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Development and internal validation of an OPCABG-specific prediction model for postoperative atrial fibrillation in Chinese patients: a retrospective cohort study

Yihan Zheng[1], Min Zhou[1], Yiting Lin[2] and Guican Zhang[3*]

Abstract

Background Postoperative atrial fibrillation (POAF) is a common complication after off-pump coronary artery bypass grafting (OPCABG), associated with increased morbidity and healthcare costs. Existing POAF prediction models, developed mainly for Western populations, may not account for genetic, lifestyle, and healthcare disparities in Chinese patients. This study aimed to develop and validate a Chinese-specific nomogram for POAF risk stratification in OPCABG patients.

Methods A retrospective cohort study was conducted at a single Chinese center, including 456 consecutive OPCABG patients (2018–2022). Patients were divided into a training set (2018–2021, $n=319$) and validation set (2022, $n=137$). Multivariable logistic regression with LASSO regularization identified predictors of POAF (occurrence within 7 postoperative days). Model performance was evaluated using C-index, calibration curves, decision curve analysis (DCA), and clinical impact curves (CIC).

Results The final nomogram included five independent predictors: age (OR, 1.03), diabetes (OR, 1.85), hypertension (OR, 1.90), previous PCI (OR, 2.51) and last intraoperative blood potassium concentration (OR, 0.30). The model demonstrated excellent discrimination (C-index: 0.809 in training, 0.886 in validation) and good calibration. DCA and CIC showed superior clinical utility compared with existing scores (C2HEST, CHADS2, CHA2DS2-VASc).

Conclusions This OPCABG-specific nomogram outperforms conventional risk scores in predicting POAF in Chinese patients, enabling personalized prophylaxis and resource allocation. External validation in diverse populations is needed to confirm generalizability.

Keywords Postoperative atrial fibrillation, Off-pump coronary artery bypass grafting, Nomogram, Clinical risk factors, Risk models

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Introduction

Postoperative atrial fibrillation (POAF) complicates 20–40% of coronary artery bypass grafting (CABG) procedures [1], increasing stroke risk by 3-fold and hospitalization costs by 8,000 – 8,000 – 12,000 per case [2, 3]. While existing models like CHA2DS2-VASc [4] and C2HEST [5] demonstrate moderate discrimination in on-pump CABG cohorts, their performance deteriorates in off-pump (OPCABG) populations [6]. *Current models derive from predominantly on-pump cohorts. When applied to OPCABG patients, these models exhibit poor calibration, reflecting unaddressed surgical modality effects.* This discrepancy may stem from fundamental pathophysiological differences: OPCABG induces 52% less systemic inflammation than on-pump surgery [7], potentially altering POAF risk profiles. *Vogireddy R Krishna et al. confirms OPCABG reduces POAF incidence, underscoring distinct risk profiles* [8].

In China, the annual Coronary Artery Bypass Grafting (CABG) volume exceeds 46,000 and OPCAB has become a common practice [9]. Compared with CABG under traditional cardiopulmonary bypass, OPCAB has the advantages of reducing stroke rate and decreasing the duration of hospital stay [10], reducing the demand for blood products, and decreasing renal dysfunction [11]. However, it is still controversial whether prognosis can be improved by OPCAB [12]. Therefore, the risk factors of post-operative atrial fibrillation after off-pump coronary artery bypass grafting (OPCAB-POAF) need to be clarified.

Currently, most research on POAF (postoperative atrial fibrillation) prediction models mainly focuses on broader cardiac surgery populations or specific groups like on-pump CABG, but there hasn't been much dedicated exploration of OPCABG (off-pump coronary artery bypass grafting) patients. As a minimally invasive surgical approach, OPCABG involves unique hemodynamic changes, surgical stress patterns, and patient profiles compared to on-pump procedures [13]. Those existing POAF prediction models—designed for mixed surgical populations—completely overlook OPCABG-specific risk factors. This creates a problem in clinical practice: doctors lack a tailored tool to accurately predict POAF in OPCABG patients, making it tough to roll out preemptive interventions.

In this work, we aimed to develop and validation a novel nomogram for OPCAB-POAF. We focus on OPCABG patients specifically to tackle this unsolved issue. We aim to build a precise risk stratification model that matches the unique physical and pathological traits of this patient group. Some scholars have tried to establish a prediction model of POAF after cardiac surgery to evaluate high-risk patients before surgery and administer personalized preventive treatment, but the prediction of POAF is not satisfactory [14]. This work not only fill a research gap— it also directly helps doctors make better decisions, letting them use personalized prevention strategies to cut down on POAF-related complications (e.g., strokes and longer hospital stays) in OPCABG patients.

Methods

Data source

This retrospective observational study included 578 patients diagnosed with coronary atherosclerotic heart disease from June 2018 to December 2020 and scheduled for OPCAB. Based on the 10:1 events-per-variable (EPV) rule [15] and 5 candidate predictors, a minimum of 50 POAF events were required. Our cohort included 112 POAF events, exceeding this threshold.

Patients were included if they were 18–85 years old, undergoing elective isolated OPCABG, without a preoperative history of atrial fibrillation (AF) confirmed by sinus rhythm on 12-lead ECG, with normal thyroid function (FT3, FT4, TSH), and no acute myocardial infarction within 4 weeks preoperatively. Exclusion criteria included: [1] valvular/congenital heart disease or cardiomyopathy (altering atrial remodeling pathways); [2] conversion to on-pump CABG or prior cardiac surgery (confounding POAF risk factors); [3] preoperative hyperthyroidism/hypothyroidism (independent AF risk, OR = 2.3); [4] ventricular arrhythmias/atrial flutter on preoperative ECG; [5] postoperative survival ≤ 24 h; [6] decompensated chronic kidney disease (creatinine > 177 μmol/L, OR = 1.9); and [7] emergency/complex surgeries (introducing confounding stressors).

According to the diagnostic criteria of postoperative new-onset atrial fibrillation, all patients after OPCAB were admitted to the ICU for monitoring and treatment on the same day, with continuous ECG monitoring all day. ECG diagnostic criteria of atrial fibrillation include the following: absence of distinct P waves and replaced by atrial fibrillation waves (F waves) with an irregular shape, amplitude, spacing, and irregular ventricular law. The diagnosis of POAF includes the following: no history of atrial fibrillation before the operation, confirmation by postoperative ECG and physical examination results, and a duration of 5 min or longer. The subjects were divided into two groups: a POAF group and non-POAF group.

Through the His system, anesthesia clinic information system, and ICU information system, 18 factors (patient history, anesthesia record, intensive care nursing record, physical examination report, chemical examination report, and execution of doctor's order) were recorded and discussed. We selected variables for inclusion in the model based primarily on POAF risk factors and potential biological markers, as well as availability of clinical data. The following information was included [1] age, gender, diabetes history, hypertension history, smoking

history, drinking history, other social history, and history of old myocardial infarction and cerebrovascular accident [16, 17]; [2] New York Heart Association (NYHA) cardiac function classification [18]; [3] left ventricular ejection fraction (LVEF), left atrial diameter (LAD), and left ventricular end-diastolic diameter (LVED) [19]; [4] history of percutaneous coronary intervention (PCI) [20]; [5] preoperative amino-terminal B-type urinary natriuretic peptide precursor (NT pro-BNP) level [21]; [6] duration of anesthesia and the last intraoperative blood potassium concentration [22]; and [7] mechanical ventilation time in ICU [23]. The design of this study follows the STROBE statement and TRIPOD checklist.

Statistical analyses

We used packages implemented in R software (R version 4.1.3., the R Foundation for Statistical Computing, Vienna, Austria) for all statistical analyses and generation of plots. The continuous variables conforming to the normal distribution are represented as the means ± standard deviation. Continuous variables are represented as the medians (interquartile ranges), and the classified variables are represented as constituent ratios or rates. A two-sample t-test was used for statistical inference of continuous quantitative variables that were independent, normal, and homogenous of variance. The Mann – Whitney U test was used for continuous quantitative variables with skewed distribution. The χ^2 test or Fisher's exact test was used for categorical variables. The ordered categorical data were tested using the Mann – Whitney U test. Construction and validation of the nomogram: To construct and validate the nomogram, we first randomly divided samples into training cohort and validation cohort, in its design. Summarily, 70% ($n = 319$) of the participants were randomly assigned to the training cohort, whereas the rest of ($n = 137$) were assigned to the validation cohort. Second, the univariate and multivariate logistics regression model was applied to select significant variables in training cohort. Finally, based on the results of the multivariable analyses the nomogram was created. In validation cohort, we first undertook internal validation, with a concordance index (C-index) estimation, then plotted calibration curves to determine concordance of the predicted and observed probabilities. Second, bootstrap resampling (1000 resamples) was used for this plot. Moreover, we evaluated clinical usefulness of the nomograms using decision curve analysis (DCA) and clinical impact curve (CIC). Finally, we compared the C2HEST, CHADS2 and CHADS2-VASc with our model.

Results

Patient characteristics

From September 2018 to December 2020, 578 patients who underwent OPCAB were included. According to the inclusion and exclusion criteria, participants who had previous history of atrial fibrillation, postoperative survival time ≤ 24 h, emergency surgery or organic heart diseases were excluded. Finally, 456 patients were

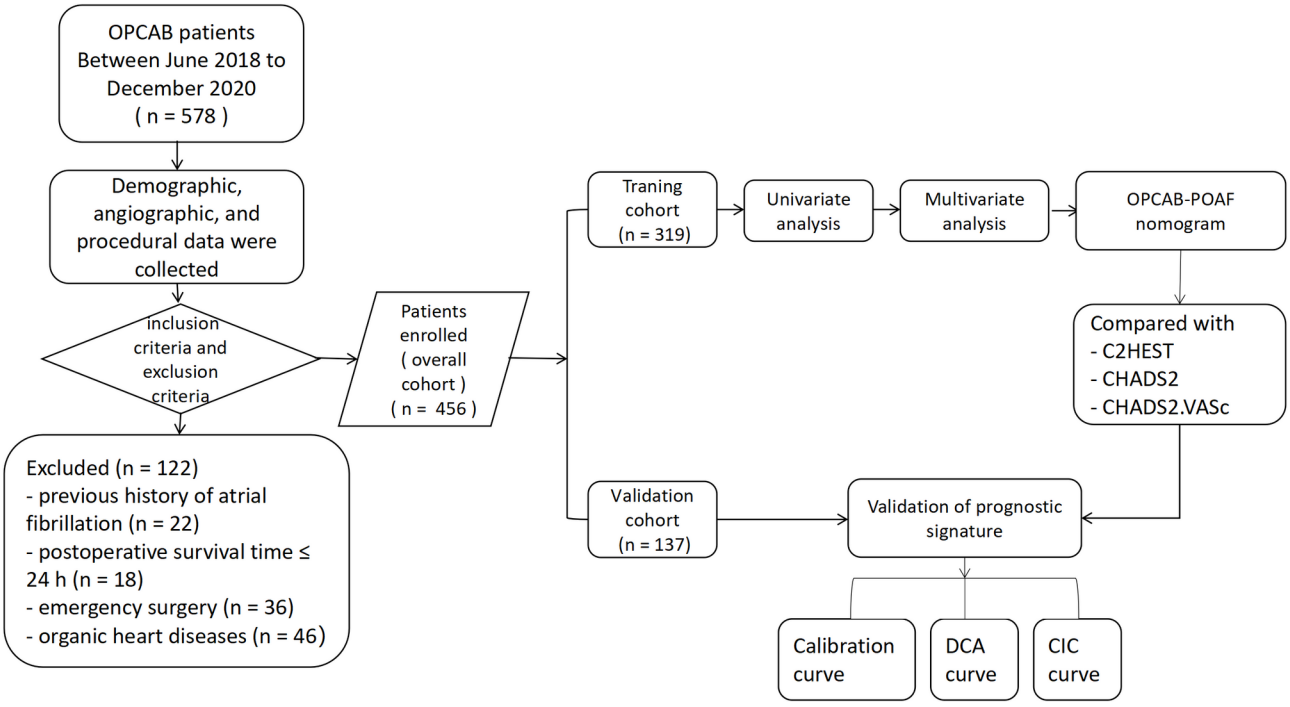

Fig. 1 Flow chart

included in the analysis (see Fig. 1). Clinical characteristics of the training ($n=319$) and validation ($n=137$) cohorts revealed no statistically significant differences between the groups (Table 1). Participants mean age was 62.00 years (IQR: 54.00–67.00), whereas about 89.9% participants were male (410 of 456). The total incidence of OPCAB-POAF was 22.15% (101 of the 456). In addition, 71 patients in training cohort were diagnostic with POAF, 57.7% had diabetes, 71.8% had hypertension and 14.1% had cerebrovascular accident. (Table 2).

Predictors of OPCAB-POAF

Univariate analysis revealed that age, diabetes, hypertension, cerebrovascular accident, previous PCI, NYHA ≥ III, EF, LAD, LVED, Last intraoperative blood potassium concentration, ICU stay time and postoperative drainage volume were significant, and multivariate analysis showed that age, diabetes, hypertension, previous PCI and last intraoperative blood potassium concentration were associated with POAF (Table 3). Eventually, we developed nomogram with these independent predictors (see Fig. 2).

Clinical case examples

Case 1 (high-risk patient)

A 68-year-old male underwent OPCABG with the following characteristics:

- **Age**: 68 years → 30 points.
- **Diabetes**: Yes → 20 points.
- **Hypertension**: Yes → 18 points.
- **PCI history**: No → 0 points.
- **Potassium**: 3.3mmol/L → 82 points.

Total Points = 30 + 20 + 18 + 0 + 82 = **150 points**.

Referring to the nomogram's total points scale (0-180), 150 points corresponds to a **62% predicted POAF probability**. The patient developed POAF on postoperative day 3.

Case 2 (intermediate-risk patient)

A 47-year-old female with:

- **Age**: 47 years → 20 points.
- **Diabetes**: Yes → 20 points.
- **Hypertension**: Yes → 18 points.
- **PCI history**: No → 0 points.
- **Potassium**: 4.5mmol/L → 50 points.

Total Points = 20 + 20 + 18 + 0 + 50 = **108 points → 20% predicted POAF probability**. No arrhythmia occurred during the 7-day monitoring period.

Table 1 Clinical characteristics of the training and validation cohorts

Variable	Overall	Validation cohort	Training cohort	*P**
	n = 456	*n* = 137	*n* = 319	Value
sex = male (%)	410 (89.9)	122 (89.1)	288 (90.3)	0.82
age (median [IQR])	62.00 [54.00, 67.00]	61.00 [52.00, 67.00]	63.00 [55.00, 68.00]	0.07
cigarette = yes (%)	284 (62.3)	82 (59.9)	202 (63.3)	0.55
drinking = yes (%)	218 (47.8)	62 (45.3)	156 (48.9)	0.54
diabetes = yes (%)	192 (42.1)	54 (39.4)	138 (43.3)	0.51
hypertension = yes (%)	264 (57.9)	80 (58.4)	184 (57.7)	0.97
hyperlipidemia = yes (%)	46 (10.1)	11 (8.0)	35 (11.0)	0.43
cerebrovascular accident = yes (%)	34 (7.5)	10 (7.3)	24 (7.5)	1.00
myocardial infarction = yes (%)	112 (24.6)	26 (19.0)	86 (27.0)	0.09
Previous PCI = yes (%)	50 (11.0)	11 (8.0)	39 (12.2)	0.25
NYHA ≥ III = yes (%)	142 (31.1)	43 (31.4)	99 (31.0)	1.00
EF (median [IQR])	60.05 [47.95, 67.17]	60.10 [47.30, 66.80]	60.00 [48.00, 67.80]	0.80
LVED (median [IQR])	49.05 [45.27, 53.00]	49.50 [45.50, 53.00]	48.90 [45.10, 52.85]	0.28
LAD (median [IQR])	35.70 [32.10, 39.28]	35.10 [32.50, 39.00]	35.70 [32.05, 39.60]	0.87
NTpro-BNP (mean (SD))	641.53 (977.16)	547.64 (797.59)	681.85 (1043.42)	0.18
Anesthesia duration (median [IQR])	314.00 [284.00, 344.00]	314.00 [290.00, 345.00]	312.00 [284.00, 344.00]	0.56
Last intraoperative blood potassium concentration (median [IQR])	4.10 [3.80, 4.50]	4.10 [3.80, 4.40]	4.10 [3.80, 4.50]	0.55
ICU mechanical ventilation time (median [IQR])	21.50 [19.00, 37.25]	21.00 [19.00, 31.00]	22.00 [19.00, 38.50]	0.22
ICU stay time (median [IQR])	67.00 [44.00, 94.00]	67.00 [44.00, 91.00]	67.00 [43.00, 95.00]	0.82
postoperative drainage volume (median [IQR])	937.50 [585.75, 1381.00]	914.00 [591.00, 1340.00]	965.00 [581.00, 1430.00]	0.88
POAF = yes (%)	101 (22.1)	30 (21.9)	71 (22.3)	1.00

*t test or χ2 test; Mann-Whitney U test was applied for non-normally distributed data

IQR interquartile range, SD standard deviation

Table 2 Sample characteristics based on OPCAB-POAF status

Variable	Overall	non-POAF	POAF	*P* Value
	n **= 319**	***n*** **= 248**	***n*** **= 71**	
sex = male (%)	288 (90.3)	225 (90.7)	63 (88.7)	0.785
age (median [IQR])	63.00 [55.00, 68.00]	62.00 [54.00, 67.00]	64.00 [56.50, 69.00]	0.053
cigarette = yes (%)	202 (63.3)	156 (62.9)	46 (64.8)	0.88
drinking = yes (%)	156 (48.9)	123 (49.6)	33 (46.5)	0.742
diabetes = yes (%)	138 (43.3)	97 (39.1)	41 (57.7)	0.008
hypertension = yes (%)	184 (57.7)	133 (53.6)	51 (71.8)	0.009
hyperlipidemia = yes (%)	35 (11.0)	28 (11.3)	7 (9.9)	0.901
cerebrovascular accident = yes (%)	24 (7.5)	14 (5.6)	10 (14.1)	0.034
myocardial infarction = yes (%)	86 (27.0)	68 (27.4)	18 (25.4)	0.846
Previous PCI = yes (%)	39 (12.2)	21 (8.5)	18 (25.4)	< 0.001
NYHA ≥ III = yes (%)	99 (31.0)	71 (28.6)	28 (39.4)	0.112
EF (median [IQR])	60.00 [48.00, 67.80]	60.10 [49.08, 68.28]	59.00 [44.15, 65.15]	0.038
LVED (median [IQR])	48.90 [45.10, 52.85]	48.50 [44.90, 52.32]	49.50 [45.65, 54.00]	0.11
LAD (median [IQR])	35.70 [32.05, 39.60]	35.60 [31.67, 39.20]	36.50 [33.30, 41.10]	0.018
Preoperative NTpro-BNP (mean (SD))	681.85 (1043.42)	662.00 (1063.64)	751.18 (973.45)	0.526
Anesthesia duration (median [IQR])	312.00 [284.00, 344.00]	316.00 [288.25, 341.50]	294.00 [271.50, 351.00]	0.092
Last intraoperative blood potassium concentration (median [IQR])	4.10 [3.80, 4.50]	4.20 [3.90, 4.60]	3.90 [3.65, 4.10]	< 0.001
ICU mechanical ventilation time (median [IQR])	22.00 [19.00, 38.50]	22.00 [19.00, 37.00]	21.00 [19.00, 41.50]	0.721
ICU stay time (median [IQR])	67.00 [43.00, 95.00]	67.00 [43.75, 93.00]	68.00 [43.00, 115.00]	0.33
postoperative drainage volume (median [IQR])	965.00 [581.00, 1430.00]	855.00 [530.00, 1307.25]	1180.00 [860.50, 1618.00]	0.001

*t test or χ2 test; Mann-Whitney U test was applied for non-normally distributed data

Table 3 Predictors of OPCAB-POAF success rate based on the nomogram

	Univariate analysis			Multivariate analysis		
Characteristics	**OR**	**CI**	***P***	**OR2**	**CI2**	**P2**
age	1.03	1-1.06	0.04	1.03	1-1.07	0.09*
sex (male)	0.80	0.34–1.89	0.62	/	/	/
cigarette (yes)	1.09	0.63–1.88	0.77	/	/	/
diabetes (yes)	2.13	1.25–3.63	0.01	1.85	0.99–3.45	0.05*
drinking (yes)	0.88	0.52–1.5	0.64	/	/	/
hyperlipidemia (yes)	0.86	0.36–2.06	0.73	/	/	/
hypertension (yes)	2.20	1.24–3.92	0.01	1.90	0.97–3.74	0.06*
cerebrovascular accident (yes)	2.74	1.16–6.47	0.02	1.49	0.55–4.01	0.43
Previous PCI (yes)	3.67	1.83–7.37	< 0.001	2.51	1.1–5.71	0.03*
Myocardial infarction (yes)	0.90	0.49–1.64	0.73	/	/	/
NYHA ≥ III (yes)	1.62	0.94–2.81	0.08	/	/	/
NTpro-BNP	1.00	44562.00	0.53	/	/	/
EF	0.97	0.95–0.99	0.02	0.97	0.94–1.01	0.12
LAD	1.06	1.02–1.11	0.01	1.03	0.97–1.09	0.32
LVED	1.05	1-1.09	0.04	1.00	0.93–1.06	0.88
Last intraoperative blood potassium concentration	0.34	0.19–0.6	< 0.001	0.30	0.16–0.57	< 0.001*
Anesthesia duration	1.00	0.99-1	0.43	/	/	/
ICU mechanical ventilation time	1.00	0.99–1.02	0.66	/	/	/
ICU stay time	1.01	1-1.01	0.05	1.00	1-1.01	0.33
postoperative drainage volume	1.00	44562.00	0.00	1.00	44562.00	0.00

OR odds ratio, CI confidence interval

*$P<0.05$

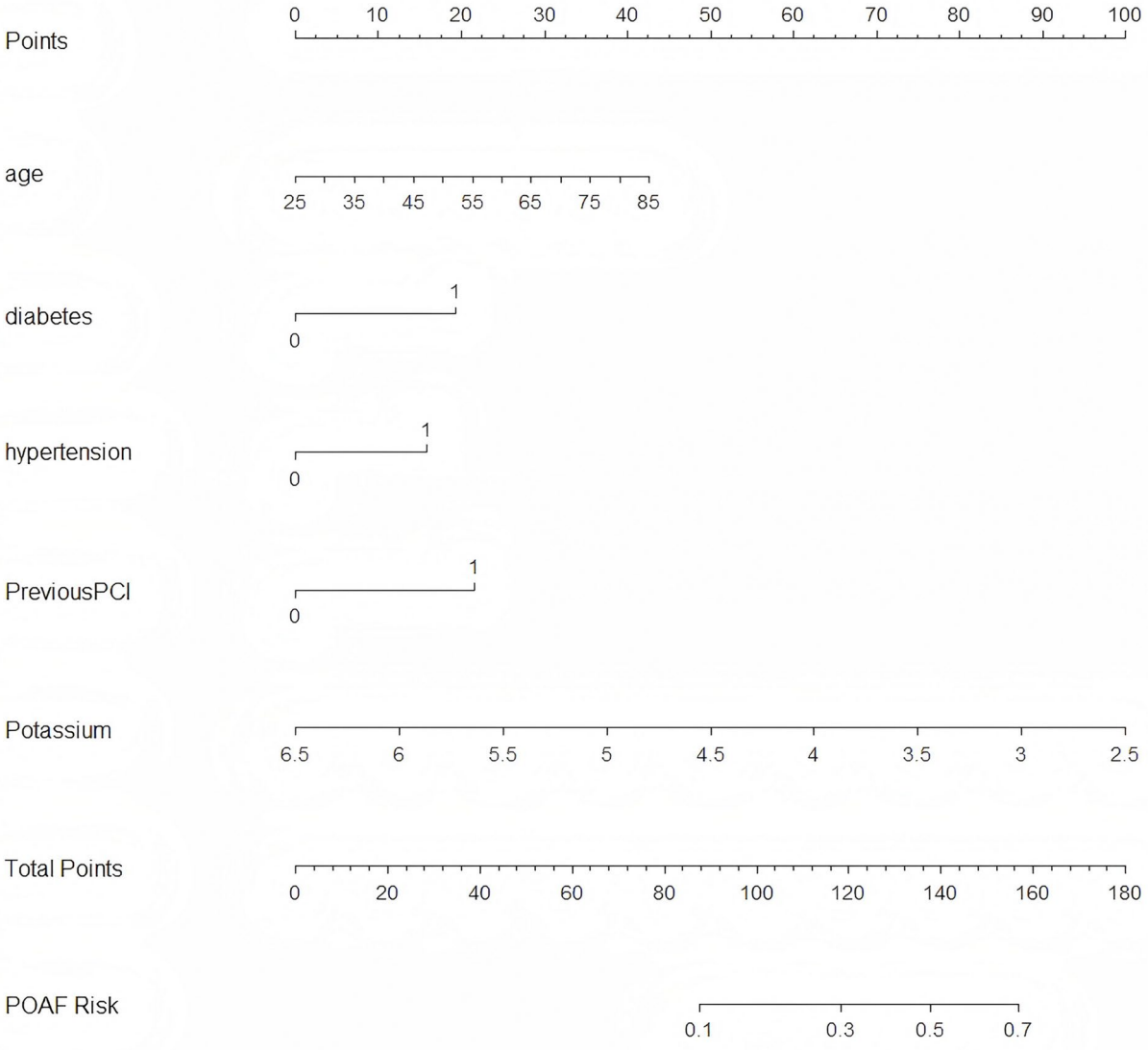

Fig. 2 OPCAB-POAF nomogram

A step-by-step guide

1. Locate each predictor's value on the corresponding nomogram axis.
2. Draw vertical lines to the "Points" scale to obtain individual scores.
3. Sum all points on the "Total Points" axis.
4. Project the total to the "Predicted Probability" axis for final risk estimation.

Comparative analysis

Using the CHA2DS2-VASc score, Case 1 would score 3 (38% POAF risk), failing to reflect his actual POAF risk. This contrast highlights our model's enhanced contextual specificity.

Validation and compare the nomogram

Predictive accuracy, for the POAF as measured by C-index was 0.809 in training cohort. The calibration plot for the probability of POAF's success showed a strong correlation between the actual (observed) outcome and that predicted by the nomogram (Fig. 3a). In addition, we plotted calibration curves to evaluate performance of the novel nomogram in validation cohort and compared with C2HEST, C2HEST, CHADS2 and CHADS2-VASc models in both Calibration curves (Fig. 3) and DCA curves (Fig. 4). Our model: C-index: 0.809 (train) and 0.886 (validation), C2HEST, CHADS2 and CHA2DS2.VASc is 0.642, 0.668 and 0.668 respectively. Results reveled that the novel nomogram was superior to other models.

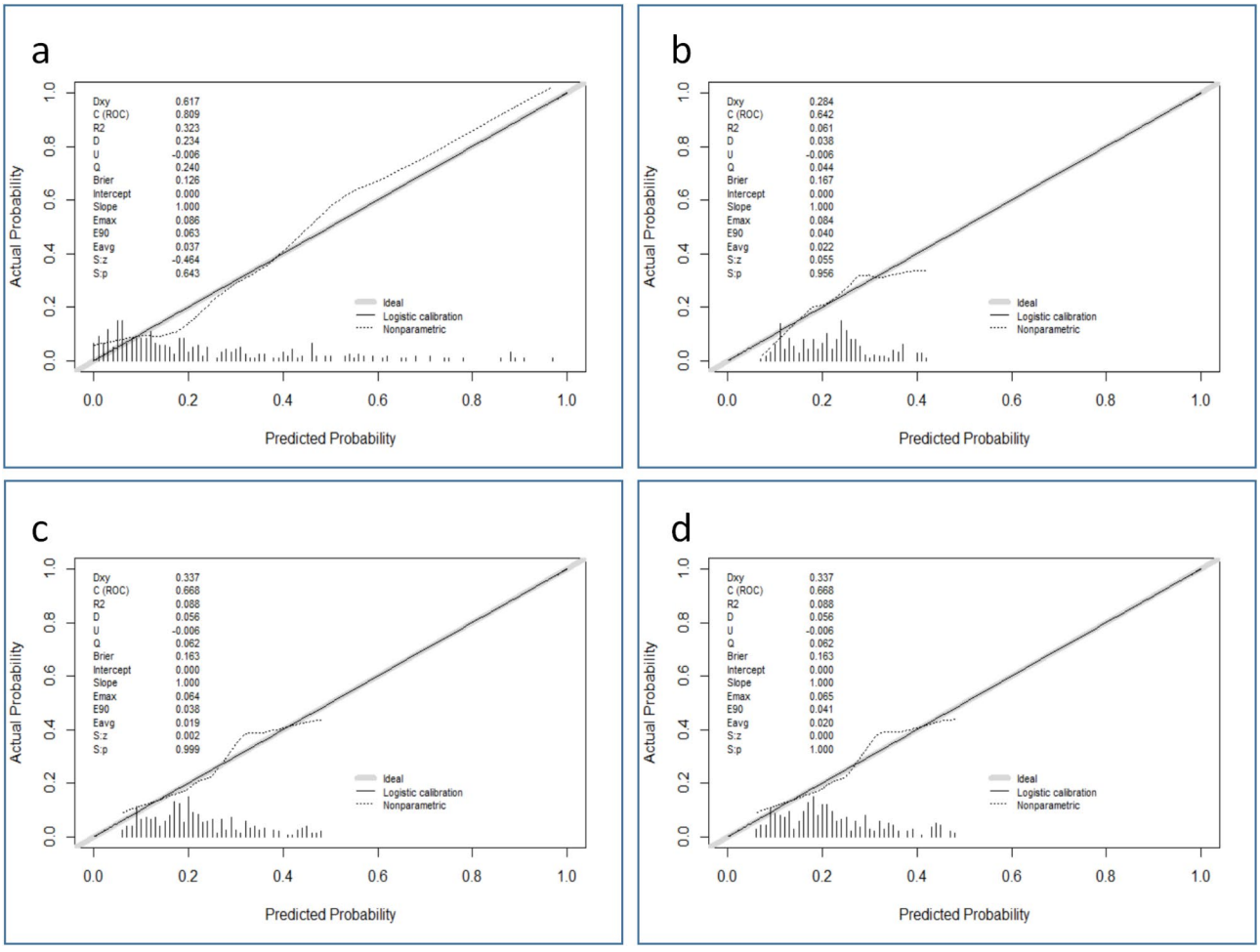

Fig. 3 The calibration curves for the four models: (**a**) OPCAB-POAF, C-index = 0.809; (**b**) C2HEST, C-index = 0.642; (**c**) CHADS2, C-index = 0.668; (**d**) CHA2DS2-VASC, C-index = 0.668. Each subplot presents a calibration curve, with the x-axis indicating the "Predicted Probability" and the y-axis showing the "Actual Probability". Curves: The "Ideal" line represents the perfect 1:1 alignment between predicted and actual probabilities. The "Logistic calibration" line reflects calibration via logistic regression, while the "Nonparametric" line (dashed) shows nonparametric calibration results

Clinical impact curve analysis

In addition, we plotted clinical impact curve to find out the risk threshold. Using the novel model to predict the risk stratification of 1000 people, showing the' cost: benefit' axis, the CIC indicated that 0.6 was the high-risk threshold, preventive measures must be taken (Fig. 4d).

Calibration analysis and linear term validation for continuous variables

The weak calibration analysis has been performed for all models in Fig. 5. The results of observed-to-expected (O/E) ratios [24] are presented in supplementary table S1-S4. The results show that the prediction performance of our model is quite consistent. For continuous variables, we directly incorporated linear terms primarily based on the following considerations: (1) Scatter plots showed an approximately linear trend between age/potassium concentration and the outcome (Supplementary Fig. a and b); (2) Likelihood ratio tests for quadratic terms were nonsignificant ($P(\text{age}^2) = 0.971$, $P(\text{potassium}^2) = 0.135$), indicating negligible nonlinear components; (3) Residual analysis revealed no significant heteroscedasticity or trends (Supplementary Fig. c and d).

Discussion

In recent years, the nomogram has been used extensively in clinical research, and shows more accurate advantages than the traditional scoring system, which can predict the prognosis of some diseases [25]. In view of the importance of POAF in the prognosis of patients, there is great clinical interest in preventing this arrhythmia. However, undifferentiated conventional drug treatment will cause drug side effects in 60-80% of patients [26]. Quantifying POAF risk is critical for precision prophylaxis.

Present study validated the ability of novel nomogram for predicting the incidence of POAF in patients undergoing OPCAB. In previous researchers, the risk factors for POAF included age, diabetes, cerebrovascular

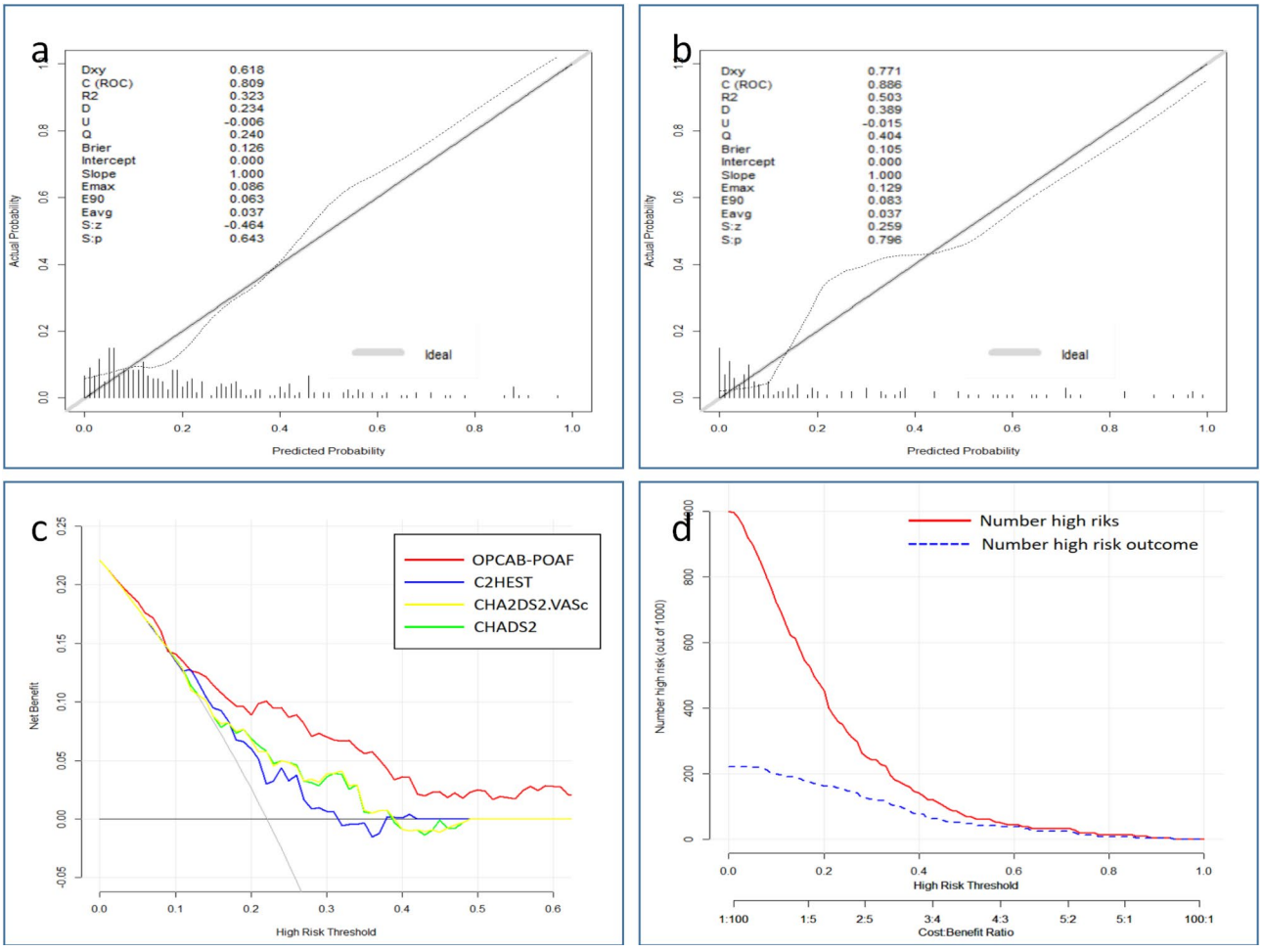

Fig. 4 Calibration curves of the nomogram in training cohort and validation cohorts of OPCAB-POAF. **a** Calibration curves for predicting success of OPCAB-POAF nomogram construction (Bootstrap = 1000 repetitions) in training cohort. **b** Calibration curves for predicting success of OPCAB-POAF nomogram construction (Bootstrap = 1000 repetitions) in validation (test) cohort **c**. Decision curve analysis compared with C2HEST, CHA2DS2-VASC and CHADS2 models. **d.** Clinical impact curve for nomogram in training cohort

accident, PCI history, chronic heart failure, left ventricular ejection fraction, left atrial enlargement, and electrolyte disturbance [27, 28]. Our research indicated that age, diabetes, hypertension, previous PCI, and intraoperative potassium were related to the occurrence of POAF. And the authors compared it with C2HEST, CHADS2, and CHA2DS2-VASc scores. According to the DCA curves, the novel nomogram performed better than the C2HEST, CHADS2, and CHA2DS2-VASc scores. This nomogram demonstrated a predictive performance with a good discriminative ability (C-index in training and validation cohort respectively: 0.809 and 0.886) and calibration.

The C2HEST score has shown promising results as a simple practical tool for predicting incident AF based on clinical risk factors [29, 30]. Correspondently, serious studies found that CHADS2 and CHA2DS2-VASc score, were independent predictors of POAF [4, 31, 32]. The clinical practice of these risk scores has been proven in different participants, however, the population of these studies concentrated on inhomogeneous patients undergoing different types of cardiac surgery. And an easy-to-remember bedside tool is especially needed in a busy clinical setting. Therefore, the authors development a novel nomogram to visualize scores items. Race/ethnicity significantly impacts POAF due to biological disparities like genetic predispositions, lifestyle differences, and variations in medical practices [33, 34]. For example, genetic variations in cardiac electrophysiology and inflammation pathways may differ across ethnic groups, altering POAF susceptibility [35]. Existing risk scores, mainly developed for Western populations, often overlook the unique profiles of Chinese patients, including influences from diet, healthcare access, and cultural health management approaches. To our knowledge, as of the writing of this article, this study was the first to construct a quantitative nomogram to predict the probability of POAF in a Chinese population undergoing isolated OPCAB.

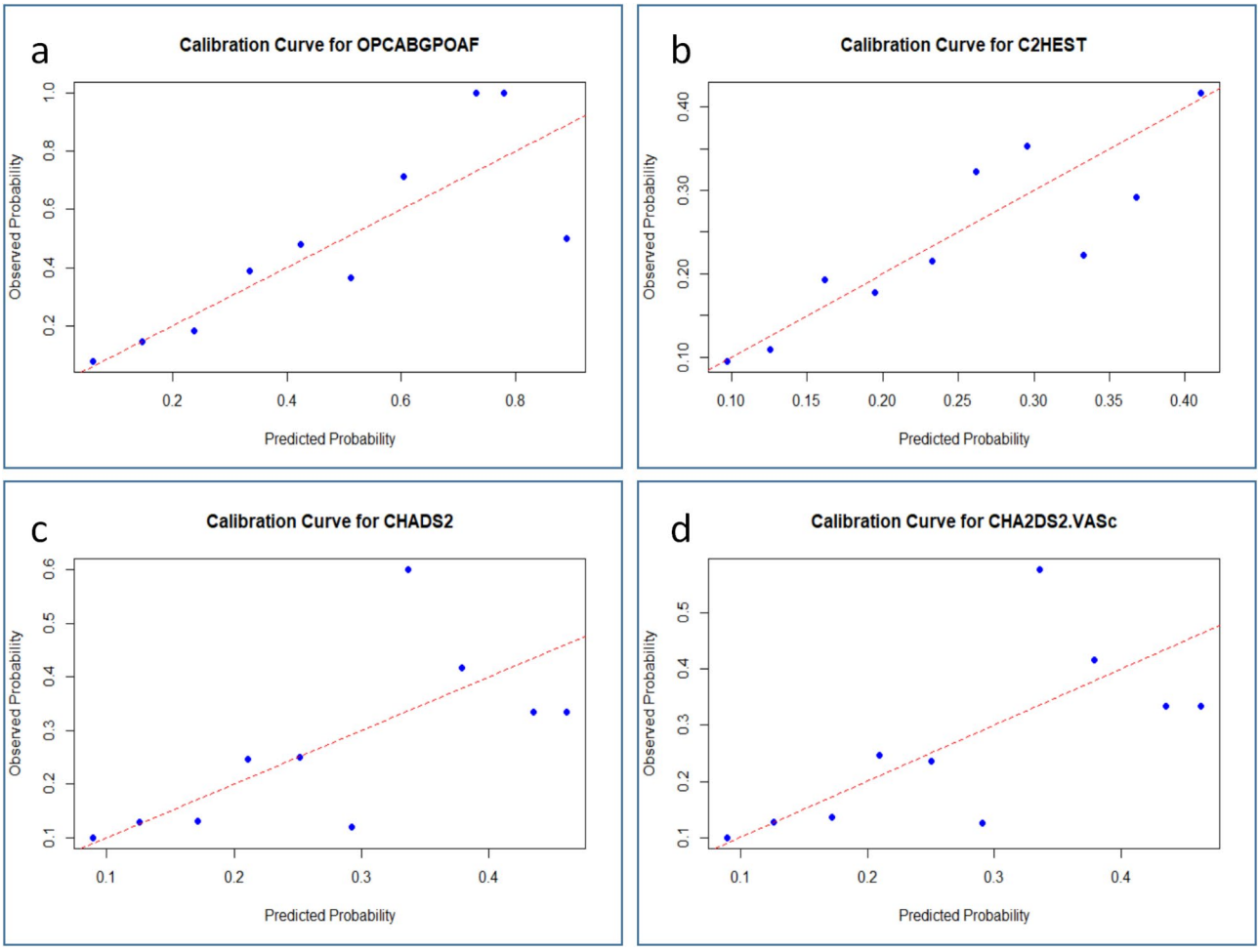

Fig. 5 Weak calibration for four models: (**a**) OPCAB-POAF; (**b**) C2HEST; (**c**) CHADS2; (**d**) CHA2DS2-VASC. The x-axis denotes the predicted probability of the outcome, while the y-axis represents the observed probability. The dashed line signifies the ideal 1:1 alignment between predicted and observed probabilities, highlighting the weak calibration of each model

According to researchers, apart from a history of AF, age is the single best predictor for AF, regardless of surgical or non-surgical AF [36, 37]. Degeneration of the atrial myocardium with aging may lead to a loss of side-to-side electrical coupling between muscle fibers, slowing down electrical conduction of the sinoatrial and atrioventricular nodes and atria, thereby providing an anatomic or electrophysiologic substrate for arrhythmogenesis [38]. Our findings align with a recent prospective cohort study [39], which identified diabetes as an independent POAF predictor (OR = 2.1, 95% CI 1.3–3.3). Earlier studies showed that diabetes has increased the risk of atrial fibrillation by 35% [40]. The underlying mechanism of atrial fibrillation induced by diabetes is that the increase in blood glucose results in the transformation of epicardial adipose tissue, inducing endothelial dysfunction and myocardial fibrosis induced by proinflammatory mediators, leading to atrial remodeling and electrophysiological remodeling [41].

The current research results show that hypertension was associated with POAF. Notably, hypertension may induce atrial stretch and cardiomyopathy, which ultimately lead to structural and electrophysiological remodeling conducive to POAF [42]. Hypertension, fluid overload, pathological activation of the renin-angiotensin-aldosterone system (RAAS) with subsequent enhanced myocardial fibrosis may be the underlying mechanisms by which renal dysfunction increases the likelihood of AF [43].

Deepak L. Bhatt and others believed that if patients are suitable for PCI or CABG at the same time, PCI will lead to a higher rate of repeated revascularization, and the probability of repeat PCI or CABG will be greatly increased, which will increase the incidence of postoperative complications [44]. This study found that previous percutaneous coronary intervention (PCI) was an independent risk factor for OPCAB-POAF. According to the review of literature, existing evidence suggests three potential mechanisms: First, most patients with branch

PCI have right coronary artery lesions, and the right coronary artery is the main blood supply source of the sinoatrial node and right atrium. PCI is not conducive to the physiology of coronary artery- and distal endothelial-mediated vasodilation, which easily causes myocardial ischemia and induces arrhythmia [45]. Secondly, the incidence of myocardial infarction and coronary restenosis after PCI is 1.5%~6%. Insufficient myocardial blood supply easily leads to cardiac rhythm disorders and atrial fibrillation [45]. Thirdly, most patients with PCI are more likely to have deterioration of cardiac function after repeat CABG. Heart failure increases CABG of the left ventricle and the pressure load of the left atrium. These pathophysiological changes may be the inducing factors of OPCAB-POAF in patients after PCI [1].

It is well known that blood potassium concentration plays an important role in cardiac electrophysiology. Intraoperative blood potassium concentration is related to adverse prognosis such as cardiovascular events [46]. This study showed that low blood potassium concentration in the last intraoperative blood collection was an independent risk factor for OPCAB-POAF. The blood potassium index was obtained by blood gas analysis of the patient's arterial blood for the last time before the patient left the operating room. Raymond et al. clarified that low serum potassium concentration is related to the risk of atrial fibrillation. Serum K^+ concentration is usually low in patients undergoing cardiac surgery, and the incidence of atrial fibrillation increases when K^+ concentration is lower than 3.5 mmol/L [47]. It is worth noting that our study found that even if the blood potassium concentration of most patients remained at 3.5-4.0 mmol/L before leaving the operating room, the probability of postoperative POAF is still very high. Combined with clinical and previous literature analysis, the possible reasons are as follows: First, the blood potassium level changes dynamically. Cardiac patients continue to pump dopamine and adrenaline after the operation, which further reduce blood potassium. Second, because patients need to continue mechanical ventilation for a period after cardiac surgery, they cannot consume food for an extended period, and the maintenance of blood potassium depends on intravenous potassium supplementation. If blood potassium is not detected and intravenous potassium supplementation is not timely after cardiac surgery, the potassium levels will continue to decline. Third, the arterial blood potassium concentration is inconsistent with that of myocardial extracellular fluid, and the value obtained by blood gas analysis is usually low. Many centers around the world believe that efforts should be made to maintain the serum K^+ concentration in the "normal high" range (4.5–5.5 mmol/L), rather than intervene only when potassium drops below its "normal" lower threshold. Although there is no evidence that this association is causal, it is still considered as a routine method in many centers to prevent atrial fibrillation [36, 48]. In addition, abnormal electrical remodeling of K^+ channels can change the electrophysiological characteristics of the atria, change the duration and characteristics of the refractory period, and induce ectopic pacing or arrhythmia of atrioventricular cells [49]; thus, it indirectly shows the effect of potassium ions on cardiac electrophysiology and arrhythmia.

Limitations: First, the retrospective study is not randomized but naturally grouped according to different factors related to levels of exposure, resulting in an imbalance between groups and bias. Second, the case data of the nomogram established in this study was derived from only a single center, and the sample sizes were limited, which makes the statistical results unreliable and produces a large standard error. Therefore, data acquired from more research centers and from larger sample sizes are needed to further demonstrate the model in the future. Third, this study is a retrospective study, and there are limitations in data collection. In the future, it is necessary to design a reasonable prospective study to demonstrate the model. Fourth, this study uses an internal validation method to verify the model. However, the performance of models that perform well in a single case data set is not necessarily satisfactory in other data sets. Therefore, future prospective cohort studies are needed to externally verify the prediction model in a new case data set.

Conclusions

According to the results, Age, diabetes, hypertension, previous PCI, and last intraoperative blood potassium concentration were associated with POAF. A nomogram was constructed and validated to predict POAF in patients who underwent OPCAB and provide accurate and individualized survival predictions.

Abbreviations

POAF	Postoperative atrial fibrillation
OPCAB	Off-pump coronary artery bypass grafting
OPCAB-POAF	New-onset postoperative atrial fibrillation after off-pump coronary artery bypass grafting
CAD	Coronary atherosclerotic heart disease
LVEF	Left ventricular ejection fraction
LAD	Left atrium diameter
CA	Cerebrovascular accident
PCI	Percutaneous coronary intervention
AF	Atrial fibrillation
NYHA	New York heart association

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions
Yihan Zheng helped design, analysis of data and drafting for the work; YT helped acquisition and analysis of the data for the work; GZ and MZ helped final approval of the version to be published. All authors read and approved the final manuscript.

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

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the local Institutional Review Board (IRB). The full name of institutional review board is Ethics Committee of Fujian Medical University Union Hospital. Written informed consent was waived by the IRB. All methods were performed in accordance with the relevant guidelines and regulations (e.g., Declaration of Helsinki).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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