CLINICAL INVESTIGATIONS

Hemodynamic parameters predict the risk of atrial fibrillation after cardiac surgery in adults

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Background: Postoperative atrial fibrillation (POAF) is a common complication following cardiac surgery and is associated with poorer prognosis. This study attempted to evaluate whether hemodynamic parameters determined by a right heart catheter predict the occurrence of POAF.

Hypothesis: We hypothesized that atrial fibrillation after cardiac surgery can be predicted by hemodynamic parameters determined by a right heart catheter.

Methods: Between October 2015 and January 2017, 126 patients with preoperative sinus rhythm undergoing coronary artery bypass grafting and/or aortic valve replacement were enrolled in this study. Complete echocardiographic examination was performed preoperatively, and hemodynamic parameters were recorded via a right heart catheter before anesthesia induction. Postoperative telemetry strips and electrocardiogram were used to detect atrial fibrillation until discharge. Multivariate logistic regression was used to identify risk factors of POAF.

Results: The overall incidence of POAF was 40/126 (31.7%). Multivariate logistic regression analysis determined that left atrial dimension (LAD) (adjusted odds ratio [OR]: 1.118, 95% confidence interval [CI]: 1.020-1.227, $P = 0.018$), pulmonary capillary wedge pressure (PCWP) (adjusted OR: 1.225, 95% CI: 1.082-1.387, $P = 0.001$), and pulmonary artery systolic pressure (PASP) (adjusted OR: 1.076, 95% CI: 1.019-1.137, $P = 0.008$) were significant predictors of POAF.

Conclusions: The present study suggested that LAD, PCWP, and PASP were robust predictors of POAF. These parameters may indicate a patient's susceptibility toward developing POAF and help to identify patients who need preventive treatment.

KEYWORDS

Hemodynamic Parameters, Postoperative Atrial Fibrillation, Pulmonary Artery Systolic Pressure, Pulmonary Capillary Wedge Pressure

1 | INTRODUCTION

Postoperative atrial fibrillation (POAF) is a frequent complication after cardiac surgery and affects approximately one-third of all patients.¹⁻³ It is the most common form of postoperative arrhythmia and is associated with higher mortality, hemodynamic instability, and a prolonged hospital stay.⁴⁻⁶ POAF most commonly occurs between the second and the fourth postoperative days.^{5,7,8}

Risk factors confirmed to be associated with POAF after cardiac surgery mainly include advanced/increasing age, chronic obstructive pulmonary disease (COPD), elevated plasma B-type natriuretic peptide levels, and renal dysfunction.⁹⁻¹¹ Beyond these, certain echocardiographic parameters, such as left atrial dimension (LAD) and left ventricular function, have also been shown to be associated with POAF.^{12,13} Right heart catheterization is widely used in cardiac surgery to detect the hemodynamic parameters and to guide the use of vasoactive drugs, but previous studies have not shown the effect of hemodynamic parameters in predicting POAF after cardiac surgery.

Rongxin Lu and Nan Ma were co-first authors and contributed equally to this work.

The aim of the present study was to evaluate whether hemodynamic parameters determined by a right heart catheter were predictors of POAF following cardiac surgery.

2 | METHODS

2.1 | Study population

We performed a single-center, prospective cohort study. A total of 126 patients undergoing coronary artery bypass grafting and/or aortic valve replacement between October 2015 and January 2017 were recruited to this study. Patients with a history of atrial fibrillation (AF) or flutter, defined as detection of AF or flutter on any single electrocardiogram (ECG), were excluded from the analysis. The other exclusion criterion was use of antiarrhythmic drugs within 1 week preoperatively, combined with congenital heart disease, end-stage renal failure, and implanted cardiac pacemaker. Complete ECG evaluation was performed. Baseline clinical data and demographics obtained for each patient included age, gender, history of diabetes, hypertension, smoking, cerebral infarction, and COPD. Preoperative medications were documented, including β -blockers, diuretic, statins, angiotensin-converting enzyme inhibitors, angiotensin receptor blocker, anticoagulants, and calcium channel blockers. Informed consent was obtained from all study subjects before all procedures, and the protocol was approved by the local ethics committee.

2.2 | Hemodynamics

All patients underwent cardiac catheterization through a right internal jugular vein access. Hemodynamic parameters were measured with a balloon-tipped pulmonary artery catheter (Swan-Ganz; Edwards Lifesciences, Irvine, CA). The correct positioning of the catheter was confirmed by the appearance of a typical wedge pressure waveform or by fluoroscopy. Each detection was repeated 3 times, and the results were averaged. The recorded hemodynamic parameters mainly included the following: central venous pressure, pulmonary capillary wedge pressure (PCWP), pulmonary arterial systolic pressure (PASP), cardiac index (CI), systemic vascular resistance, pulmonary vascular resistance, and stroke volume.

2.3 | Postoperative management and grouping

Patients were continuously monitored by telemetry strips to assess cardiac rhythm during the intensive care unit (ICU) stay. A standard 12-lead ECG was obtained each morning for all patients until discharge. When AF was suspected on the telemetry strip or if the patient felt palpitations, a 12-lead ECG recording was performed to confirm the diagnosis. In this study, the definition of AF was the absence of a P wave before the QRS wave with irregular ventricular rhythm on a 12-lead ECG. In addition, an AF wave lasting for 30 s or more was necessary for the diagnosis of POAF. If POAF was definitively diagnosed, antiarrhythmia drugs, including amiodarone and/or esmolol, were administered. Electrical cardioversion was performed if pharmacological treatment failed to restore sinus rhythm or if there was the presence of hemodynamic instability. Based on whether they

developed POAF, patients were divided into 2 groups: the POAF group and the non-POAF group.

2.4 | Statistical analysis

All continuous variables are presented as the mean $\pm$ standard deviation. Continuous variables were tested for normality using the Levene test. A *t* test was applied for normally distributed continuous variables, and the Mann-Whitney *U* test was applied for variables without normal distribution. Categorical variables, presented as number (%), were compared using the χ^2 test or Fisher exact test (when appropriate). Multiple logistic regression analysis was used to determine the predictors of POAF after adjusting for age, gender, left ventricular ejection fraction (LVEF), hypertension, β -blocker use, type of surgery, and CI. The odds ratio (OR) and 95% confidence interval for each independent variable in the regression model were presented. A 2-tailed *P* value <0.05 was considered statistically significant. Statistical analyses were performed with the SPSS version 20 software (IBM, Armonk, NY).

3 | RESULT

A total of 126 patients were included in this study. POAF was documented in 40 patients (31.7%). Patients were divided into the POAF group (*n* = 40) and the non-POAF group (*n* = 86) based on whether they developed POAF. Baseline and preoperative characteristics of all enrolled patients are summarized in Table 1, as well as comparisons of preoperative clinical variables in patients with and without POAF. Patients with POAF were significant older (65.3 ± 8.8 vs 61.3 ± 9.7 years, *P* = 0.032) with a larger LAD (41.6 ± 5.4 vs 37.9 ± 3.9 mm, *P* < 0.001) than those without POAF. There was no significant difference in sex distribution, hypertension, diabetes, smoking history, cerebral infarction, COPD, and medications between the 2 groups. All patients with POAF received intravenous amiodarone for pharmacological cardioversion, and 17 patients with hemodynamic instability required both pharmacological and electrical cardioversion, 4 had persistent AF lasting longer than 24 h, and β -blockers were administered to 7 patients who failed to exhibit a well-controlled ventricular rate.

Comparisons of hemodynamic parameters detected by the right heart catheter in patients with and without POAF are shown in Table 2. Both PCWP and PASP were higher in the POAF group compared with the non-POAF group (PCWP, 13.4 ± 3.8 vs 10.5 ± 3.7 mmHg, *P* < 0.001; PASP, 31.8 ± 9.5 vs 26.9 ± 8.1 mmHg, *P* = 0.004). However, patients with POAF had a lower CI (2.48 ± 0.59 vs 2.69 ± 0.50 L/min/m², *P* = 0.044). Other hemodynamic parameters did not show significant differences between the 2 groups.

In a multivariable logistic regression model that adjusted for age, sex, type of surgery, LVEF, hypertension, use of β -blockers, and CI, the independent predictors of POAF were LAD (adjusted OR: 1.118, 95% confidence interval: 1.020-1.227, *P* = 0.018), PCWP (adjusted OR: 1.225, 95% confidence interval: 1.082-1.387, *P* = 0.001), and PASP (adjusted OR: 1.076, 95% confidence interval: 1.019-1.137,

TABLE 1 Preoperative clinical findings among patients with or without POAF

Characteristic	POAF, n = 40	No POAF, n = 86	P
Age, y	65.3 ± 8.8	61.3 ± 9.7	0.032
Male sex, n (%)	26 (65)	53 (62)	0.716
Hypertension, n (%)	27 (68)	50 (58)	0.316
Diabetes, n (%)	15 (38)	29 (34)	0.679
COPD, n (%)	6 (15)	9 (10)	0.464
Cerebral infarction, n (%)	6 (15)	11 (13)	0.735
NYHA class, n (%)			0.231
I-II	31 (78)	74 (86)	
III-IV	9 (22)	12 (14)	
LVEF %	54.4 ± 8.1	57.1 ± 7.9	0.073
LAD, mm	41.6 ± 5.4	37.9 ± 3.9	<0.001
Congestive heart failure, n (%)	6 (15)	10 (11)	0.597
Smoking history, n (%)	15 (38)	23 (27)	0.221
Drinking history, n (%)	14 (35)	22 (26)	0.276
β-Blockers, n (%)	21 (53)	55 (64)	0.221
Calcium channel blocker, n (%)	10 (25)	16 (19)	0.409
Anticoagulants, n (%)	17 (43)	29 (34)	0.341
ACEI or ARB, n (%)	18 (45)	38 (44)	0.932
Statins, n (%)	18 (45)	27 (31)	0.138
Diuretics, n (%)	14 (35)	40 (47)	0.224
Type of surgery, n (%)			0.339
Valvular	22 (55)	38 (44)	
Coronary	15 (37)	44 (51)	
Valvular + coronary	3 (8)	4 (5)	

Abbreviations: ACEI, angiotensin-converting enzyme inhibitors; ARB, angiotensin receptor blocker; COPD, chronic obstructive pulmonary disease; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; POAF, postoperative atrial fibrillation.

$P = 0.008$); the remaining factors were not independent predictors of POAF (Table 3).

The prognostic indicators are shown in Table 4. POAF was associated with increased use of the intra-aortic balloon pump (IABP) (33% vs 16%, $P = 0.039$). Patients with POAF also had a longer ICU stay (5.6 ± 3.2 vs 4.6 ± 2.3 days, $P = 0.044$) and prolonged postoperative hospitalization (16.7 ± 5.5 vs 14.9 ± 3.4 days, $P = 0.027$). There were no significant differences between the 2 groups in

TABLE 2 Hemodynamic indexes of patients with and without POAF

Characteristic	POAF, n = 40	No POAF, n = 86	P
CVP (cm H ₂ O)	10.9 ± 1.6	10.6 ± 1.5	0.879
CI (L/min/m ²)	2.48 ± 0.59	2.69 ± 0.50	0.044
SVR (dyn/s/cm ⁵)	1110.9 ± 123.8	1083.6 ± 161.8	0.345
PASP (mm Hg)	31.8 ± 9.5	26.9 ± 8.1	0.004
PCWP (mm Hg)	13.4 ± 3.8	10.5 ± 3.7	<0.001
PVR (dyn/s/cm ⁵)	169.8 ± 33.9	161.5 ± 34.6	0.209
SV (mL)	62.6 ± 9.4	65.4 ± 10.1	0.144

Abbreviations: CI, cardiac index; CVP, central venous pressure; PASP, pulmonary artery systolic pressure; PCWP, pulmonary capillary wedge pressure; POAF, postoperative atrial fibrillation; PVR, pulmonary vascular resistance; SV, stroke volume; SVR, systemic vascular resistance.

TABLE 3 Multivariable logistic regression models for the prediction of POAF

	Odds Ratio	95% Confidence Interval	P
Age, y	1.011	0.959-1.065	0.690
Sex, male	1.104	0.5435-2.803	0.836
LAD (mm)	1.118	1.020-1.227	0.018
LVEF (%)	0.953	0.900-1.010	0.105
Hypertension	2.167	0.789-5.950	0.134
PCWP (mm Hg)	1.225	1.082-1.387	0.001
PASP (mm Hg)	1.076	1.019-1.137	0.008
CI (L/min/m ²)	0.829	0.353-1.946	0.667
Type of surgery			0.708
Coronary	Ref	—	
Valve	1.087	0.412-2.867	0.866
Valve + coronary	2.270	0.327-15.749	0.407
Use of β-blockers	0.502	0.193-1.308	0.158

Abbreviations: CI, cardiac index; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; PASP, pulmonary artery systolic pressure; PCWP, pulmonary capillary wedge pressure; POAF, postoperative atrial fibrillation.

mechanical ventilation time, lung infection, use of continuous renal replacement therapy, mortality and ventricular arrhythmia during hospitalization. Cerebral infarctions did not occur in either group.

4 | DISCUSSION

POAF is a frequent complication of cardiac surgery and is associated with worse clinical outcomes. Considerable work has focused on predicting the occurrence of POAF but had limited results. This is the first time that a right heart catheter was used as a tool for predicting POAF and the first time that both PASP and PCWP were identified as powerful predictors of POAF.

Although elevated left atrial pressure (LAP) was widely recognized to play an important role in the development of AF,¹⁴ previous studies have not evaluated elevated LAP (measured as PCWP) in the occurrence of POAF. PCWP was widely used as an indirect measure of LAP. Nagy et al. had found that the clinical use of PCWP as an estimate of LAP was effective during both the physiological and pathological states.¹⁵ LAP is an indicator for atrial and pulmonary vein stretch and plays a key role in the development and maintenance of AF.¹⁶ A recent study had found that prolonged P-wave duration was associated with higher LAP in AF patients; they suggested that pressure overload of the left atrium might slow down atrial electrical activation.¹⁷ It has been reported that chronic atrial stretch induces structural remodeling.¹⁸ Left atrial interstitial fibrosis develops after exposure to elevated LAP and may cause electrical and mechanical remodeling, which will ultimately facilitate the development of AF.¹⁹ In summary, identifying elevated LAP may not only lead to a better understanding of the mechanism of POAF but also predict the occurrence of POAF.

Whether elevated PASP is associated with the development of POAF is still under debate. Malik et al. showed that higher PASP was associated with a lower risk of AF after lung transplantation, and they

TABLE 4 Postoperative data of the two groups

Characteristic	POAF, n = 40	No POAF, n = 86	P
Mechanical ventilation, h	43.6 ± 28.0	34.2 ± 23.8	0.055
IABP, n (%)	13 (33)	14 (16)	0.039
Lung infection, n (%)	8 (20)	11 (13)	0.292
Ventricular arrhythmia, n (%)	6 (15)	7 (8)	0.239
CRRT, n (%)	3 (8)	4 (5)	0.816
ICU stay, d	5.6 ± 3.2	4.6 ± 2.3	0.044
Postoperative hospitalization, d	16.7 ± 5.5	14.9 ± 3.4	0.027
Mortality during hospitalization, n (%)	2 (5)	3 (3)	1.000

Abbreviations: CRRT, continuous renal replacement therapy; IABP, intra-aortic balloon pump; ICU, intensive care unit; POAF, postoperative atrial fibrillation.

thought the potential mechanism may be that elevated right-sided pressure prevents the expansion of the left atrium, and the blockade of the pulmonary vein during surgical procedures may also contribute to a lower risk of POAF.²⁰ Their conclusion appears to be contrary to ours, and the difference in disease models and preoperative pathophysiological changes may contribute to the different mechanisms of POAF. Our research showed that elevated PASP was an independent predictor of POAF and was in accordance with a retrospective study that suggested that pulmonary hypertension, as evaluated by transthoracic echocardiography, was associated with an increased prevalence of POAF.²¹ The potential mechanism can be explained as 2 aspects: (1) In some patients, the simultaneously elevated PASP and PCWP may both reflect the overloading of left heart, which was mostly recognized to be responsible for the occurrence of POAF. (2) In other patients with elevated PASP but normal PCWP, the overloading of left heart may not be the main cause of POAF. The elevated PASP may cause the matrix remodeling of the right atrium, which was also thought to be the ectopic activity of AF.^{22,23} A previous study concerning the association between right atrial fibrosis and AF had suggested that right atrial fibrosis was positively correlated with PASP.²⁴ We have reason to believe that the elevated PASP may also participate in the pathophysiology of POAF. Whether the elevated PASP was only a reflection of left heart filling pressure or may also be associated with POAF by participating right atrial matrix remodeling deserves further research.

4.1 | Study limitations

The main limitation of the present study is the relatively small sample size. An additional limitation is that it was a single-center study. Both limitations may have biased the investigation. Furthermore, all of the hemodynamic parameters were achieved before thoracotomy, and therefore, anesthesia may have impacted the accuracy of the results, and the parameters may fluctuate significantly postoperatively. Future research should focus on postoperative dynamic changes of hemodynamic parameters and their impact on the occurrence of POAF in a larger cohort of patients.

5 | CONCLUSION

The impact of POAF on postoperative recovery has been widely recognized as hemodynamic instability and thrombotic events. The

present research showed that more patients in the POAF group needed the use of IABP. There were no cases of cerebral infarction, which can be explained as the timely use of anticoagulants and mild clinical symptoms. PASP and PCWP that were determined by a right heart catheter were accurate and easily obtained predictors for POAF, allowing for the identification of patients at a high risk of POAF, which may help identify patients who need prophylactic measures. Meanwhile, the present research may provide a new treatment strategy for POAF, which involves the effective control of PCWP and PASP. As PCWP and PASP were found to be predictors of POAF, preventing the overload of the left heart is an effective way of lowering PCWP and PASP, and would minimize the incidence of POAF. Drugs that reduce PASP may have the same effect of preventing POAF.

Conflicts of interest

The authors declare no potential conflicts of interest.

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