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Article

Incidence, Timing, and Clinical Outcomes of Postoperative Atrial Fibrillation After On-Pump Versus Off-Pump Coronary Artery Bypass Grafting

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Abstract

Background: Postoperative atrial fibrillation (POAF) is common after coronary artery bypass grafting (CABG); however, whether POAF characteristics and follow-up outcomes differ between off-pump and conventional on-pump CABG remains incompletely defined. Clinically applicable tools for individualized postoperative mortality risk stratification after CABG are also required. Thus, this study aimed to compare the incidence and timing of POAF onset, perioperative course, and follow-up outcomes between on-pump and off-pump CABG, and to develop a mortality prediction nomogram. **Methods:** This retrospective cohort included 159 patients undergoing on-pump CABG and 518 undergoing off-pump CABG. In-hospital outcomes and follow-up events were compared between groups, and overall survival was assessed using Kaplan–Meier analysis. Predictors were selected using least absolute shrinkage and selection operator (LASSO)-penalized Cox regression and then entered into a multivariable Cox proportional hazards regression model for nomogram construction. **Results:** On-pump CABG was associated with longer operative time, more frequent blood product transfusion, and longer hospital stay (IQR 15 (12.5, 18) vs. 13 (10, 15) days; $p < 0.001$). The incidence of POAF was similar between groups (23.27% vs. 21.62%; $p = 0.661$), but onset occurred later after on-pump CABG (IQR 2 (2, 4) vs. 2 (1, 3) days; $p = 0.014$). Long-term outcomes did not differ significantly between groups, and disease-free survival was comparable (log-rank $p = 0.659$). In the multivariable Cox analysis, age (hazard ratio (HR) 1.10, 95% confidence interval (CI) 1.05–1.14), duration of mechanical ventilation (HR 1.02, 95% CI 1.01–1.04), and prior cerebrovascular accident (CVA) (HR 2.54, 95% CI 1.28–5.03) independently predicted mortality (all $p < 0.05$). A Cox-based nomogram was developed to estimate individualized 1-, 3-, and 5-year survival. **Conclusions:** In this cohort, on-pump and off-pump CABG had similar POAF incidence and comparable follow-up outcomes, supporting individualized operative strategy selection based on patient and procedural considerations. A Cox-based nomogram may aid postoperative mortality risk stratification, although external validation is required before broader clinical application.

Keywords: coronary artery bypass grafting; cardiopulmonary bypass; postoperative atrial fibrillation; survival analysis; nomogram

1. Introduction

Atrial fibrillation (AF) is the most common sustained arrhythmia worldwide and represents a major public health burden with a steadily increasing prevalence [1]. Contemporary estimates suggest that the number of individuals living with AF increased from approximately 33.5 million in 2010 to 59 million in 2019, and that the lifetime risk after the age of 45 years ranges from approximately one in five to one in three [2]. In cardiac surgery, postoperative atrial fibrillation (POAF) is the most common arrhythmic complication, occurring in approximately 20%–40% of patients after isolated coronary artery bypass grafting (CABG) [3]. Accumulating evidence indicates that POAF is not merely a transient rhythm disturbance but is associated with clinically important adverse outcomes, including stroke, mortality, prolonged intensive care unit (ICU) and hospital stay, and increased healthcare resource utilization [4,5]. POAF typically occurs early after surgery, with a peak around postoperative day 2, and often follows a self-limited course with spontaneous restoration of sinus rhythm over subsequent weeks [6,7]. Nevertheless, POAF may precipitate rapid ventricular rates and hemodynamic compromise requiring timely pharmacologic or electrical intervention. In addition, meta-analytic evidence suggests that POAF may also identify patients at increased longer-term risk after discharge, underscoring the importance of structured follow-up [8].

CABG can be performed either with cardiopulmonary bypass (CPB) and cardioplegic arrest (“on-pump” CABG) or on the beating heart without CPB (“off-pump” CABG/OPCABG). These two strategies differ in their technical requirements and the degree of perioperative physiologic stress. CPB has been proposed to increase POAF by increasing systemic inflammation and oxidative stress via blood contact with the extracorporeal circuit and by adding ischemia–reperfusion injury related to cardioplegic arrest [9]. Beyond systemic effects, on-pump CABG entails additional atrial manipulation for venous cannulation and

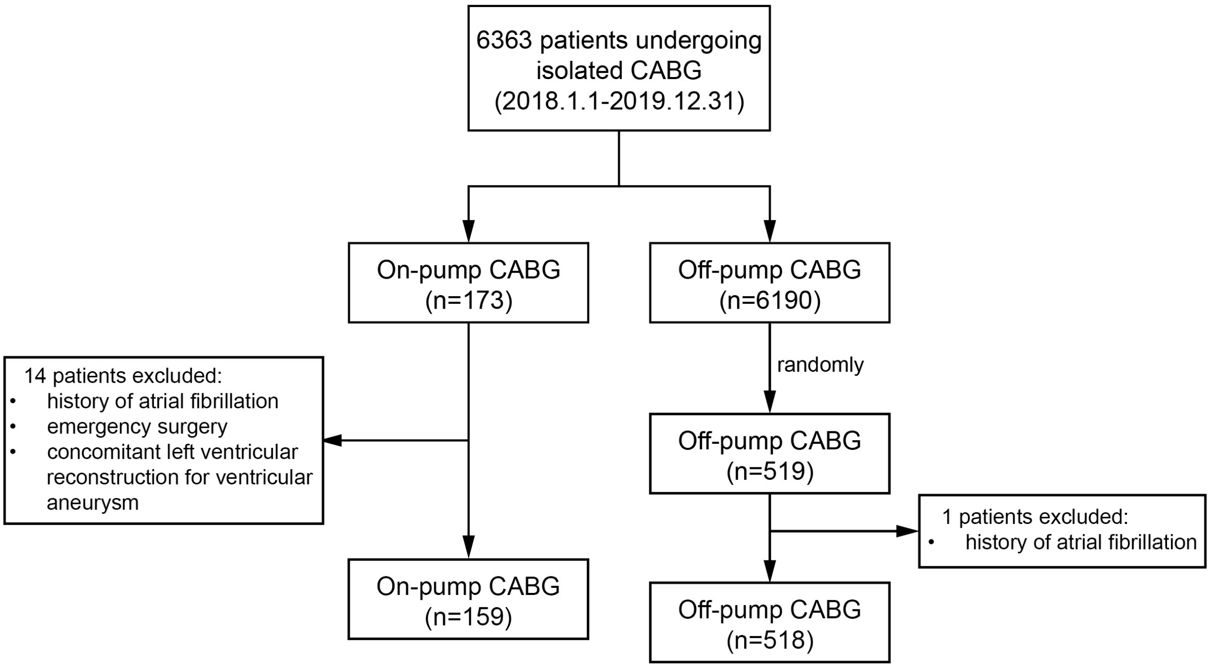

Fig. 1. Flow diagram of patient selection and cohort formation for the on-pump and off-pump CABG groups. CABG, coronary artery bypass grafting.

purse-string closure, which may lead to focal atrial injury. Experimental evidence suggests that atrial incision–related inflammation can promote conduction inhomogeneity and increase the susceptibility to AF [10]. OPCABG is technically demanding, as distal anastomoses are constructed on a beating heart, requiring mechanical displacement and stabilization to achieve adequate exposure, particularly for circumflex and posterior descending targets. These maneuvers may transiently compromise hemodynamics, result in atrial stretch, and reduce coronary perfusion, potentially leading to myocardial ischemia and, in severe cases, hemodynamic instability [11].

Risk factors for POAF remain incompletely defined, and the influence of operative strategy on POAF and subsequent outcomes after CABG is still debated. In addition, individualized postoperative risk stratification remains clinically relevant after CABG. Therefore, this study aimed to compare the incidence and timing of POAF, the perioperative course, and follow-up outcomes between off-pump and on-pump CABG, and to develop a Cox-based nomogram to predict individual mortality.

2. Materials and Methods

A total of 6363 adult patients who underwent isolated CABG between 1 January 2018 and 31 December 2019 were identified from the surgical database of Beijing Anzhen Hospital. During the study period, 173 patients underwent on-pump CABG with cardiopulmonary bypass. To mitigate the marked imbalance in procedural volume, 519 eligible off-pump CABG cases were selected by simple random sampling (random-number table) from patients treated during the same timeframe at a 1:3 ratio. After sampling, 14 on-pump patients were excluded because of a history of atrial fibrillation, emergency surgery, or concomitant left ventricular reconstruction for ventricular aneurysm, and 1 off-pump patient was excluded based on the predefined criteria, leaving 159 on-pump and 518 off-pump patients in the pre-matching cohort (Fig. 1).

Clinical and perioperative information was retrieved from the electronic medical record and institutional databases, including baseline demographics, cardiovascular risk factors, comorbidities, preoperative medications, and echocardiographic findings. Operative and anesthesia records were reviewed to capture procedural details such as coronary anatomy and target-vessel characteristics, preoperative rhythm status, echocardiographic parameters, the number of distal anastomoses, and graft configuration. For patients undergoing on-pump CABG, cardiopulmonary bypass–related variables (aortic cross-clamp duration, total CPB time, and cardioplegia administration) were also collected. Postoperative variables included ventilatory support duration, ICU and total hospital length of stay, drainage volume, blood product utilization, postoperative pharmacotherapy, and in-hospital complications, as well as mortality and morbidity endpoints recorded during the index admission. All patients underwent continuous electrocardiographic telemetry until the day of discharge, supplemented by 12-lead ECGs as clinically indicated. POAF was defined as new-onset atrial fibrillation (or atrial flutter) postoperatively, documented on telemetry rhythm strips or 12-lead ECG with characteristic AF features lasting ≥30 seconds [6].

Table 1. Patient characteristics.

Variables	Off-pump (n = 518)	On-pump (n = 159)	*p*
Age, years, median (Q1, Q3)	63 (56, 68)	61 (54, 66)	0.006
Sex, no (%)			0.259
Male	374 (72.20)	122 (76.73)	
Female	144 (27.80)	37 (23.27)	
BSA, m^2, mean ± SD	1.78 ± 0.18	1.81 ± 0.16	0.157
BMI, kg/m^2, median (Q1, Q3)	25.70 (23.73, 27.55)	25.80 (23.88, 28.44)	0.316
Smoking, no (%)	240 (46.33)	85 (53.46)	0.116
Clinical history, no (%)			
Hypertension	327 (63.13)	96 (60.38)	0.531
Diabetes mellitus	203 (39.19)	53 (33.33)	0.183
Dyslipidemia	181 (34.94)	47 (29.56)	0.209
COPD	5 (0.97)	2 (1.26)	1
Previous myocardial infarction	44 (8.49)	26 (16.35)	0.004
Previous PCI	72 (13.90)	24 (15.09)	0.706
Previous stroke	78 (15.06)	23 (14.47)	0.854
Peripheral arterial disease	13 (2.51)	2 (1.26)	0.529
Renal dysfunction	10 (1.93)	0 (0)	0.165
Number of diseased vessels			<0.01
1	8 (1.54)	1 (0.63)	
2 or left main	44 (8.49)	56 (35.22)	
3	466 (89.96)	102 (64.15)	
LVEF	58 (53, 63)	59.00 (51.00, 64.75)	0.012
LVEDD, mm, median (Q1, Q3)	48 (46, 52)	49 (46, 53)	0.094

BSA, Body Surface Area; PCI, percutaneous coronary intervention; COPD, Chronic Obstructive Pulmonary Disease; LVEDD, left ventricular end-diastolic diameter; BMI, body mass index.

Perioperative data were extracted from the electronic hospital records. Follow-up data were obtained through outpatient visits and telephone interviews. Patients who could not be reached by either method were classified as lost to follow-up. Cardiac death was defined as death attributable to myocardial infarction, heart failure, fatal arrhythmia, or other cardiovascular causes. Deaths with an unequivocal non-cardiovascular cause were classified as non-cardiac, whereas deaths of unknown cause were classified as unknown and were included only in all-cause mortality. Secondary outcomes included (1) Long-term atrial fibrillation defined as any episode of atrial fibrillation occurring more than 30 days after surgery and documented by 12-lead electrocardiography or ambulatory ECG monitoring; (2) stroke, including ischemic and hemorrhagic stroke, which was identified according to clinical diagnoses documented in patients' postoperative follow-up medical records; and (3) rehospitalization for cardiovascular causes requiring inpatient treatment.

Categorical variables are summarized as counts and percentages and were compared using the chi-square test or Fisher's exact test. Continuous variables are presented as mean ± SD for normally distributed data or median (IQR) for non-normally distributed data and were compared using the independent-samples *t*-test or the Mann–Whitney U test, as appropriate. Time-to-event outcomes were analyzed using the Kaplan–Meier method, and curves were compared using the log-rank test. Participants who did not experience the event were censored at the date of the last follow-up (last known contact). All tests were two-sided, and $p < 0.05$ was considered statistically significant. Statistical analyses and data visualization were performed using R (version 4.4.0; R Foundation for Statistical Computing, Vienna, Austria).

The least absolute shrinkage and selection operator (LASSO) regression was used for feature selection. Variables selected by LASSO were entered into a multivariable Cox proportional hazards model to develop the final prediction model, which was then visualized as a nomogram. Model performance was assessed by discrimination (C-index) and calibration plots.

3. Results

3.1 Baseline, Perioperative, and Long-Term Outcomes According to Surgical Strategy

Of the enrolled patients, 159 underwent on-pump CABG and 518 underwent off-pump CABG. The baseline demographic and clinical characteristics of the two groups are summarized in Table 1. There was no significant difference between the groups in sex, race, body mass index (BMI), body surface area (BSA), hypertension, diabetes mellitus, dyslipidemia, chronic obstructive pulmonary disease (COPD), history of percutaneous coro-

Table 2. Intraoperative and postoperative characteristics of patients undergoing off pump versus on pump CABG.

Variables	Off-pump (n = 518)	On-pump (n = 159)	p
Operative time, h, median (Q1, Q3)	4.83 (4.33, 5.41)	6.10 (5.50, 6.67)	<0.001
CPB time, min, median (Q1, Q3)	N/A	123 (85, 151)	N/A
ACC time, min, median (Q1, Q3)	N/A	95 (72, 123.25)	N/A
ICU hours, median (Q1, Q3)	20.83 (16.6, 26.16)	20.07 (15.95, 23.97)	0.201
Intubation duration (h)	19.5 (15.5, 22.5)	18.5 (15, 22)	0.520
24-h tube drainage (mL)	450 (250, 805)	400 (250, 600)	0.008
LVEDD (mm), median (Q1, Q3)	45 (42, 49)	46 (42.5, 50.5)	0.168
Blood product transfusion	144 (27.8)	72 (45.28)	<0.001
Postoperative outcomes			
In-hospital mortality	0 (0)	2 (1.26)	0.055
Deep sternal wound infection	0 (0)	1 (0.63)	0.235
Stroke	1 (0.19)	2 (1.26)	0.139
Pneumonia	0 (0)	1 (0.63)	0.235
Postoperative atrial fibrillation	112 (21.62)	37 (23.27)	0.661
Time to POAF development, day	2 (1, 3)	2 (2, 4)	0.014
Acute kidney injury requiring dialysis	1 (0.19)	2 (1.26)	0.139
ECMO used	0 (0)	1 (0.63)	0.235
Hospital-stay, days, median (Q1, Q3)	13 (10, 15)	15 (12.5, 18)	<0.001

CPB, Cardiopulmonary bypass; ACC, Aortic cross-clamp; ICU, intensive care unit; POAF, Postoperative atrial fibrillation; ECMO, Extracorporeal Membrane Oxygenation; N/A, not applicable.

Table 3. Follow-up outcomes.

Variables	Off-pump (n = 518)	On-pump (n = 159)	p
Follow-up time, months, median (Q1, Q3)	79.9 (74.21, 87.03)	87.1 (82.47, 89.2)	<0.001
All-cause death, no (%)	34 (6.56)	12 (7.55)	0.719
Cardiac death, no (%)	7 (1.35)	2 (1.26)	1
Atrial fibrillation, no (%)	6 (1.16)	0 (0)	0.379
Stroke, no (%)	15 (2.9)	3 (1.89)	0.682
Cardiovascular readmission, n (%)	42 (8.11)	7 (4.4)	0.115

nary intervention (PCI), history of peripheral artery disease (PAD), or history of cerebrovascular accident (CVA). Patients in the off-pump group were older than those in the on-pump group, with median ages of 63 (56, 68) and 61 (54, 66) years, respectively ($p = 0.006$). The on-pump group had a higher prevalence of previous myocardial infarction (16.35% vs 8.49%; $p = 0.004$) and a different distribution of the number of diseased vessels compared with the off-pump group ($p < 0.01$). Left ventricular ejection fraction also differed slightly between groups, with a median LVEF of 58% (53, 63) in the off-pump group and 59% (51, 64.75) in the on-pump group ($p = 0.012$; Table 1).

Perioperative and postoperative outcomes are shown in Table 2. Operative time was longer in the on-pump group than in the off-pump group, with median values of 6.10 (5.50, 6.67) and 4.83 (4.33, 5.41) h, respectively ($p < 0.001$). In the on-pump cohort, the median cardiopulmonary bypass (CPB) time was 123 (85–151) min, and the median aortic cross-clamp (ACC) time was 95 (72–123.25) min. Postoperative 24-h chest tube drainage was lower in the on-pump group (400 (250–600) vs 450 (250–805) mL; $p = 0.008$), whereas ICU stay and intubation duration were similar between groups. Blood product transfusion was more frequent after on-pump CABG (Table 2).

Regarding postoperative outcomes, the incidence of POAF was comparable between the on-pump and off-pump groups (23.27% vs 21.62%; $p = 0.661$). Notably, the time to POAF onset differed, with onset shifted toward later postoperative days in the on-pump group (2 (2–4) vs 2 (1–3) days; $p = 0.014$). Other in-hospital adverse events were infrequent and did not differ between groups (all $p > 0.05$), including in-hospital mortality, deep sternal wound infection, stroke, pneumonia, acute kidney injury requiring dialysis, and ECMO use. By contrast, length of hospital stay was significantly longer in the on-pump group (15 (12.5–18) vs 13 (10–15) days; $p < 0.001$) (Table 2). Follow-up outcomes are summarized in Table 3. Follow-up was completed in 546 patients (80.65%), including 434 off-pump patients (83.78%) and 112 on-pump patients (70.44%). Patients without complete follow-up were censored at the last available contact. The on-pump group had a longer median follow-up duration than the off-pump group (87.1 (82.47–89.2) vs 79.9 (74.21–87.03) months; $p < 0.001$). Long-term outcomes were comparable between groups, with no signif-

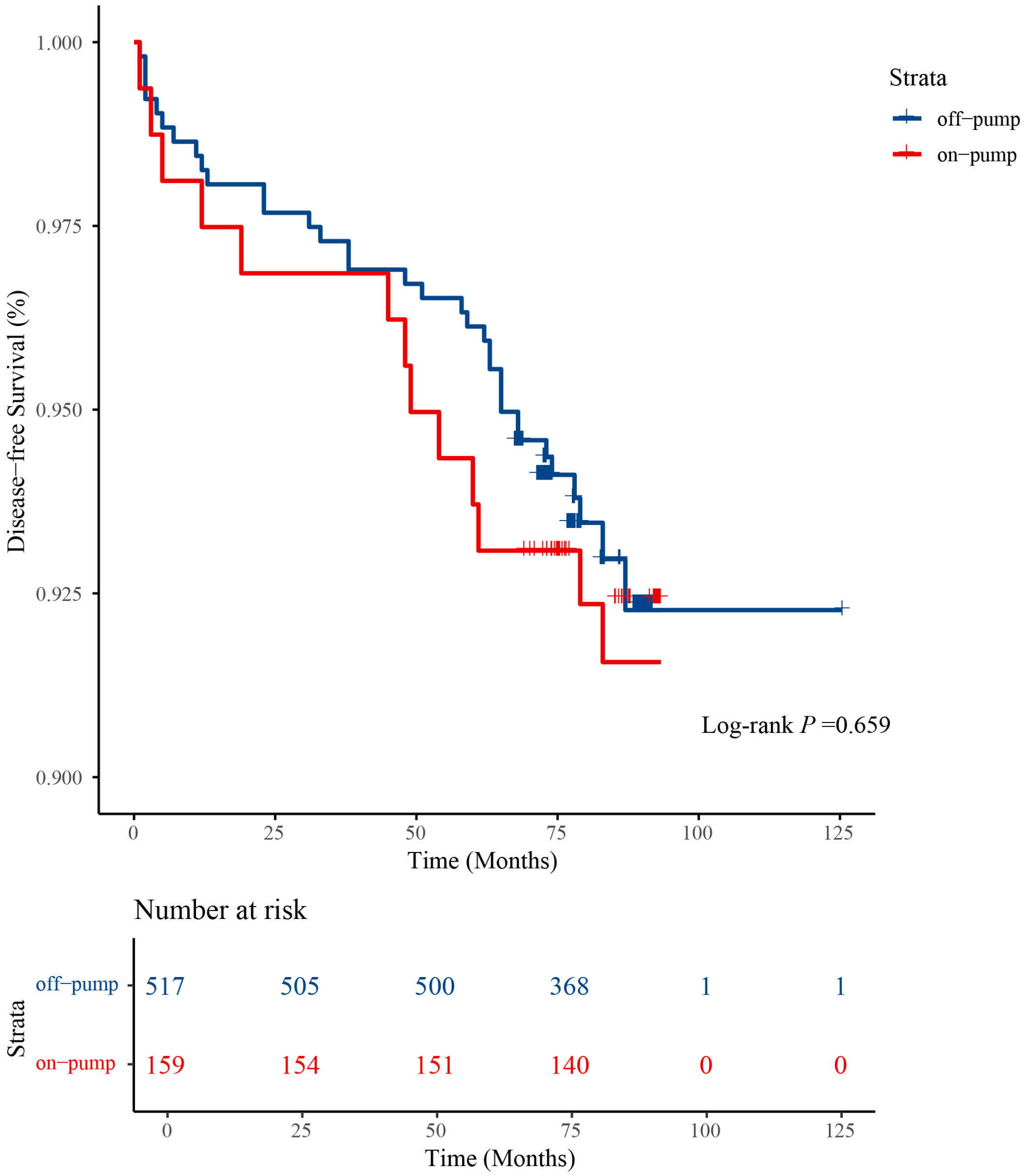

Fig. 2. Kaplan–Meier curves for disease-free survival in the on-pump and off-pump groups.

icant between-group differences in major events, including all-cause death, cardiac death, late atrial fibrillation, stroke, and cardiovascular readmission. Kaplan–Meier analysis demonstrated no significant difference in disease-free survival between the on-pump and off-pump strategies (log-rank $p = 0.659$; Fig. 2).

3.2 Prognostic Factor Identification and Nomogram Development

Candidate variables were entered into a LASSO-penalized Cox model, including preoperative characteristics, operative variables, and early postoperative course variables. Using cross-validation to determine the optimal penalty parameter, the LASSO model selected six variables with non-zero coefficients: age, duration of mechanical ventilation, history of cerebrovascular accident, hypertension, ICU length of stay, and postoperative IABP use (Fig. 3A,B). These variables were subsequently included in a multivariable Cox proportional hazards model (Table 3). In the adjusted model, older age (HR 1.10, 95% CI 1.05–1.14; $p < 0.001$), longer mechanical ventilation duration (HR 1.02, 95% CI 1.01–1.04; $p < 0.001$), and prior cerebrovascular accident (HR 2.54, 95% CI 1.28–5.03; $p = 0.008$) were independently associated with higher mortality, whereas hypertension (HR 0.54, 95% CI 0.30–0.99; $p = 0.049$) and ICU length of stay (HR 0.99, 95% CI 0.97–0.99; $p = 0.036$) were also significant. Postoperative IABP use was not significant after adjustment (HR 0.20, 95% CI 0.02–2.07; $p = 0.179$) (Fig. 4). Based on the multivariable Cox model, a nomogram was developed to estimate individualized 1-, 3-, and 5-year survival probabilities (Fig. 3C).

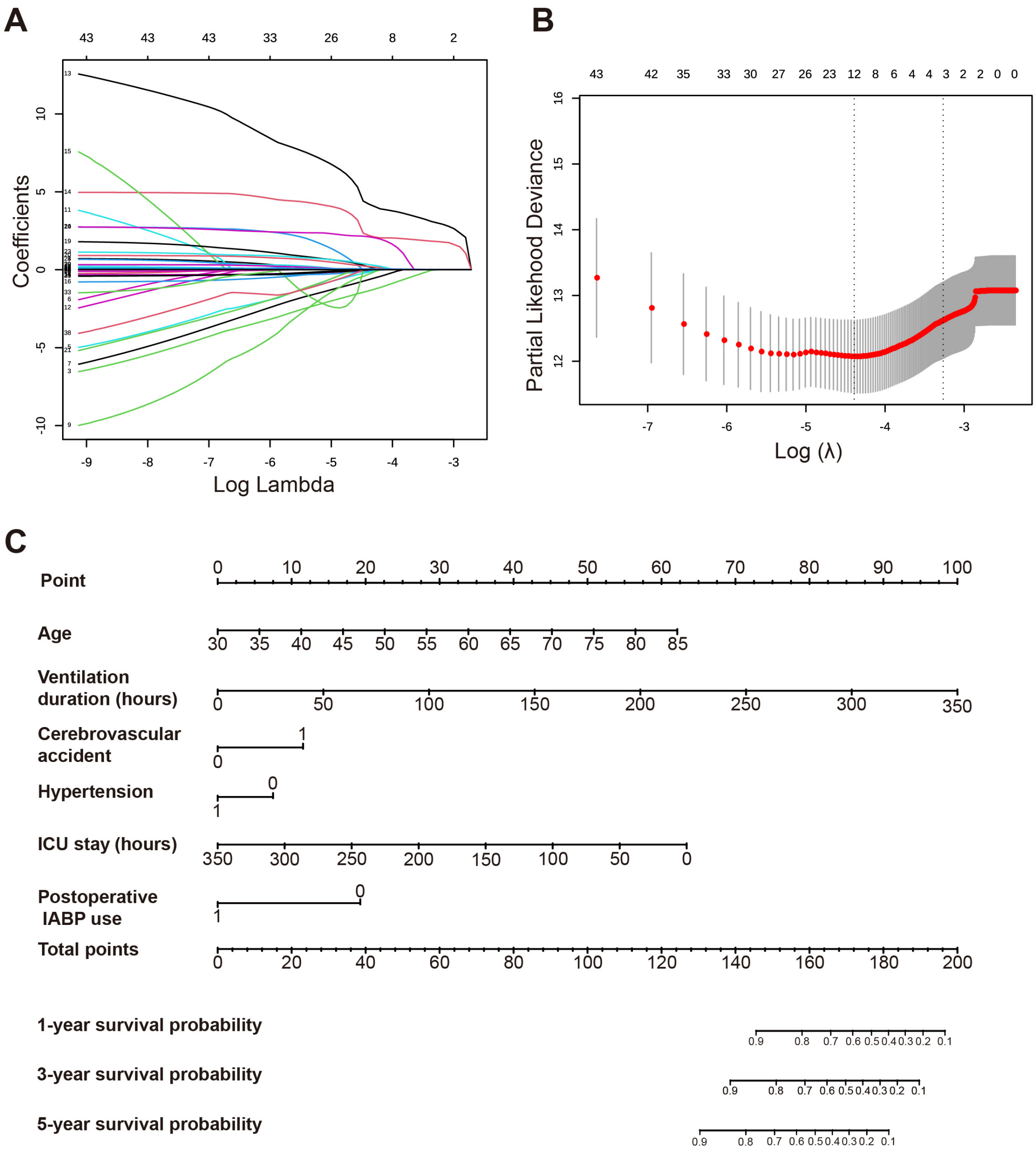

Fig. 3. Variable selection by LASSO Cox regression and construction of the prognostic nomogram. (A) LASSO coefficient profiles of candidate predictors. (B) Cross-validation for identification of the optimal penalty parameter in the LASSO Cox model. (C) Nomogram for predicting 1-, 3-, and 5-year survival after CABG.

4. Discussion

In this retrospective cohort of patients undergoing CABG, operative and early postoperative characteristics differed between surgical strategies: on-pump CABG was associated with longer operative time and more frequent blood product transfusion, whereas ICU length of stay and duration of intubation were comparable. Importantly, POAF incidence did not differ between strategies, although the distribution of onset timing shifted toward later postoperative days in the on-pump group. Despite these perioperative differences, long-term outcomes—including all-cause death, cardiac death, late atrial fibrillation, stroke, and cardiovascular readmission—were comparable. Using penalized variable selection followed by multivariable Cox modeling, age, duration of mechanical ventilation, and CVA history emerged as independent predictors of mortality, and these variables were used to develop a postoperative nomogram to estimate individualized mid-term survival. Overall, these findings are consistent with recent meta-analytic evidence showing comparable long-term mortality between on-pump and off-pump CABG strategies in well-selected patients [12].

Consistent with previous reports emphasizing the technical complexity and experience-dependent nature of off-pump CABG [13], our findings should be interpreted

Variable	HR (95% CI)	P value
Age (per 1 year)	1.10 (1.05–1.14)	<0.001
Ventilation duration (per 1 hour)	1.02 (1.01–1.04)	<0.001
Cerebrovascular accident (Yes vs No)	2.54 (1.28–5.03)	0.008
Hypertension (Yes vs No)	0.54 (0.30–0.99)	0.049
ICU stay (per 1 hour)	0.99 (0.97–0.99)	0.036
Postoperative IABP use (Yes vs No)	0.20 (0.02–2.07)	0.179

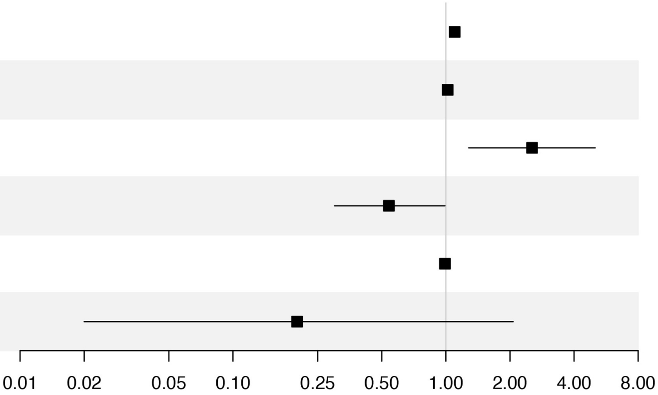

Fig. 4. Forest plot of multivariable Cox regression analysis.

in the context of a high-volume cardiovascular center with established expertise in off-pump surgery. Nevertheless, surgeon-level experience, intraoperative hemodynamic stability, and completeness of revascularization were not fully captured, and residual confounding cannot be excluded. Off-pump CABG is intrinsically more technically demanding because distal anastomoses must be constructed on a beating heart under limited exposure and stabilization, which can affect hemodynamicstability and potentially affect the completeness of revascularization and graft durability. When these technical challenges are not fully mitigated, evidence from randomized trials and observational analyses suggests that off-pump CABG may be associated with lower graft patency and/or higher rates of incomplete or less durable revascularization compared with conventional on-pump surgery [14]. Accordingly, operative strategy should be individualized by balancing anticipated technical complexity against patient-specific benefits, surgeon experience, and the likelihood of safe and complete revascularization, with a low threshold for elective conversion to cardiopulmonary bypass when necessary.

Contemporary guidelines support an individualized approach to isolated CABG. In patients with significant aortic calcification, techniques that avoid aortic manipulation are considered reasonable to reduce perioperative stroke when performed by experienced surgeons [15]. Beyond aortic pathology, strategy selection is also influenced by patient comorbidities, operative risk, coronary anatomical complexity, feasibility of complete revascularization, and surgeon experience with OPCABG [13]. In our cohort, baseline LVEF, left main disease, and three-vessel disease were comparable between the on-pump and off-pump groups, suggesting that differences in these key markers of disease severity were unlikely to be the primary drivers of strategy selection. The remaining "gray-zone" decision-making may therefore reflect factors not fully captured in our dataset. The literature, however, is not uniform: the ROOBY-FS follow-up reported less favorable 5-year outcomes after off-pump CABG in its study setting, and meta-analyses of randomized trials have suggested that any long-term differences, when present, may be mediated by factors such as completeness of revascularization and graft durability rather than short-term perioperative morbidity alone [16]. In GOPCABE, incomplete revascularization occurred more frequently with off-pump CABG and was associated with lower survival, underscoring the importance of technical completeness and institutional experience when interpreting comparisons between techniques [17].

POAF remains one of the most frequent complications after cardiac surgery, with an incidence commonly in the 15–40% range, and typically presents on postoperative days 2–4 [18]. In the present cohort, the similar POAF incidence between on-pump and off-pump groups suggests that avoidance of cardiopulmonary bypass alone may be insufficient to significantly reduce the risk of POAF in routine clinical practice. Mechanistically, POAF is multifactorial (operative trauma, atrial stretch, autonomic imbalance, and systemic inflammation/oxidative stress), and cardiopulmonary bypass can further amplify inflammatory and oxidative pathways through circuit exposure and ischemia–reperfusion injury [9]. The later distribution of POAF onset observed in the on-pump group may reflect differences in postoperative inflammatory kinetics, fluid balance, transfusion exposure, or sedation and warrants cautious interpretation. This pattern could be examined further by modeling time to in-hospital POAF while accounting for competing events (e.g., discharge without POAF and in-hospital death) and by stratifying analyses according to perioperative exposures. Clinically, POAF is increasingly recognized as more than a transient inpatient event. Meta-analyses have linked POAF after cardiac surgery and after CABG specifically with higher long-term mortality, supporting the need for structured follow-up and attention to recurrence, stroke prevention, and risk-factor modification beyond discharge [19].

In the nomogram-based model, age remains a key determinant of long-term survival after CABG in large registry-linked survival models [20]. Prolonged postoperative ventilation has been associated with increased morbidity and early mortality and is commonly interpreted as an integrative marker of perioperative cardiopulmonary dysfunction and postoperative complications [21], making ventilation duration a practical early signal to identify patients who may benefit from intensified pulmonary optimization, rehabilitation, and closer post-discharge surveillance. CVA likewise likely captures systemic atherosclerotic burden and vulnerability to perioperative neurologic injury; consistent with this, large CABG cohorts and meta-analytic evidence have shown that perioperative stroke is associated with a markedly increased risk of mortality [22].

In contrast, the inverse associations observed for hypertension and ICU length of stay (ICU LOS) warrant cautious interpretation. Hypertension may appear "protective" due to confounding and treatment effects, while the "no hypertension" category may include patients with lower baseline blood pressure related to frailty or reduced cardiac output; in very old adults, lower systolic blood pressure has been associated with higher mortality, consistent with reverse causation [23]. Although ICU LOS is clinically informative, it was not included as a fixed baseline predictor because it is a postoperative variable rather than a preoperative risk factor. Moreover, its association with mortality appears non-linear, with substantially higher risk observed after prolonged ICU stays [24]. Accordingly, ICU LOS in this model should be interpreted primarily as a predictive marker of postoperative trajectory rather than a causal protective factor [23]. Postoperative IABP use, although selected by LASSO, did not remain significant after adjustment; its prognostic signal depends on indication and timing, with meta-analyses suggesting benefit for prophylactic IABP in high-risk CABG [25], whereas rescue or postoperative IABP use after cardiac surgery identifies a clinically unstable cohort with substantially higher early and 1-year mortality [26]. In addition, an observational cohort comparing preoperative versus intraoperative insertion reported no significant difference in 30-day mortality, underscoring the susceptibility of IABP variables to confounding by indication and collinearity with other severity markers [27]. Because the nomogram incorporated post-treatment variables, including ventilation duration and ICU LOS, it should be interpreted as an early postoperative risk stratification tool rather than a preoperative decision-making model for selecting surgical strategy. Its clinical utility should be further validated in independent cohorts.

Limitations

The current study has several limitations. First, the comparison between on-pump and off-pump CABG was not randomized, and the retrospective, single-center design may have introduced selection bias and residual confounding, thereby limiting the generalizability of the findings. Second, the relatively limited sample size and follow-up duration may have reduced the statistical power and precluded a comprehensive assessment of late clinical outcomes. Further large-scale, prospective randomized controlled studies with longer follow-up are warranted to confirm these findings.

5. Conclusions

In summary, on-pump and off-pump CABG demonstrated similar POAF incidence and comparable long-term outcomes in this cohort. Age, duration of mechanical ventilation, and cerebrovascular disease were robust predictors of mortality, underscoring the prognostic value of both baseline comorbidity burden and early postoperative course. The resulting nomogram may enable early postoperative risk stratification, but careful interpretation of postoperative predictors and rigorous external validation are required prior to broad clinical application.

Abbreviations

POAF, Postoperative atrial fibrillation; CABG, coronary artery bypass grafting; AF, Atrial fibrillation; LASSO, least absolute shrinkage and selection operator; BMI, body mass index; BSA, body surface area; COPD, chronic obstructive pulmonary disease; PCI, percutaneous coronary intervention; PAD, peripheral artery disease; CVA, cerebrovascular accident; CPB, cardiopulmonary bypass; ACC, aortic cross-clamp; ICU, intensive care unit.

Availability of Data and Materials

Data may be made available upon reasonable request to the corresponding author.

Author Contributions

XX, JW contributed to study conception and design. XX and CZ contributed to data collection and analysis. XX contributed to the interpretation of data for the work. XX, CZ, and JW contributed to manuscript drafting and revision. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This retrospective cohort study was approved by the Institutional Review Board of Beijing Anzhen Hospital (approval No. KS2025262). The requirement for written informed consent was waived by the Institutional Review Board because of the retrospective nature of the study and the use of anonymized clinical data. The study was conducted in accordance with the principles of the Declaration of Helsinki.

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Conflicts of Interest

The authors declare no conflicts of interest.

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