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Research article

Postoperative QRS duration to left ventricular end-diastolic diameter ratio as a predictor for the risk of postoperative atrial fibrillation in cardiac surgery: A single-center prospective study

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Background and aims: Postoperative atrial fibrillation (POAF) is a frequent complication following cardiac surgery and is associated with adverse clinical outcomes. Our study aimed at determining the clinical and echocardiographic predictors of POAF in patients with cardiac surgery and management of this group of patients may improve their outcome.
Methods: We prospectively enrolled patients from the department of cardiovascular surgery in the Second Hospital of Tianjin Medical University from October 23, 2020 to October 30, 2022, without a history of atrial fibrillation. Cox regression was used to identify significant predictors of POAF.
Results: A total of 217 patients (79 [36.41 %] were female, 63.96 ± 12.32 years) were included. 88 (40.55 %) patients met the criteria for POAF. Cox regression showed that preoperative left atrial diameter (LAD) (HR: 1.040, 95 % CI 1.008–1.073, p = 0.013) and postoperative QRS/LVEDD (HR: 0.398, 95 % CI 0.193–0.824, p = 0.013) and E/e' (HR: 1.029, 95 % CI 1.002–1.057 , p = 0.033) were predictors of POAF.
Conclusion: Preoperative LAD and postoperative QRS/LVEDD and E/e' were predictors of POAF in patients undergoing cardiac surgery.
Trial registration site: http://www.chictr.org.cn
Registration number: ChiCTR2200063344.

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1. Introduction

Postoperative atrial fibrillation (POAF), defined as new-onset atrial fibrillation in the immediate period after cardiac and non-cardiac surgery [1], is the most common cardiac arrhythmia in the surgical setting, with a prevalence ranges between 20 % and 40 % [2,3]. Previous reports have suggested that POAF is associated with excess hospitalization cost, prolonged hospital admission, stroke, perioperative mortality, myocardial infarction and long-term mortality [2–7].

Non-standard abbreviations and acronyms

AF	atrial fibrillation
POAF	postoperative atrial fibrillation
ECG	electrocardiogram
BMI	body mass index
LAD	left atrial diameter
ROC	receiver operating characteristic
AUC	area under the curve
CABG	coronary artery bypass grafting
VR	valve replacement
LVEDD	left ventricular end-diastolic diameter
CRT	cardiac resynchronization therapy
HFrEF	heart failure with preserved ejection fraction

Numerous studies have attempted to identify ways to prevent POAF after cardiac surgery. Beta-adrenergic blockers, non-dihydropyridine calcium channel blockers, amiodarone and sotalol which are commonly used drugs for atrial fibrillation [8], or steroids [9] can also be used to prevent POAF. Both preoperative and postoperative factors may be helpful for predicting the occurrence of POAF, such as increasing age, male sex [5], history of atrial fibrillation (AF), chronic obstructive pulmonary disease [10], and inflammatory markers such as neutrophil-to-lymphocyte ratio, IL-2 and IL-6 [11–13].

QRS duration can be normalized to left ventricular dimension to adjust for ventricular conduction path length [14]. A common calculation is the ratio between QRS duration to left ventricular end-diastolic volume (QRS/LVEDV) or left ventricular end-diastolic diameter (QRS/LVEDD). Lower QRS/LVEDD has been linked to higher mortality in patients receiving cardiac resynchronization therapy [15]. However it is not known whether there is a clinical significant relationship between QRS/LVEDD and POAF.

Our study aimed at determining the clinical and echocardiographic predictors of POAF in patients with cardiac surgery and management of this group of patients may improve their outcome.

2. Methods

2.1. Study population

This study was conducted as a single-center prospective cohort study and was performed according to the tenets of the Declaration of Helsinki and approved by the local ethics committee of the Second Hospital of Tianjin Medical University (Approval Number: KY2021K007, Registration number: ChiCTR2200063344). Written informed consents were obtained from all participants.

All measurements and recordings were collected in the Department of Cardiovascular Surgery at the Second Hospital of Tianjin Medical University from October 23, 2020 to October 30, 2022. Patients who were at least 18 years of age without a history of atrial fibrillation were enrolled. Patients with at least one of the following criteria were excluded: (1) patients with a history of atrial fibrillation or atrial fibrillation occurred prior to the cardiac surgery; (2) patients combined with acute infectious disease or other serious diseases; (3) life expectancy was less than one year; (4) patients died after cardiac surgery; (5) patients declined to participate in this study.

2.2. Clinical, biochemical and echocardiography data

Baseline data concerning demographic and clinical data included gender, age, body mass index (BMI), hospital stay, blood pressure, concomitant disease, medications. All detailed information was taken by an experienced physician. All patients received a thorough physical exam, resting ECG and routine blood testing. Participants were investigated with the 12-lead electrocardiogram (ECG) using machines (FUKUDA Electronics FX-7402, Beijing, China) in the supine position after resting in a quiet room for at least 5 min. Parameters in ECG were calculated by machine automatically. Two electrocardiograms were analyzed for each subject, which were collected at admission or within 24 h after operation. Echocardiography data was measured by trained sonographers using Philips IE33 machines (Philips Ultrasound, Bothell, WA, USA). Biochemical results mainly included coagulation function tests and electrolyte. Electrocardiogram was collected immediately after admission and surgery. ECG data measurements were performed automatically by the ECG machines.

2.3. Outcomes

POAF typically occurs on postoperative day 2, and 70 % occurs within the first four days after surgery [5]. In this study, all patients were divided into two groups based on the occurrence of the POAF in the postoperative period up to discharge. Patients were monitored continuously using five-lead ECG monitor until discharged from the hospital as described in previous study [16]. The endpoint was the occurrence of POAF, which was defined as atrial fibrillation episodes lasting >30 s captured on a continuous wireless rhythmic monitor or electrocardiogram monitor during the period from immediately after surgery to discharge [17].

2.4. Statistical analysis

Patients were divided into two groups based on the occurrence of endpoint. Clinical variables were reported as the mean ± SD or median and interquartile range, while median (interquartile range) was used for variables with a skewed distribution, Kruskal–Wallis test was used to analyze group differences. Categorical variables are presented as n (%), and the $\chi 2$ test was used for comparisons between groups. Multivariable Cox proportional hazard regression models were constructed to estimate the association of clinical variable and POAF. Subgroup analyses were performed to explore the contribution of different types of surgery to POAF. Subgroup analyses were also performed according to age, gender, BMI and types of surgery. The Kaplan–Meier curve was performed to evaluate the incidence rate of POAF and differences among groups. The diagnostic accuracy, sensitivity, specificity, receiver operating characteristic (ROC) curve, and area under the curve (AUC) were calculated, and combined variation was calculated according to the regression coefficients in multivariable Cox proportional hazard regression models. All data were analyzed using SPSS statistical software (SPSS 25.0, SPSS Inc., Chicago, IL, USA) and R programming (version 4.1.2; R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Baseline characteristics

We continuously enrolled 351 patients from the department of cardiovascular surgery from October 23, 2020 to October 30, 2022 (Fig. 1). Of these 53 patients who did not undergo surgery and 81 patients who did not meet the eligibility criteria were excluded. Therefore, 217 patients were included, of whom 110 patients had coronary artery bypass grafting (CABG) (50.69 %), 35 patients had valve replacement (16.13 %), 35 patients had combined CABG and valve replacement (16.13 %) and 37 patients accepted other surgeries (17.05 %).

The clinical characteristics of patients stratified by the presence or absence of POAF are shown in Table 1. Of the 217 patients that were enrolled, 79 (36.41 %) were female. The average age of patients was 63.96 ± 12.32 years. 88 (40.55 %) patients met the criteria for POAF, of whom 29 (32.95 %) were female. No difference was observed in basic history (gender, age, BMI, smoking, drinking,

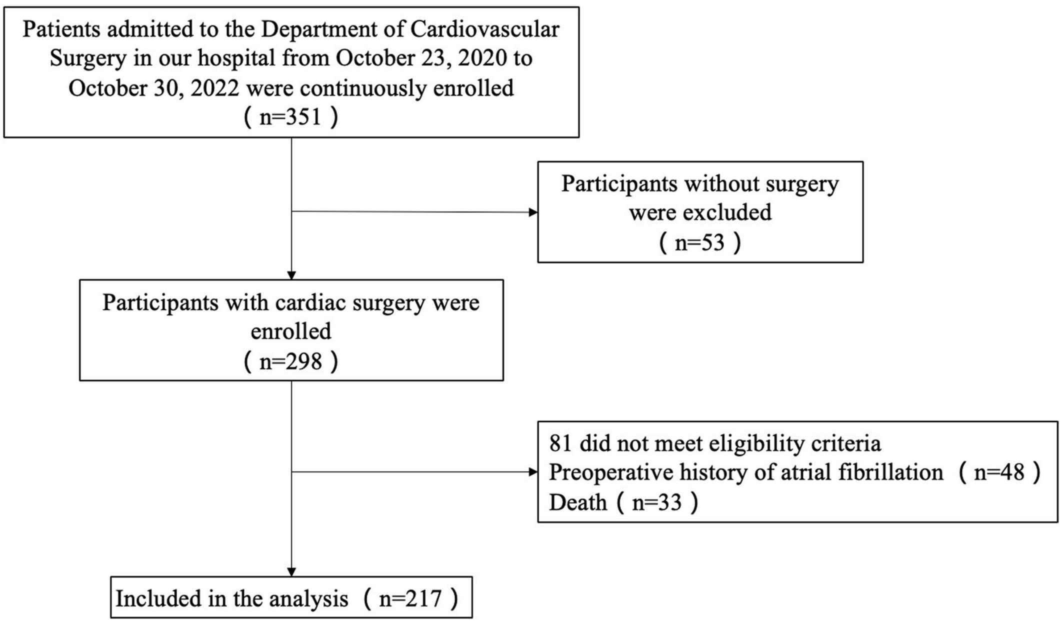

Fig. 1. Flow chart. 351 patients were continuously screened and 134 patients who did not meet the eligibility criteria were excluded. 217 patients were included in final.

hospital stay, concomitant disease, medications) between patients with or without POAF. Patients with POAF had a lower diastolic blood pressure (76.50 [66.00,82.00]vs 77.00 [71.00,86.25]). But there was no difference between types of surgery and POAF.

3.2. Preoperative predictors of POAF

Preoperative parameters of the patients were shown in Table 2. Patients who suffered POAF had a significantly larger preoperative left atrial diameter (44.19 ± 7.23 mm vs 40.72 ± 6.40 mm, $p < 0.001$), lower aspartate aminotransferase (17.10 [11.75,25.13] U/L vs 19.50 [12.50,31.90]U/L, $p = 0.040$) and creatine kinase-MB (9.17 [6.90,12.20]U/L vs 10.20 [8.09,16.73]U/L, $p = 0.015$), prolonged partial thromboplastin time (28.25 ± 5.76s vs 26.90 ± 4.05s, $p = 0.047$) and thrombin time (18.37 ± 2.55s vs 17.63 ± 1.19s, $p = 0.005$). QRS/LVEDD was significantly shorter in POAF patients (1.82 [1.61,2.02] vs 1.93 [1.72,2.24], $p = 0.009$).

The results of Cox regression for preoperative parameters were shown in Table 3. Univariable Cox regression identified preoperative left atrial diameter (LAD) (HR: 1.053, 95 % CI 1.024–1.082, $p < 0.001$), partial thromboplastin time (HR: 1.048, 95 % CI 1.001–1.096, $p = 0.043$) , creatine kinase-MB (HR: 0.965, 95 % CI 0.935–0.997, $p = 0.032$)and QRS/LVEDD (HR: 0.518, 95 % CI 0.295–0.909, $p = 0.022$) were predictors of POAF. On multivariable adjustment, only LAD (HR: 1.040, 95 % CI 1.008–1.073, $p = 0.013$) remained the only independent predictors of POAF. Interestingly, preoperative QRS/LVEDD was no longer predictive (HR: 0.680, 95 % CI 0.382–1.209, $p = 0.189$). We further used ROC curve to describe the predictive efficiency of preoperative LAD (Fig. 2A). The cut-off value of preoperative LAD is 45.0 mm. The area under the curve (AUC) of preoperative LAD was 0.654, with a sensitivity of 44.3 % and specificity was 86.8 % (Table 4). Kaplan-Meier Curves of preoperative LAD is shown that LAD ≥ 45 mm could increase the risk of occurrence of POAF (Fig. 3A).

3.3. Postoperative predictors of POAF

The echocardiography, resting ECG and routine blood testing data were collected immediately after the surgeries were completed, as shown in Table 5. Patients who developed POAF had a shorter postoperative QRS duration (91.71 ± 15.39 ms vs 100.50 ± 25.65 ms, $p = 0.005$) and corrected QT interval (456.85 ± 30.67 ms vs 459.40 ± 34.91 ms, $p = 0.040$), lager LAD (40.71 ± 4.69 mm vs 38.62 ± 5.75 mm, $p = 0.009$) and E/e’ (17.95[14.20,25.43] vs 14.10[11.10,18.30] $p = 0.010$). QRS/LVEDD was significantly shorter in POAF group (1.89 ± 0.05 vs 2.16 ± 0.05, $p = 0.001$).

Cox regression was also applied for postoperative parameters (Table 3), with ROC analyses shown in Fig. 2B. Univariable Cox regression showed that left atrial diameter (HR: 1.048, 95 % CI 1.010–1.088, $p = 0.013$), E/e’ (HR: 1.033, 95 % CI 1.009–1.057, $p = 0.007$), urea (HR: 1.047, 95 % CI 1.001–1.095, $p = 0.047$), and QRS/LVEDD (HR: 0.352, 95 % CI 0.177–0.697, $p = 0.003$) after surgery were significantly associated with POAF. On multivariable adjustment, QRS/LVEDD (HR: 0.398,95 % CI 0.193–0.824, $p = 0.013$) and

Table 1
Clinical characteristics of the groups.

Characteristics	Total (n = 217)	No POAF (n = 129)	POAF (n = 88)	P value
Female (%)	79 (36.41)	50 (38.76)	29 (32.95)	0.383
Age (years)	63.96 ± 12.32	62.71 ± 13.52	65.78 ± 10.02	0.072
BMI (kg/m^2)	24.09 ± 4.38	24.48 ± 3.44	23.52 ± 5.43	0.445
Smoking status (%)	86 (39.63)	49 (37.98)	37 (42.05)	0.548
Drinking status (%)	47 (21.66)	25 (19.38)	22 (25.00)	0.324
NYHA class				
I (%)	78 (35.94)	49 (37.98)	29 (32.95)	0.448
II (%)	81 (37.33)	46 (35.66)	35 (39.77)	0.538
III (%)	47 (21.66)	29 (22.48)	18 (20.45)	0.722
IV (%)	11 (5.07)	5 (3.88)	6 (6.82)	0.332
Time of hospitalization (days)	17 (14,22)	16 (14,21)	19 (15,24)	0.103
Systolic blood pressure (mmHg)	131.00 (119.00,147.25)	132.00 (119.00,148.50)	131.00 (116.75,143.00)	0.971
Diastolic blood pressure (mmHg)	77.00 (68.00,84.00)	77.00 (71.00,86.25)	76.50 (66.00,82.00)	**0.045**
Concomitant disease				
Hypertension (%)	123 (56.68)	76 (58.91)	47 (53.41)	0.422
Diabetes mellitus (%)	77 (35.48)	49 (37.98)	28 (31.82)	0.351
Heart failure (%)	26 (11.98)	12 (9.30)	14 (15.91)	0.141
Surgery				
CABG (%)	110 (50.69)	69 (53.49)	41 (46.59)	0.318
VR (%)	35 (16.13)	21 (16.28)	14 (15.91)	0.942
CABG + VR (%)	35 (16.13)	17 (13.18)	18 (20.45)	0.152
Others (%)	37 (17.05)	22 (17.05)	15 (17.05)	0.999
Medications				
Beta-blockers (%)	97 (44.70)	62 (48.06)	35 (39.78)	0.228
Calcium channel blocker (%)	50 (23.04)	31 (24.03)	19 (21.59)	0.675
ACEI (%)	26 (11.98)	15 (11.63)	11 (12.50)	0.846

We compared clinical characteristics of patients stratified by the presence or absence of POAF and found that there was no significant deference in sex, age, BMI, concomitant disease, surgery and medications. BMI, Body mass index; NYHA, New York Heart Association; CABG, coronary artery bypass grafting; VR, valve replacement; ACEI, angiotensin converting enzyme inhibitor.

Table 2
Laboratory and other preoperative parameters of the groups.

Parameters	Total (n = 217)	No POAF (n = 129)	POAF (n = 88)	P value
HR (bpm)	73 (66,84)	71 (66,82)	75 (68,84)	0.127
QRS duration (ms)	99.63 ± 19.63	100.93 ± 20.86	97.76 ± 16.98	0.249
QT interval (ms)	403.98 ± 40.29	406.14 ± 43.15	400.91 ± 36.11	0.361
Corrected QT interval (ms)	447.77 ± 30.38	447.37 ± 30.92	448.33 ± 29.96	0.825
LAD (mm)	42.13 ± 6.96	40.72 ± 6.40	44.19 ± 7.23	**<0.001**
LVEDD (mm)	51.77 ± 8.52	50.75 ± 8.10	53.21 ± 9.00	0.052
LVEF (%)	54.71 ± 11.54	55.03 ± 12.12	54.24 ± 10.62	0.613
E/e'	15.00 (11.90,21.15)	14.15 (11.95,19.10)	15.65 (11.90,22.12)	0.172
WBC count (x10^9/L)	6.94 (5.61,8.33)	6.88 (5.42,8.51)	6.98 (5.72,7.85)	0.302
Neutrophil count (x10^9/L)	4.39 (3.25,5.79)	4.39 (3.21,5.79)	4.37 (3.48,5.79)	0.212
Lymphocyte count (x10^9/L)	1.59 (1.22,2.02)	1.55 (1.22,2.09)	1.61 (1.24,1.99)	0.201
Hemoglobin (g/L)	125.63 ± 25.29	127.02 ± 25.58	123.59 ± 25.01	0.328
Sodium (mmol/L)	141.13 ± 3.53	141.06 ± 3.84	141.24 ± 3.02	0.711
Potassium (mmol/L)	4.18 ± 0.54	4.19 ± 0.49	4.18 ± 0.60	0.875
Albumin (g/L)	39.79 ± 4.85	40.22 ± 4.66	39.17 ± 5.04	0.126
Aspartate aminotransferase (U/L)	18.20 (12.30,28.83)	19.50 (12.50,31.90)	17.10 (11.75,25.13)	**0.040**
Creatinine (umol/L)	80.10 (66.90,100.80)	80.00 (65.50,100.80)	81.70 (67.48,99.93)	0.512
Partial thromboplastin time(s)	27.45 ± 4.87	26.90 ± 4.05	28.25 ± 5.76	**0.047**
Thrombin time(s)	17.94 ± 1.90	17.63 ± 1.19	18.37 ± 2.55	**0.005**
Creatine kinase-MB(U/L)	9.83 (7.63,14.1)	10.20 (8.09,16.73)	9.17 (6.90,12.20)	**0.015**
QRS/LVEDD (ms/mm)	1.88 (1.68,2.12)	1.93 (1.72,2.24)	1.82 (1.61,2.02)	**0.009**

Laboratory and other preoperative parameters of the groups were compared and it was found that patients who suffered POAF had a significantly larger preoperative left atrial diameter, lower aspartate aminotransferase and creatine kinase-MB, prolonged partial thromboplastin time and thrombin time. QRS/LVEDD was significantly shorter in POAF patients. LVEF, left ventricular ejection fraction; HR, heart rate; LVEDD, left ventricular end-diastolic dimension; LAD, left atrial diameter; WBC, white blood cell.

Table 3
Univariate and multivariate COX regression analyses of independent parameters for POAF.

Variables		Univariate analysis			Multivariate analysis		
		HR	95 % CI	P	HR	95 % CI	P
Preoperative characteristics	Male (%)	1.251	0.802–1.951	0.324			
	Age (years)	1.017	0.999–1.037	0.070			
	BMI (kg/m^2)	0.980	0.929–1.034	0.458			
	Time of hospitalization (days)	1.014	0.995–1.034	0.149			
	Left atrial diameter (mm)	1.053	1.024–1.082	**<0.001**	1.040	1.008–1.073	**0.013**
	Upper and lower diameter of RA (mm)	1.008	0.979–1.039	0.583			
	Left and right diameters of RA (mm)	1.010	0.978–1.044	0.542			
	LVEF (%)	0.997	0.980–1.014	0.723			
	E/e'	1.020	0.994–1.047	0.132			
	Partial thromboplastin time (s)	1.048	1.001–1.096	**0.043**	1.012	0.963–1.064	0.635
	Urea (mmol/L)	1.000	0.998–1.001	0.583			
	Creatine kinase-MB (U/L)	0.965	0.935–0.997	**0.032**	0.977	0.945–1.009	0.159
	Corrected QT interval (ms)	1.000	0.993–1.007	0.932			
	QRS/LVEDD (ms/mm)	0.518	0.295–0.909	**0.022**	0.680	0.382–1.209	0.189
Postoperative characteristics	Left atrial diameter (mm)	1.048	1.010–1.088	**0.013**	1.012	0.956–1.071	0.687
	Upper and lower diameter of RA (mm)	1.014	0.974–1.056	0.492			
	Left and right diameters of RA (mm)	1.043	0.991–1.097	0.108			
	LVEF (%)	0.998	0.976–1.021	0.864			
	E/e'	1.033	1.009–1.057	**0.007**	1.029	1.002–1.057	**0.033**
	Partial thromboplastin time (ms)	1.004	0.994–1.014	0.447			
	Urea (mmol/L)	1.047	1.001–1.095	**0.047**	0.996	0.931–1.066	0.914
	Creatine kinase-MB (U/L)	1.002	0.996–1.008	0.546			
	Corrected QT interval (ms)	0.998	0.991–1.004	0.482			
	QRS/LVEDD (ms/mm)	0.352	0.177–0.697	**0.003**	0.398	0.193–0.824	**0.013**

Univariate and multivariate Cox regression showed that preoperative left atrial diameter, postoperative E/e' and QRS/LVEDD were predictors of POAF.BMI，Body mass index; RA, right atrium; LVEF, left ventricular ejection fraction; LVEDD, left ventricular end-diastolic dimension.

E/e' (HR: 1.029，95 % CI 1.002–1.057, p = 0.033) remained significant predictors of POAF. QRS/LVEDD showed a better specificity (0.656, sensitivity 43.6 %, specificity 82.4 %). E/e' had a sensitivity of 50.0 %, specificity of 78.1 % and AUC was 0.640. The combination of E/e' and QRS/LVEDD had maximum AUC (0.699 sensitivity 65.3 %, specificity 68.4 %) (Table 4). Kaplan-Meier curves for four parameters showed that QRS/LVEDD < 1.76, and combined variation ≥-1.29 were associated with an increased risk of POAF (Fig. 3B and D). E/e'>15.10 has a higher risk of POAF, especially in E/e'> 21.45 (Fig. 3C).

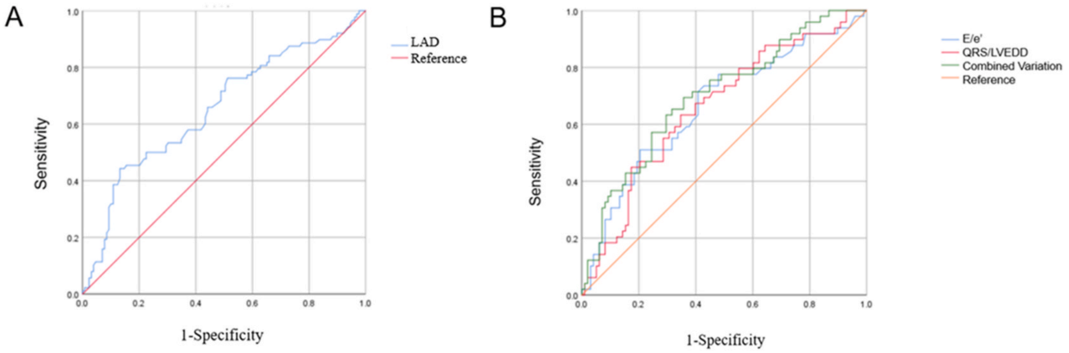

Fig. 2. ROC curve of parameters predicting POAF. Preoperative LAD, postoperative QRS/LVEDD and E/e' were independent predictors of POAF. (A)The ROC curve of preoperative LAD; (B)The ROC curve of postoperative E/e', QRS/LVEDD and the combined variation. LAD, left atrial diameter; LVEDD, left ventricular end-diastolic diameter; AUC, area under the curve.

Table 4
Area under the curve and cut-off value of parameters predicting POAF.

Parameter	AUC	Sensitivity (%)	Specificity (%)	Cut-off Value
Preoperative LAD	0.654	44.3	86.8	45
Postoperative CV	0.699	65.3	68.4	−1.29
Postoperative E/e'	0.640	50.0	78.1	18.8
Postoperative QRS/LVEDD	0.656	43.6	82.4	1.76

Table 4 showed the AUC, cut-off value, sensitivity and specificity of the predictors for POAF. AUC, area under curve; LAD, left atrial diameter; CV, combined variation; LVEDD, left ventricular end-diastolic dimension.

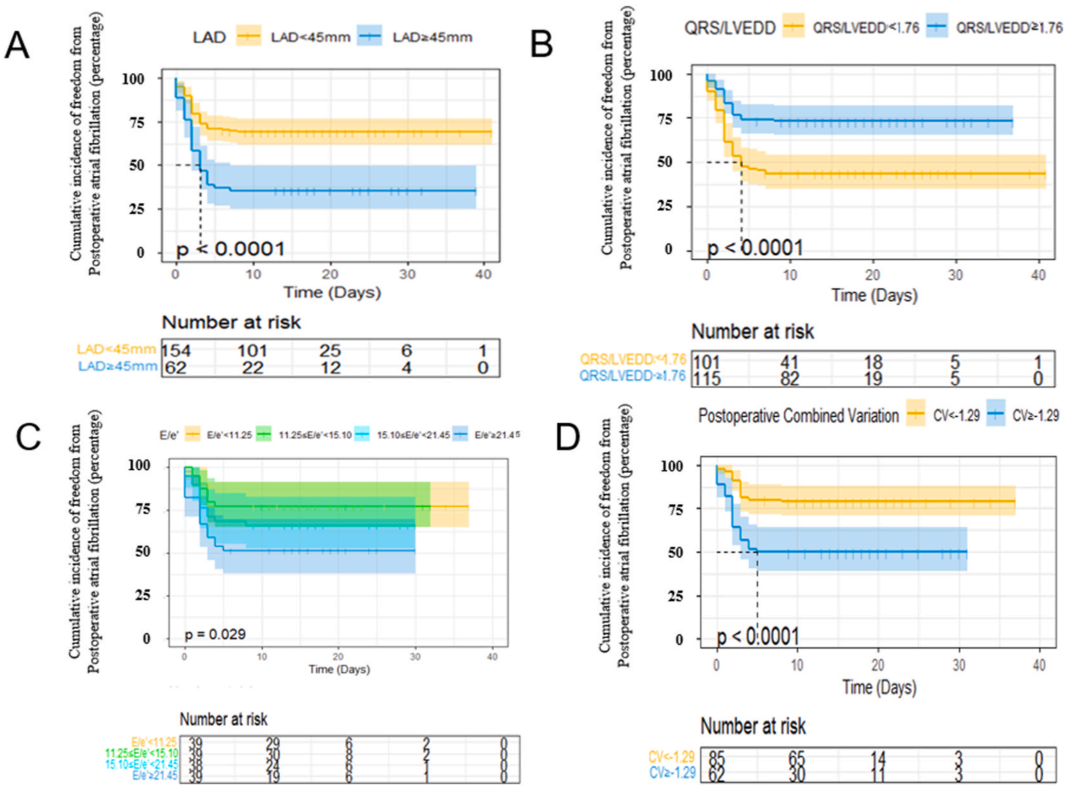

Fig. 3. Kaplan–Meier curves for parameters of cumulative incidence of POAF. (A) Showed the association between preoperative LAD and POAF. (B) to (D) showed the association between postoperative QRS/LVEDD, E/e', combined variation and POAF. LVEDD, left ventricular end-diastolic diameter; POAF, postoperative atrial fibrillation.

Table 5
Laboratory and other postoperative parameters of the groups.

Parameters	Total (n = 217)	No POAF (n = 129)	POAF (n = 88)	P value
HR (bpm)	81.00 (68.00,96.00)	79.00 (67.50,96.00)	84.50 (72.25,94.75)	0.158
QRS duration (ms)	96.81 ± 22.26	100.50 ± 25.65	91.71 ± 15.39	**0.005**
QT interval (ms)	395.81 ± 51.85	401.27 ± 54.24	388.26 ± 47.98	0.077
Corrected QT interval (ms)	458.33 ± 33.22	459.40 ± 34.91	456.85 ± 30.67	**0.040**
LAD (mm)	39.43 ± 5.43	38.62 ± 5.75	40.71 ± 4.69	**0.009**
LVEDD (mm)	47.73 ± 7.08	47.06 ± 6.85	49.02 ± 7.46	0.101
LVEF (%)	53.15 ± 9.45	53.31 ± 10.04	52.90 ± 9.40	0.772
E/e'	15.10 (11.25,21.45)	14.10 (11.10,18.30)	17.95 (14.20,25.43)	**0.010**
WBC count (x10^9/L)	8.88 (6.33,11.59)	8.93 (6.06,11.68)	8.83 (6.76,11.30)	0.941
Neutrophil count (x10^9/L)	7.31 (4.85,9.33)	7.31 (4.47,9.30)	7.23 (4.96,9.37)	0.984
Lymphocyte count (x10^9/L)	1.05 (0.70,1.54)	1.11 (0.68,1.62)	1.02 (0.77,1.52)	0.788
Hemoglobin (g/L)	104.60 ± 21.08	105.59 ± 21.83	103.15 ± 20.09	0.397
Sodium (mmol/L)	143.40 ± 5.78	143.54 ± 5.87	143.19 ± 4.89	0.634
Potassium (mmol/L)	4.16 ± 0.65	4.13 ± 0.62	4.21 ± 0.69	0.387
Albumin (g/L)	31.92 ± 9.83	31.96 ± 5.99	31.86 ± 6.04	0.905
Aspartate aminotransferase (U/L)	25.00 (16.60,37.70)	26.20 (17.70,41.00)	24.15 (16.28,34.58)	0.140
Creatinine (umol/L)	194.25 (231.93,362.70)	73.90 (59.70,95.00)	79.90 (61.30,115.95)	0.092
Partial thromboplastin time (ms)	34.00 (30.30,40.20)	33.80 (29.28,38.58)	35.60 (31.50,42.50)	0.572
Thrombin time (ms)	26.76 ± 20.37	25.76 ± 1.75	28.13 ± 2.58	0.432
Creatine kinase-MB(U/L)	16.80 (8.70,31.65)	17.30 (7.05,34.15)	16.45 (9.68,31.00)	0.778
QRS/LVEDD (ms/mm)	2.07 ± 0.51	2.16 ± 0.05	1.89 ± 0.05	**0.001**

Analysis of laboratory and other postoperative parameters showed patients who developed POAF had shorter a postoperative QRS duration and corrected QT interval, lager LAD and E/e'. QRS/LVEDD was significantly shorter in POAF group. LVEF, left ventricular ejection fraction; HR, heart rate; LVEDD, left ventricular end-diastolic dimension; LAD, left atrial diameter; WBC, white blood cell.

3.4. Subgroup analyses

We further analyzed the clinical parameters using subgroup analyses (Table 6). As for preoperative parameters, it was showed that preoperative LAD was associated with POAF in the older (age ≥65 years: HR: 1.056, 95 % CI 1.005–1.109; age<65 years: HR: 1.036,95 % CI 0.991–1.084; interaction *P* value 0.009). There was no interaction association between gender, BMI or types of surgery with POAF. For postoperative parameters, E/e' was associated with POAF in the male (male: HR: 1.050,95 % CI 1.018–1.083; female: HR: 0.947,95 % CI 0.849–1.056; interaction *P* value < 0.001), the older (age ≥65 years: HR: 1.050, 95 % CI 1.009–1.093; age<65 years: HR: 1.031,95 % CI 0.989–1.075; interaction P value 0.045), and patients undergone CABG or valve replacement (CABG: HR: 1.160,95 % CI 1.010–1.173; valve replacement: HR: 1.160,95 % CI 1.017–1.323; CABG + valve replacement: HR: 0.995,95 % CI0.952-1.040; others: HR: 1.099,95 % CI 0.959–1.259). The most interesting finding was that there were no significant differences for QRS/LVEDD in various subgroups.

4. Discussion

In this single center, prospective study, several key findings were noted. First, among the patients who received cardiac surgery, we found that preoperative LAD associated with POAF occurrence. Second, in the clinical data after surgery, QRS/LVEDD and E/e' were predictors of POAF. Third, preoperative LAD was associated with POAF in the older and postoperative E/e' was associated with POAF in the male, the older and patients who suffered coronary artery bypass grafting or valve replacement.

The pathophysiology of developing POAF after cardiac surgery is not fully understood. The occurrence of POAF requires the present of an electrical or/and structural substrates, which can be influenced by the baseline status and comorbidities, surgery, anesthetic and some postoperative factors. Cardiac surgery always associated with physiological disturbances, such as acute hemodynamic disturbance, pulmonary vein vent, cardiac ischemia and hypoxia, surgical atrial injury and autonomic nervous activation, which are all potential factors of arrhythmia [18,19]. These operative, as well as postoperative changes, may play a role in mediating POAF.

The QRS duration is typically determined by myocardial conduction velocity and conduction path length. Postoperative QRS duration was shorter in individuals who suffered POAF in this study (91.71 ± 15.39 ms vs 100.50 ± 25.65 ms, p = 0.005). LVEDD is a common and important indicator in echocardiogram, which reflects the size of cardiac as well as left ventricular function. We didn't find postoperative LVEDD has a significant difference between these patients (47.06 ± 6.85 vs 49.02 ± 7.46 mm, p = 0.101). Differences in left ventricular size is postulated to contribute to variations of QRS with sex, race and obesity [20]. QRS duration can be normalized to left ventricular dimension to adjust for ventricular conduction path length, result in a measure of conduction velocity of myocardial [14]. we found that QRS/LVEDD after cardiac surgery, an electroanatomic ratio, but not QRS duration was an independent predictor of POAF. This finding therefore suggests that abnormal postoperative electric conduction velocity may be related with POAF occurrence. Subgroup analyses showed that QRS/LVEDD was stable in each subgroup, which indicated that QRS/LVEDD was a predictor which would not influence by gender, aging, BMI or types of surgery. In previously studies, Chyou JY et al. has found that indexing of QRS to LVEDV can predict mortality in patients with heart failure with preserved ejection fraction (HFrEF) with non-ischemic cardiomyopathy [20], and strongly correlated with cardiac resynchronization therapy [14]. The mechanism underlying is

Table 6
Subgroup analysis.

Subgroup		95%CI	P value for interaction
Preoperative LAD	Female	1.065 (0.995–1.139)	0.104
	Male	1.038 (1.000–1.077)	
	Age≥65 years	1.056 (1.005–1.109)	**0.009**
	Age<65 years	1.036 (0.991–1.084)	
	BMI≥24 kg/m^2	1.061 (1.010–1.113)	0.823
	BMI<24 kg/m^2	1.018 (0.974–1.064)	
	CABG	1.030 (0.975–1.089)	0.105
	VR	1.095 (1.015–1.181)	
	CABG + VR	1.039 (0.962–1.122)	
	Others	0.984 (0.903–1.072)	
Postoperative E/e'	Female	0.947 (0.849–1.056)	**<0.001**
	Male	1.050 (1.018–1.083)	
	Age≥65 years	1.050 (1.009–1.093)	**0.045**
	Age<65 years	1.031 (0.989–1.075)	
	BMI≥24 kg/m^2	1.052 (1.003–1.103)	0.178
	BMI<24 kg/m^2	1.013 (0.976–1.051)	
	CABG	1.089 (1.010–1.173)	**0.011**
	VR	1.160 (1.017–1.323)	
	CABG + VR	0.995 (0.952–1.040)	
	Others	1.099 (0.959–1.259)	
Postoperative QRS/LVEDD	Female	0.534 (0.081–3.504)	0.964
	Male	0.477 (0.221–1.033)	
	Age≥65 years	0.381 (0.144–1.011)	0.699
	Age<65 years	0.594 (0.189–1.872)	
	BMI≥24 kg/m^2	0.591 (0.212–1.649)	0.272
	BMI<24 kg/m^2	0.335 (0.107–1.056)	
	CABG	0.466 (0.115–1.883)	0.597
	VR	1.493 (0.221–10.071)	
	CABG + VR	0.332 (0.052–2.141)	
	Others	0.271 (0.021–3.478)	

Subgroup analysis was constructed by sex, age, BMI and type of surgery. BMI , Body mass index; LAD, left atrial diameter; CABG, coronary artery bypass grafting; VR, valve replacement; LVEDD, left ventricular end-diastolic dimension

complex and multifactorial, with several potential pathway implicated. The cardiac surgery can lead to cardiac ischemia-reperfusion injury, inflammation, oxidative stress and autonomic dysfunction [21,22]. which are common reasons of electrical remodeling. QRS duration is a marker of electrical remodeling. Inappropriate QRS/LVEDD represent impaired electrical depolarization, which could lead to AF occurrence. There are few studies about QRS/LVEDD in the field of arrhythmia, and the specific mechanism is not completely clear. Further studies are needed to confirm the exact mechanism in basic research.

Our study found that preoperative larger LAD is significantly associated with POAF onset in cardiac surgery, which was the same as the results of Benedetto et al. [23] and Osranek et al. [24]. Several studies had found that increased LAD was a risk factor of post-ablation AF recurrence [25], and a significantly feature and one of the leading cause of AF [26,27]. However, the pathophysiological mechanisms connecting the dilation of LA to AF development are not clearly understood. Previous studies had shown that enlarged atria reflect atrial remodeling, with collagen production and atrial fibrosis [28], which provide substrate for AF occurrence. Inflammation and infiltration of immune cells are also associated with increased LAD and pathogenesis of AF [29].

In this study, elevated E/e' after surgery was a significant predictor of POAF following cardiac surgery. It is reported that E/e' calculated by echocardiography was an independent predictor of POAF after lung cancer surgery, hip fracture surgery and in patients who undergoing off-pump coronary artery bypass grafting [30–32]. E/e' is a well-established marker for high left ventricular filling pressure, which is related to increased left atrial pressure [33]. Atrial remodeling with atrial enlargement, fibrosis, and ion channel remodeling in the presence of pressure overload provides the substrate for AF [34].

In addition, previous studies have identified male gender as a predictive factor for POAF, such as the study conducted by Aranki, S. F. et al. in 1996 [5]. However, the Aranki, S.F. et al., has only included patients underwent CABG. Our study failed to observe the significant association between gender and POAF, which was in line with other studies [2]. The observed discrepancy between gender and POAF may be related to different race, population characteristics, and study design. Therefore, future large-scale investigations are needed to elucidate the association between gender and risk of POAF.

4.1. *Strengths and limitations*

Our study has several strengths. Firstly, the parameters included in this study can be obtained by non-invasive examination, with high clinical generalization and acceptability, which is of great significance for optimizing clinical management of patients. Secondly, patients undergoing cardiac surgery in our center were continuously included in this study, not limited to a single operation. Thirdly, different from previous studies, both preoperative and postoperative clinical parameters were included in this study, which has great clinical reference value; furthermore, ECG parameters in this study were automatically identified by machines to avoid possible errors in human measurement. Last, previous studies have found that QRS/LVEDD is associated with poor prognosis of heart failure and other cardiovascular diseases. To the best of our knowledge, this study is the first to confirm that QRS/LVEDD is associated with POAF, which is innovative.

In addition to the multiple strengths of our study, some limitations should be taken into account when interpreting our results. First, this study was a single-center study with limited sample size. We will further expand the sample size and seek multi-center cooperation to verify our findings. Second, the study was observational in nature and was unable to identify a causal relationship between the predictors and POAF. Third, the specific mechanisms underlying the relationship between these specific parameters and POAF required further investigations using pre-clinical studies. We will consider clinical patient samples combined with animal experiments to further explore the possible mechanism of the predictive factors. Fourth, there was a possibility of bias due to missed diagnosis of short episodes of POAF. However, it must be noted that continuous telemetry monitoring conducted in this study, rather than according to the patients' symptoms and body surface electrocardiogram in the diagnosis of POAF, can reduce missed diagnosis. Fifth， gender difference in the perception of AF-related symptoms could potentially affect our results. However, the influence of this misclassification is expected to be small, because the gender difference among the patients included in this study were small (without significant difference). In future studies, we will expand the sample size to reduce this difference in enrollments. Sixth, ECG parameters are time-sensitive and may change at any time. In this study, two electrocardiograms were included in each subject for analysis. Further studies on dynamic monitoring of electrocardiogram parameters are needed to clarify the predictive value of new-onset atrial fibrillation after cardiac surgery. Moreover, the average age of patients enrolled in this study was more than 60 years old, which could not fully represent the general population. We will further expand the sample size to further explore the predictive performance of our predictors in general population.

5. Conclusion

POAF is a frequent complication after cardiac surgery and is associated with several adverse clinical events. In this single center prospective study, we found that preoperative LAD, postoperative QRS/LVEDD and E/e' may be parameters in predicting POAF occurrence.

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Consent for publication

All authors consent to the publication of these findings. All authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

Ethics approval

The study was performed according to the guidelines of the Helsinki Declaration and was approved by the Ethics Committee of the Second Hospital of Tianjin Medical University (Approval Number:KY2021K007, Registration number: ChiCTR2200063344). Written informed consents were obtained from all participants.

Data availability statement

This study has registered in Chinese Clinical Trial Registry， which is not public. The data that support the findings of this study are available from the corresponding author, upon reasonable request.

CRediT authorship contribution statement

Bingxin Xie: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Wenhua Song:** Writing – original draft, Methodology, Investigation, Data curation. **Yingqun Yan:** Writing – review & editing, Project administration, Conceptualization. **Panagiotis Korantzopoulos:** Writing – review & editing, Conceptualization. **Gary Tse:** Writing – review & editing, Funding acquisition. **Huaying Fu:** Methodology. **Shuai Qiao:** Methodology, Data curation. **Yongyong Han:** Methodology, Data curation. **Meng Yuan:** Project administration, Conceptualization. **Qingmiao Shao:** Project administration, Formal analysis, Conceptualization. **Guangping Li:** Writing – review & editing, Project administration. **Tienan Chen:** Writing – review & editing, Project administration, Conceptualization. **Tong Liu:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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