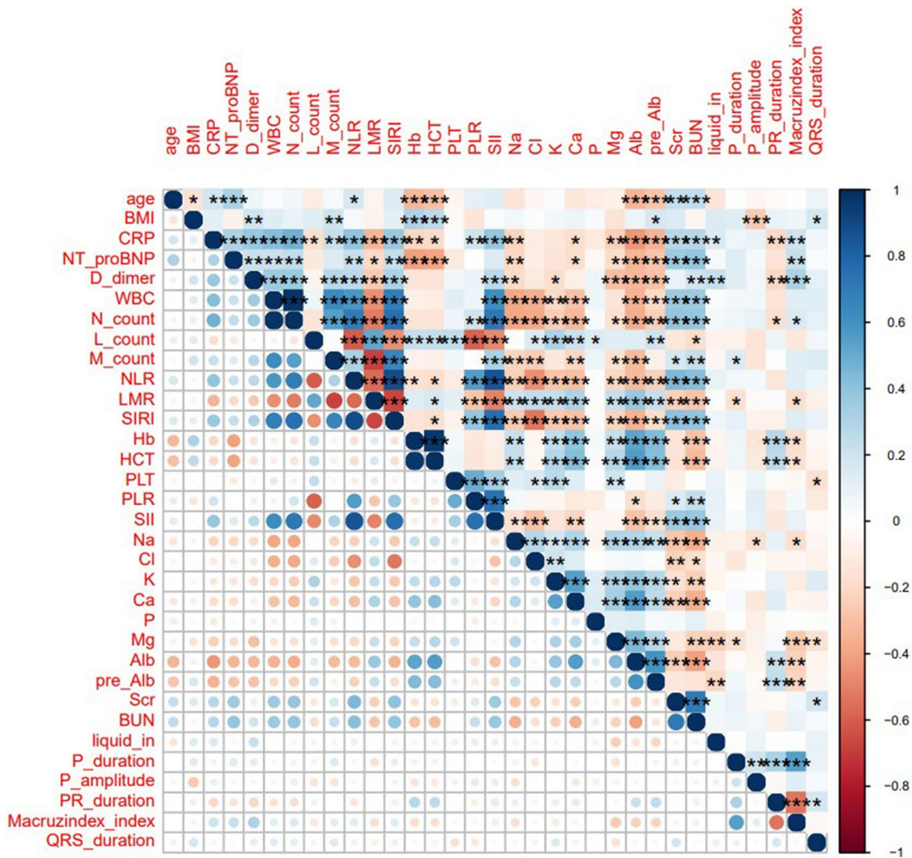

Fig. 2 Correlation heatmap of variables between the POAF group and control group. *$P<0.05$; **$P<0.01$; ***$P<0.001$; ****$P<0.0001$

history of atrial fibrillation were more prone to develop POAF after emergency abdominal surgery, and the overall incidence of POAF in the study was 4.9% (22/450) (Madsen et al. 2023). The overall incidence of POAF in this study was 2.24% (60/2675), which was slightly lower than the incidence in the above study. One possible reason is that this prospective study did not exclude patients with a history of AF. Some risks of POAF may be related to the recurrence of paroxysmal AF, which may not be related to emergency laparotomy. Another possible reason is that patients who undergo emergency abdominal surgery are more susceptible to POAF due to the combination of severe trauma and comorbidities such as uncorrected acid–base and electrolyte imbalances.

Inflammation plays a pivotal role in the pathogenesis of POAF. Bruins et al. found that patients who underwent cardiopulmonary bypass surgery had significantly elevated levels of interleukin 6, CRP, and complement-CRP complexes in the postoperative period and that peak concentrations of inflammatory markers coincided with the peak incidence of POAF, suggesting a correlation between them (Bruins et al. 1997). Olesen et al. demonstrated a dose-dependent correlation between postoperative serum CRP levels and the risk of POAF in patients who underwent coronary artery bypass graft surgery (Olesen et al. 2020). The efficacy of anti-inflammatory interventions, such as corticosteroids and colchicine, in mitigating the risk of POAF underscores the significant impact of inflammation on the onset and progression of this cardiac arrhythmia (Ho and Tan 2009; Imazio et al. 2011). In our study, both logistic regression analysis and LASSO regression analysis identified CRP as an independent predictor of POAF in patients who underwent abdominal surgery. This finding aligns with previous research on POAF in cardiac surgery.

The activation of immune cells and molecules contributes to the pathological process of AF (Liu et al. 2018). Studies have confirmed the involvement of immune cells, including macrophages, neutrophils, lymphocytes, and monocytes, in the development of AF (Liu et al. 2018). Surgical procedures can stimulate immune response and cause changes in the proportion of immune cells. Currently, no study has reported an intrinsic link between the development of POAF and LMR in patients who underwent abdominal surgery. In our study, univariate logistic regression analysis and LASSO regression analysis

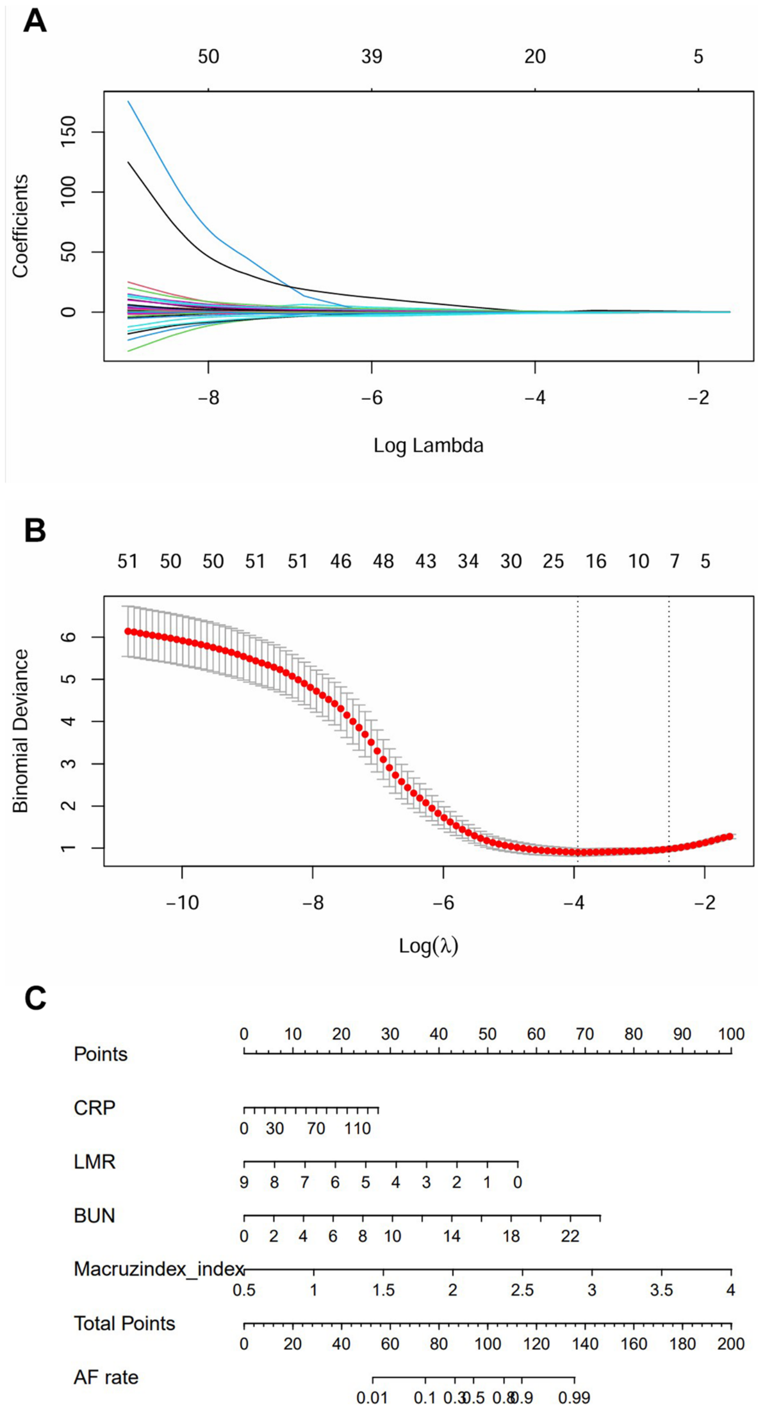

Fig. 3 LASSO regression model. **A** LASSO coefficient profiles of the 51 features. Each curve represents a coefficient, and the *X*-axis represents the regularization penalty parameter. As λ changes, a coefficient that becomes non-zero enters the LASSO regression model. **B** Cross-validation to select the optimal tuning parameter (λ). The left dotted vertical line represents the value of λ that gives a minimum mean absolute error, and the right dotted vertical line represents the largest value of λ that error was within 1 × standard error of the minimum. **C** The nomogram model for predicting the risk of POAF in patients who underwent laparotomy

Table 3 Basic clinical characteristics of the training set and the validation group

Variables	Training set (*n* = 153)	Validation group (*n* = 50)	*P* value [b]
Gender, *n* (%)			0.391
Female	55 (36)	14 (28)	
Male	98 (64)	36 (72)	
Age (years)	66 (57, 74)	66.5 (58, 72.75)	0.606
BMI (kg/m^2)	23.53 (21.8, 25.48)	23.88 (22.86, 24.64)	0.405
Hypertension, *n* (%)	71 (46)	24 (48)	0.974
Diabetes mellitus, *n* (%)	29 (19)	9 (18)	1
Stroke, *n* (%)	33 (22)	9 (18)	0.734
CHD, *n* (%)	28 (18)	11 (22)	0.712
OSAS, *n* (%)	40 (26)	12 (24)	0.909
Fever, *n* (%)	52 (34)	9 (18)	0.05
Intestinal obstruction, *n* (%)	45 (29)	8 (16)	0.091
Sepsis, *n* (%)	24 (16)	4 (8)	0.258
Daily fluid intake (l)	2.03 (1.7, 2.53)	1.94 (1.8, 2.18)	0.27
Emergency surgery, *n* (%)	24 (16)	5 (10)	0.444
Type of surgery, *n* (%)			0.207
Laparoscopic	71 (46)	29 (58)	
Open	82 (54)	21 (42)	
ASA Class, *n* (%)			0.399
I	56 (37)	20 (40)	
II	61 (40)	16 (32)	
III	31 (20)	14 (28)	
IV	5 (3)	0 (0)	
Pathology, *n* (%)			1
Malignant	88 (58)	29 (58)	
WBC count (10^9/l)	7.03 (5.79, 9.42)	7.4 (6.48, 8.56)	0.426
Neutrophil count (10^9/l)	4.74 (3.77, 7.24)	5.12 (4.22, 6.26)	0.313
Lymphocyte count (10^9/l)	1.42 (1.08, 1.78)	1.29 (1.12, 1.55)	0.194
Monocyte count (10^9/l)	0.55 (0.41, 0.74)	0.64 (0.5, 0.74)	0.093
Hemoglobin (g/l)	129 (114, 142)	129.5 (116.25, 138)	0.802
Hematocrit value	0.37 ± 0.06	0.37 ± 0.04	0.365[a]
Platelet count (10^9/l)	200.93 ± 71.29	203.88 ± 59.89	0.774[a]
Na (mmol/l)	141.6 (138.6, 142.9)	140.75 (138.52, 142.38)	0.094
Cl (mmol/l)	103.1 (101.2, 105.3)	101.4 (99.05, 103.12)	< 0.001
K (mmol/l)	3.85 ± 0.41	3.77 ± 0.31	0.121[a]
Ca (mmol/l)	2.15 (2.04, 2.25)	2.13 (1.97, 2.23)	0.241
P (mmol/l)	1.02 (0.92, 1.12)	1.04 (0.96, 1.16)	0.1
Mg (mmol/l)	0.86 (0.8, 0.93)	0.86 (0.83, 0.9)	0.915
Albumin (g/l)	36.65 ± 4.8	37.82 ± 3.27	0.055[a]
Prealbumin (g/l)	208.4 ± 62.12	233.08 ± 45.69	0.003[a]
Serum creatinine (μmol/l)	74 (63, 85)	75 (68, 85)	0.314
BUN (mmol/l)	5.88 (4.66, 7.11)	6.35 (5.26, 7.47)	0.088
CRP (mg/l)	12.19 (4.2, 26.74)	7.63 (6.32, 10.17)	0.103
NT-pro BNP (pg/ml)	450 (179, 1043)	271 (109.75, 631.75)	0.006
D-dimer (mg/l)	0.7 (0.33, 1.44)	0.58 (0.47, 0.92)	0.663
NLR	3.49 (2.23, 6.22)	4.1 (3.17, 5.15)	0.112
LMR	2.67 (1.59, 3.92)	1.9 (1.5, 2.93)	0.032
PLR	136.67 (99.5, 190.91)	153.75 (126.65, 193.13)	0.118
SIRI	1.98 (0.98, 4.27)	2.69 (1.8, 3.45)	0.056

Table 3 (continued)

Variables	Training set ($n = 153$)	Validation group ($n = 50$)	*P* value [b]
SII	654.26 (410.79, 1155.7)	821.53 (603.32, 1071.31)	0.091
SIS, *n* (%)			1
0	13 (8)	4 (8)	
1	39 (25)	12 (24)	
2	101 (66)	34 (68)	
P-wave duration (ms)	88 (80, 94)	84 (80, 87.5)	< 0.001
P-wave amplitude (mv)	1.5 (1.2, 2)	1.8 (1.5, 2)	0.073
PR interval (ms)	160 (150, 165)	160 (160, 170)	0.073
Macruz index	1.25 (1, 1.5)	1.07 (0.98, 1.14)	< 0.001
QRS wave duration (ms)	86 (80, 90)	83 (79.25, 88)	0.121
LVH, *n* (%)	26 (17)	7 (14)	0.782

Values are presented as mean ± SD, number (%), or median (interquartile range)

[a] Unpaired Student's *t*-test

[b] Mann–Whitney *U*-test and chi-square test

Table 4 Logistic regression analysis of candidate variables for the model

	β	Standard error	*Wald* χ^2	OR (95% CI)	*P* value
Intercept	− 1.9119	3.5013	− 0.55	0.1478 (0.0001–145.4922)	0.5850
CRP	0.0216	0.0108	2.00	1.0219 (1.0006–1.0445)	0.0452
NT-pro BNP	0.0001	0.0002	0.63	1.0001 (0.9998–1.0006)	0.5307
LMR	− 0.6304	0.2205	− 2.86	0.5324 (0.3352–0.8010)	0.0042
Ca	− 1.3100	1.5371	− 0.85	0.2698 (0.0120–5.1883)	0.3941
Albumin	− 0.0209	0.0661	− 0.32	0.9793 (0.8576–1.1147)	0.7521
BUN	0.2652	0.1292	2.05	1.3036 (1.0217–1.7057)	0.0402
Macruz index	3.0528	0.8068	3.78	21.1746 (5.0328–120.9576)	0.0002

Table 5 Logistic regression analysis of selected variables for the model

	β	Standard error	*Wald* χ^2	OR (95% CI)	*P* value
Intercept	− 5.8047	1.5311	− 3.79	0.0030 (0.0001–0.0473)	0.0002
CRP	0.0235	0.0100	2.34	1.0237 (1.0042–1.0451)	0.0195
LMR	− 0.6926	0.2166	− 3.20	0.5003 (0.3168–0.7450)	0.0014
BUN	0.3379	0.1172	2.88	1.4019 (1.1377–1.8007)	0.0039
Macruz index	3.1705	0.8097	3.92	23.8198 (5.6439–136.0311)	< 0.0001

showed that lymphocyte count, monocyte count, and LMR were significant predictors of POAF, which is consistent with the findings of the predictors associated with POAF after intervention in patients with ST-segment elevation myocardial infarction and after off-pump coronary artery bypass grafting (Wang et al. 2022; Magoon et al. 2023).

Deterioration of renal function is also an important risk factor for the development of POAF in patients undergoing cardiac and non-cardiac surgery. This is due to electrolyte disturbances, water and sodium retention, activation of the renin–angiotensin–aldosterone system (RAAS), and an increase in inflammatory factors, which affect the electrophysiological activity of the heart and increase the risk of AF. A meta-study by Caldonazo et al. showed that the risk of POAF in patients who underwent cardiac surgery was associated with acute renal failure (OR 2.74, 95% CI 2.42–3.11) (Caldonazo et al. 2023). The findings of Quinn et al. (Quinn et al. 2018) and Madsen et al. (Madsen et al. 2023) also confirmed that

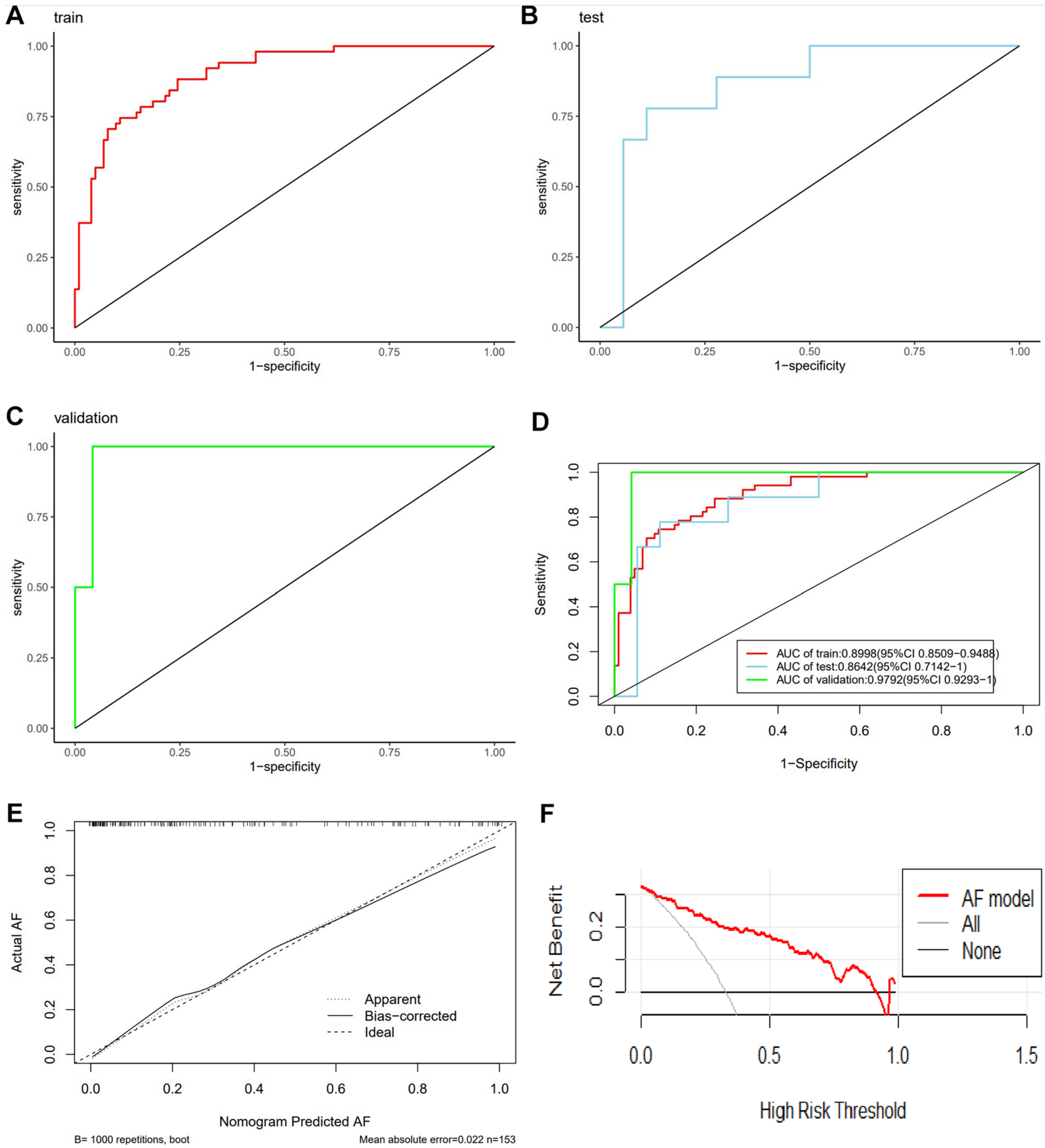

Fig. 4 The evaluation of the nomogram model. Receiver operating characteristic (ROC) curve of the prediction model in the training (**A**), test (**B**), and validation (**C**) datasets. **D** Comparison of ROC curves for the above three datasets. **E** Calibration curve of the nomogram model for predicting the risk of POAF. The calibration plot shows the agreement between the predicted (*X*-axis) and observed (*Y*-axis) risks of POAF. **F** The decision curve analysis (DCA) of the nomogram model. The gray line represents the assumption that all patients who underwent laparotomy had POAF, while the black horizontal line represents the assumption that all patients who underwent laparotomy did not have POAF. The red line represents the assumption that patients who underwent laparotomy will be judged positive if the positive probability obtained from the nomogram is higher than the threshold probability

deterioration of renal function is a risk factor for POAF in patients who underwent elective and emergency abdominal surgery. Both logistic regression and LASSO regression analysis indicated that BUN was an independent predictor of POAF in patients who underwent abdominal surgery in our study.

The concept of the Macruz index was proposed by American scholar Macruz in 1958, and it is an electrocardiographic indicator of left atrial enlargement (Macruz et al. 1958). It is calculated as the ratio of the P-wave duration to the P-R segment duration in lead II on the 12-lead electrocardiogram, with a normal range of approximately 1 to 1.6 (Macruz et al. 1958; Human and Snyman 1963). Atrial depolarization starts after the emission of sinus excitation. Depolarization occurs initially in the right atrium, followed by conduction of excitation to the left atrium, and then left atrial depolarization. The atrioventricular node was reached from the depolarization of the right atrium near the sinus orifice of the coronary vein. Meanwhile, the left atrium continues to depolarize until the end of the P-wave, when depolarization is finally completed. In cases of left atrial enlargement, right atrial depolarization, transmission time to the atrioventricular (AV) node, and timing of the onset of left atrial excitation are normal, as is the P-R interval. However, the left atrial depolarization time is prolonged, resulting in prolongation of the P-wave and shortening of the P-R segment but no change in P-R interval. This results in Macruz index > 1.6 or even > 2.0 (Macruz et al. 1958; Human and Snyman 1963). In this study, there was a significant difference in Macruz index between the POAF group and the control group, and both one-way regression analysis and LASSO regression analysis suggested that Macruz index was an independent predictor of POAF in patients who underwent abdominal surgery.

Nomograms have shown great promise in modern medical decision-making. It relies on user-friendly digital interfaces, increased accuracy, and easier-to-understand prognoses to improve patient management (Bianco 2006). Here, we constructed a novel nomogram with only four simple parameters but high accuracy for clinical doctors to predict POAF in patients undergoing laparotomy. To evaluate the reproducibility of the nomogram model development process, we used our hospital's variable data as the derivation cohort, divided into a training set (85%) and a test set (15%), and conducted internal validation. Additionally, to assess the transportability and generalizability of the nomogram model, we utilized variable data from another center as the validation cohort and conducted external validation. Despite the promising result, we still had some limitations in our study. Firstly, as a result of the low morbidity of POAF and the limited duration of the study, it was difficult for us to broaden our sample volume to form a larger and more homogeneous subject cohort. So we are willing to cooperate with other medical centers to further validate the accuracy and practicability of our results. Secondly, it has to be acknowledged that the retrospective design of our case–control study inherently introduces bias. Although we attempted to adjust for possible confounding factors in a multivariate analysis, we cannot exclude the possibility of patient selection bias or other unaccounted factors. Thirdly, the first follow-up after discharge was performed in the outpatient clinic four weeks after surgery. Unfortunately, due to incomplete laboratory test results from some patients during the follow-up period, we were unable to perform a dynamic analysis of the laboratory test variables.

Conclusion

This study developed a nomogram prediction model to assess the risk of postoperative atrial fibrillation (POAF) in patients who underwent abdominal surgery. The model utilizes readily available clinical variables such as CRP, LMR, BUN, and the Macruz index. It exhibited favorable discrimination, calibration, and clinical utility. The nomogram prediction model is expected to identify patients at high risk of POAF in clinical practice, especially elderly patients undergoing major laparotomy, thereby enabling preemptive therapeutic strategies before surgery. Future investigations will include prospective cohort studies to evaluate the clinical efficacy of interventions guided by this model.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13741-024-00472-x.

Supplementary Material 1: Table 1 Types of abdominal surgery in each group.

Authors' contributions

GZ and LW designed this study. WW conducted the statistical analysis. LW drafted the manuscript. HC and LC ensured the appropriateness of patient enrollment and collected clinical data. TW and TW analyzed the electrocardiogram data. All authors authorized the publication of this manuscript.

Data sharing statement

Data from this study are available from the corresponding author upon request.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and informed consent
This retrospective study was approved by the medical ethics committees of the 904th Hospital of the PLA Joint Logistic Support Force (No.20230722) and Hefei Third People's Hospital (No.20230628). This study adhered to the principles outlined in the Declaration of Helsinki. Given the retrospective design of this study, the requirement for patient consent was waived by the ethics committee. All patient data were anonymized or kept confidential.

Competing interests
The authors declare no competing interests.

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