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REVIEW

Atrial fibrillation following cardiac surgery: clinical features and preventative strategies

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Atrial fibrillation (AF) is a common complication of cardiac surgery, with an increasing incidence. Post-operative AF results in many complications and increased healthcare resources. Despite substantial interest in the prediction and prevention of post-operative AF, as well as guidelines for the management of this common arrhythmia, there is still some uncertainty about appropriate risk stratification and management. The aim of this review article is to provide an overview of clinical predictive features for the development of AF following cardiac surgery and suitable preventive measures, using both antiarrhythmic and non-antiarrhythmic strategies.

Keywords Atrial fibrillation • Cardiac surgery • Clinical predictive factors • Prevention

Introduction

Atrial fibrillation (AF) is a common complication of cardiac surgery, with an increasing incidence. Post-operative AF results in many complications and increased healthcare resources. The reported prevalence and incidence of AF after cardiac surgery varies among different studies, depending on population profile, type of surgery, arrhythmia definition and detection methods, and design of study. The incidence of post-operative AF is much higher when compared with the general population, even among older patients and in non-cardiac surgery patients.[1]

The incidence of AF after elective coronary artery bypass grafting (CABG) surgery has been reported in a very wide range, from 5–70%.[2,3] A meta-analysis of 24 randomized controlled trials (RCTs) found that the incidence of AF after CABG of around 26% with a 95% confidence interval (CI) 24.7–29.1 can be estimated.[4] A large, prospective, observational, international, multicentre study of 4657 patients published in 2004 found the occurrence of post-operative AF in 32.2% of patients undergoing isolated CABG surgery.[5] Interestingly, this seems to vary between different regions: for example, the USA—33.7%, Canada—36.6%, Europe—34.0%, the UK—31.6%, Middle East Europe—41.6%, South America—17.4%, and Asia— 15.7%.[5] A higher incidence of post-operative AF has been reported after valvular surgery (33–49%)[1] and combined valvular/CABG surgery (36–63%),[1,6] whereas the lowest figures are seen after heart transplantation (11%).[6]

The aim of this review is to provide an overview of clinical predictive features for the development of AF following cardiac surgery and suitable preventive measures, using both antiarrhythmic and non-antiarrhythmic strategies.

Clinical features

Many patients with post-operative AF are asymptomatic[7] or present with complications resulting from AF (see subsequently). Others may experience palpitations, breathlessness, chest pain, excessive sweating, or hypotension.

Most of arrhythmia episodes (76.8%) in the post-operative setting are diagnosed using continuous monitoring, and this prevalence figure is reduced to 17.5% by the use of the 12-lead electrocardiogram (ECG) for diagnosis and only 12.8% by physical examination.[5] Indeed, the 'pickup' rate for AF is much higher, if one looks harder for the arrhythmia. Many studies showed the presence of asymptomatic AF episodes that might be diagnosed with advanced methods of continuous ECG recording in different clinical settings[7–16] (*Table 1*).

Many clinical variables are associated with the development of post-operative AF (*Table 2*). There is some controversy relating the impact of most of these features, and of the available data, only an advanced age has the strongest and most consistent evidence.[1,5,17–24] For example, prolonged aortic cross-clamp time and cardiopulmonary bypass (CPB) time were found predictive for the development of AF following cardiac surgery in a study

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Table 1 Asymptomatic atrial fibrillation and accuracy of diagnostic methods

Author	Description
Kerr *et al.*[8]	Prevalence of asymptomatic AF, 21%
Kopecky *et al.*[9]	27% of asymptomatic AF episodes in a population-based study of lone AF
Page *et al.*[10]	Routine transtelephonic ECG records revealed 17% of asymptomatic AF recurrences
Page *et al.*[11]	Repeated 24 h Holter ECG monitorings: asymptomatic AF episodes 12 times more frequent compared with symptomatic AF
Schuchert *et al.*[12]	72 h Holter ECG monitoring was superior to 24 and 48 h Holter ECG monitorings for detection of asymptomatic AF occurrences in patients after acute ischaemic stroke
Flaker *et al.*[13]	481 (12%) patients had asymptomatic AF episodes, and they were more often men, had more cerebrovascular events, longer duration of AF, slower ventricular rate, better systolic LV function
	Mortality and major events were similar for symptomatic and asymptomatic AF patients after 5 years
Liao *et al.*[14]	Five trials with Holter ECG monitoring for patients after ischaemic stroke ($n = 588$), revealed 4.6% of new AF
	Two trials used event loop recorders for AF detection in patients after ischaemic stroke ($n = 140$): new AF was diagnosed in 5.7 and 7.7%
Roche *et al.*[15]	Negative 24 h Holter ECG monitoring followed by automatic long-term event recorder revealed 31% of AF occurrences (55% of them were asymptomatic)
Defaye *et al.*[16]	Data retrieved from pacemakers memory showed 21% of asymptomatic AF episodes in patients without previous history of arrhythmia
Landymore and Howell[7]	Asymptomatic AF episodes (54%) on 24 h Holter ECG monitor at discharge and after 3 weeks after cardiac surgery (10%)

AF, atrial fibrillation; ECG, electrocardiogram; LV, left ventricular.

Table 2 Pre-, intra-, and post-operative clinical risk factors associated with atrial fibrillation following cardiac surgery

Pre-operative risk factors
Advanced age[1,5,17–24]
Male gender[18]
Hypertension[1,5,18]
Previous AF[5,24]
History of cardiac surgery[22]
CHF[5]
COPD[5,19–21]
RCA disease[112]
Peripheral vascular disease[19]
LVH[5]
Left atrial enlargement[22,37]
Electrocardiographic features[33,35–37]
Renal failure[113]
Moderate or severe aortic atherosclerosis[5]
Withdrawal beta-blocker or ACE-I[5]
BSA[24,45]
Obesity and metabolic syndrome[114,115]
Intraoperative risk factors
Aortic cross-clamp time[1]
Bicaval canulation[5]
Pulmonary vein venting[21]
Type of surgery[5,17,21,22]
Need of perioperative IABCP[18,19]
CPB time[1,48]
CPB inclusive of cardioplegic arrest[113]
Systemic hypothermia[22]
Post-operative risk factors
Respiratory compromise[18]
Red cell transfusion[116]

ACE-I, angiotensin converting enzyme inhibitor; AF, atrial fibrillation; BSA, body surface area; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CPB, cardiopulmonary bypass; IABCP, intra-aortic balloon counterpulsation; LVH, left ventricular hypertrophy; RCA, right coronary artery.

by Almassi *et al.*,[1] but these factors were not significantly associated with post-operative AF in other work.[5] Electrocardiographic parameters are also not consistent between different studies (given subsequently). Indeed, the different recording modes are probably a factor, as only continuous ECG recording is able to detect the numerous episodes of paroxysmal AF during hospitalization, and because this is not done in common practice, the incidence of AF may be underestimated in some series. Similarly, other clinical features as predictors for post-operative AF show a large heterogeneity between various studies or otherwise, scarce evidence exists.

Almost all AF episodes are said to occur within the first 6 days following cardiac surgery, with the highest incidence on the second or third post-operative day,[5,17,24] which coincides with a peak of systemic inflammation caused by surgery[25,26] (*Table 3*) and with elevated atrial stretch, perhaps due to increased intravascular volume.[27] However, it may be of no surprise that 'most episodes of AF occur within the first 6 days' since average length of stay for cardiac surgery is 7.8 days. Again the peak incidence at the first post-operative days is skewed by the fact that patients are closely monitored immediately after the operation than during the convalescent phase.

Mortality and morbidity

This common and—at first sight, 'benign' arrhythmia—after cardiac surgery is associated with many complications, some of which are life-threatening. Various studies (*Table 4*) have reported that post-operative AF is associated with increased early and late mortality after cardiac surgery,[1,5,18,19,28,29] stroke,[1,18,19,30,31] and prolonged

Table 3 Peak of atrial fibrillation occurrences and activation of inflammation following cardiac surgery

Author	Peak of AF incidence after cardiac surgery	Peak of inflammation after cardiac surgery
Mathew *et al.*[5]	Second day, >70% of episodes within the first 3 days	
Auer *et al.*[17]	Second day, >95% of episodes before the fifth day	
Chandy *et al.*[24]	Second day, 83% of episodes within the first three days	
Bruins *et al.*[25]		Second day of complement activation and CRP elevation
Aouifi *et al.*[26]		Second day of CRP peak

AF, atrial fibrillation; CRP, C-reactive protein.

hospital length of stay.[1,5,17–20,28,32] Overall, the risk for death is increased by 9.7% (range 3–33.3%).

In addition, other complications following cardiac surgery have been found associated with post-operative AF in various studies: myocardial infarction,[1] persistent congestive heart failure (CHF) symptoms,[1,19] respiratory failure,[1,18,19] various infectious complications, renal failure,[5,18,19] severe hypotension and shock, multisystemic failure, and cardiopulmonary arrest.[19] Overall, the risk for CHF is increased by 3.5% (range 2.4–4.6%).

Healthcare costs

Post-operative AF is associated with increased hospital and healthcare costs.[17,18] This is reflected by more prolonged hospital stays, as well as an increase in post-operative complications, as discussed above, and additional investigations. For example, Mathew *et al.*[5] identified that more axial computer tomography and ultrasonography were performed in patients after AF onset following cardiac surgery, and 35% of patients with post-operative AF were discharged to an extended care facility, compared with 28% of those who remained in sinus rhythm (SR).

Electrocardiographic and echocardiographic parameters associated with the development of atrial fibrillation following cardiac surgery

The role of pre-operative electrocardiographic (ECG) changes for the prediction of AF following cardiac surgery has been investigated in many studies (*Table 5*).

The duration of P-wave reflects atrial conduction, and consequently, many studies have investigated the prognostic value of this parameter on the incidence of AF, particularly after successful cardioversion.[33,34] In contrast to the study by Chandy *et al.*,[24] other studies have found that the duration of P-wave measured pre-operatively by signal-average ECG was a significant predictive marker for post-operative AF.[33,35,36] In a small study of 95 patients, Hayashida *et al.*[37] found that signal-averaged P-wave duration together with older age and left atrial enlargement was an independent predictor for AF following cardiac surgery[37] (*Table 5*).

Chandy *et al.*[24] found that only increased dispersion of P-wave measured post-operatively compared with pre-operative measurements [odds ratio (OR)=1.13, 95% CI 1.01–1.05]. In this study, the duration of P-wave was not associated with the development of AF after CABG. Other studies (*Table 5*) have also reported that the signal-average ECG was not useful for predicting post-operative AF.[38,39]

Dispersion of the P-wave is an indirect marker of atrial refractoriness. The significance of dispersion in atrial refractoriness for the maintenance of AF has been shown in animal experimental models[40] and clinical studies.[24,41] The chance of re-entry generation increases when the atrial depolarizing impulse interferes with areas of heterogeneous refractoriness, resulting in the fragmentation of the propagating impulse. The prognostic value of dispersion of atrial refractoriness in the development of post-operative AF has been described in various electrophysiological studies.[42] However, the mechanisms and causality of post-operative dispersion of atrial refractory period are unclear, but may relate to atrial volume overload or ischaemia. A study by Dimmer *et al.*[43] found that initiation of post-CABG AF was significantly influenced by autonomic tone variations, whereby a shift in the autonomic balance with a loss of vagal tone and a moderate increase in sympathetic tone are observed before the onset of AF compared with those in controls. The study by Chandy *et al.*[24] did not find any electrographic signs of ischaemia immediately prior to the onset of post-operative AF. Recently, magnesium has been reported to diminish post-operative occurrence of P-wave dispersion.[44]

In their study of 300 patients, Chandy *et al.*[24] investigated electrocardiographic signs of pericarditis in 8 subjects, and only 2 experienced post-operative AF. A study by Leung *et al.*[45] investigated the relation of pre-operative and post-operative echocardiographic parameters on the occurrence of post-operative AF (as detected by continuous telemonitoring during their full hospitalization period) in 300 patients undergoing elective CABG surgery. Larger LA area and lower LA ejection fraction (EF) pre-operatively were associated with the occurrence of post-operative AF on univariate analysis. Multivariate analysis showed that predictors for the post-operative AF development were the following: greater age, body surface area, white race, a lower atrial filling fraction post-operatively, and a left ventricular (LV) diastolic dysfunction post-operatively[45] (*Table 5*). This study also showed that patients with an increased risk for the incidence of post-operative AF have architecturally and functionally abnormal and remodelled LA prior to undergoing surgery.

Other earlier and more controversial works on echocardiographic parameters as predictors for the development of post-operative AF involved smaller number of patients[46] (*Table 5*). For example, Tsang *et al.*[47] reported that diastolic LV dysfunction and its severity were independent predictors for the development of future non-valvular AF. Benedetto *et al.*[48] used tissue Doppler

Table 4 Post-operative atrial fibrillation and outcomes

Author	*n*; type of surgery	In-hospital mortality: post. AF vs. no post. AF	Late mortality: post. AF vs. no post. AF	Length of stay (days): post. AF vs. no post. AF	Stroke: post. AF vs. no post. AF
Aranki *et al.*[18]	570, CABG	3.9 vs. 1.8%, $P = 0.15$	NS	15.3 ± 28.6 vs. 9.3 ± 19.6, $P = 0.001$;	3.7 vs. 1%, $P = 0.025$
Almassi *et al.*[1]	3794, CABG, valvular, combined	5.95 vs. 2.95%, $P = 0.001$ (30 days)	9.36 vs. 4.17%, $P = 0.001$ (6 months)	Median: ICU: 3.6 vs. 2, $P < 0.001$; Hospital: 10 vs. 7, $P < 0.001$; Re-admission to the ICU: 13.49 vs. 3.52%, $P < 0.001$	5.3 vs. 2.4%, $P < 0.001$
Borzak *et al.*[20]	436, CABG	NS	NS	Adjusted multivariate analysis: 9.2 ± 5.3 vs. 6.4 ± 5.3, $P < 0.001$	NS
Tamis and Steinberg[32]	216, elective CABG	NS	NS	15.1 ± 9.0 vs. 10.0 ± 4.6, $P < 0.001$; Adjusted multivariate analysis: AF patients stayed 3.2+/−1.7 days longer, $P < 0.001$	NS
Stamou *et al.*[28]	969, off-pump CABG	3 vs. 1%, $P = 0.009$ (in-hospital)	NS	9 ± 6 vs. 6 ± 5, $P < 0.001$	NS
Stamou *et al.*[30]	16 528, CABG	NS	NS	NS	Post. AF as a predictor for stroke: OR 1.7, 95% CI 1.4–2.2, $P < 0.001$
Likosky *et al.*[31]	11 825, CABG	NS	NS	NS	2.7% vs. 1.2%, $P < 0.001$; Post. AF as a predictor for stroke: OR 1.82, $P < 0.001$
Villareal *et al.*[19]	6475, CABG	7.4 vs. 3.4%, $P = 0.0007$ (in-hospital)	Post. AF as independent predictor: adjusted OR 1.5, $P < 0.001$ in the retrospective cohort, and OR 3.4, $P = 0.0018$ in the case-matched group (mean follow-up 5 ± 2 years)	Median: 14 vs. 10, $P < 0.0001$	5.2 vs. 1.7%, $P < 0.0001$;
Mathew *et al.*[5]	4657, CABG	4.7 vs. 2.11%, $P < 0.001$	NS	Median (IQR): ICU, hours: 36.3 (21.7–68.2) vs. 25.5 (21.0–47.3), $P < 0.001$; hospital, days: 9 (7–12) vs. 7 (6–10), $P < 0.001$	No significant association
Auer *et al.*[17]	253, CABG, valvular, combined	NS	NS	Adjusted multivariate analysis: 14.2 ± 5.3 vs. 10.8 ± 3.8, $P < 0.01$	NS
Ahmadi *et al.*[29]	11 183, CABG	33.3 vs. 1.07%, $P < 0.05$ (24 h)	NS	NS	NS

Post. AF, post-operative atrial fibrillation; CABG, coronary artery bypass grafting; ICU, intensive care unit; IQR, interquartile range; NS, not stated; OR, odds ratio.

Table 5 Studies on electrocardiographic and echocardiographic parameters for prediction of post-operative atrial fibrillation

Author, number of patients, type of surgery	ECG parameters	Results	Echocardiographic parameters	Results
Steinberg *et al.*[35], $n = 130$; cardiac surgery	fPWD on the SAECG pre-operatively	fPWD >40 ms predicted post-operative AF (sensitivity of 77%, specificity of 55%, negative predictive value of 87%, positive predictive value of 37%)		
Caravelli *et al.*[36], $n = 129$; CABG	fPWD on the SAECG pre-operatively; RMSV10; RMSV20	fPWD ≥135 ms predicted post-operative AF (sensitivity of 84%, specificity of 73%, negative predictive value of 85%, positive predictive value of 70%); smaller RMSV10 ($P < 0.001$) and RMSV20 ($P < 0.001$) in the post-operative AF group		
Aytemir *et al.*[33], $n = 53$; CABG	fPWD on the SAECG pre-operatively	fPWD >22.3 ms predicted post-operative AF (sensitivity of 68%, specificity of 88%, negative predictive value of 83%, positive predictive value of 76%)	LV EF; LA posteroanterior diameter	NS
Hayashida *et al.*[37], $n = 95$; CABG or aortic valve replacement	fPWD on the SAECG pre-operatively	fPWD ≥35 ms predicted post-operative AF ($P = 0.02$; OR 3.5)	LA diameter	Larger LA diameter in post-operative AF patients ($P = 0.003$)
Budeus *et al.*[117], $n = 101$; CABG	fPWD on the SAECG pre-operatively; RMSV20	fPWD ≥24 ms predicted post-operative AF (sensitivity of 78%, specificity of 75%, negative predictive value of 86%, positive predictive value of 64%); reduced RMSV20 ($P < 0.0001$) in post-operative AF group		
Gang *et al.*[38], $n = 151$; CABG	fPWD on the SAECG pre-operatively; P-wave morphology dispersion	NS		
Chandy *et al.*[24], $n = 300$; CABG	P-wave characteristics pre- and post-operatively	Larger decrease in post-operative P-wave duration in post-operative AF group ($P < 0.0001$); Larger increase in post-operative P-wave dispersion in the post-operative AF group ($P = 0.028$)		

Dogan *et al.*[41], $n = 57$; CABG	P-wave dispersion on the surface 12-lead ECG pre-operatively	Longer P-wave dispersion was associated with post-operative AF (55.0 ± 8.2 ms vs. 41.3 ± 14.3 ms, $P = 0.008$)		
Stafford *et al.*[118], $n = 201$; CABG	fPWD on the SAECG pre-operatively	fPWD > 141 ms predicted post-operative AF (negative predictive value 83%, positive−34%)	LA diameter	NS
Amar *et al.*[39], $n = 250$; thoracic surgery	fPWD on the SAECG pre-operatively	NS		
Açil *et al.*[46], $n = 102$; CABG			LA diameter	LA diameter significantly predicted the development of AF following CABG ($P = 0.047$)
Osranek *et al.*[50], $n = 205$; cardiac surgery			LAV; LV EF; LV diastolic function	Larger LAV in post-operative AF group ($P = 0.0001$)
Benedetto *et al.*[48], $n = 96$; CABG			LA area; peak atrial systolic mitral annular velocity	Larger LA area in post-operative AF group ($P = 0.007$); lower peak atrial systolic mitral annulus velocity ($P = 0.01$)
Nakai *et al.*[49], $n = 93$; CABG			LA area; LA function	Larger LA area in post-operative AF group ($P < 0.001$); Lower atrial index ($P = 0.008$)
Leung *et al.*[45], $n = 300$; CABG			LA area, LAA area, LA EF, LAA EF, LV EF, LA length, LAA peak velocity, VTI of E/A, E/A, E duration, atrial filling fraction, peak A velocity, hepatic vein diameter and velocity, pulmonary vein haemodynamics and diameter; all measurements were done pre- and post-surgery	Pre-surgery measurements: larger LA area ($P = 0.0092$), lower LA EF ($P = 0.027$) in post-operative AF group; Post-surgery findings: atrial filling fraction ≤0.36 and E duration ≥270 ms increased the risk of post-operative AF ($P = 0.04$ and $P = 0.0067$, respectively)
Roshanali *et al.*[51], $n = 355$; CABG			LV EF; max transmitral A-wave Doppler flow velocity; LA volume; atrial electromechanical interval	Patients with post-operative AF had lower LV EF, reduced max transmitral A-wave Doppler flow velocity, increased total LA volume; prolonged atrial electromechanical interval

AF, atrial fibrillation; CABG, coronary artery bypass grafting; ECG, electrocardiogram; EF, ejection fraction; fPWD, filtered P-wave duration; SAECG, signal-averaged electrocardiogram; LA, left atrial; LAA, left atrial appendage; LAV, left atrial volume; LV, left ventricular; NS, no significance; RMSV10, root mean square voltage of the last 10 ms of atrial depolarization; RMSV20, root mean square voltage of the last 20 ms of atrial depolarization; VTI, velocity time integral.

imaging techniques to show that patients with an increased risk for the development of post-operative AF had functionally abnormal LA function pre-operatively (*Table 5*). In contrast, Nakai *et al.*[49] reported that LA volume—but not LA function—was predictive for the occurrence of AF following cardiac surgery. This is consistent with the study by Osranek *et al.*,[50] which showed that LA volume assessed pre-operatively is associated with the occurrence of post-operative AF in a study of 205 patients undergoing cardiac surgery (*Table 5*).

More recently, Roshanali *et al.*[51] described a new echocardiographic parameter—an atrial electromechanical interval measured using tissue Doppler echocardiography—for the prediction of AF following CABG, which had a 100% sensitivity and 94.8% specificity. They speculated that prolonged atrial electromechanical interval in patients, who develop post-operative AF, might be explained by LA enlargement and atrial conduction delay.[51]

The impact of the renin–angiotensin–aldosterone system

The renin–angiotensin–aldosterone system (RAAS) has been implicated in the pathophysiology of atrial remodelling. Indeed, substantial clinical data on RAAS blockade by the angiotensin-converting enzyme inhibitors (ACE-Is) and angiotensin receptor blockers (ARBs) in modulating AF have accumulated, although these are largely in non-surgical populations, with limited data in the post-CABG setting[52,53] reporting that inhibition of RAAS prevented the development of new-onset AF, improved the likelihood of SR restoration after electrical cardioversion, and decreased the number of AF recurrences after successful cardioversion. The GISSI-AF trial—a prospective, randomized, placebo-controlled, multicentre study—would hope to clarify the effect of the ARB valsartan on SR maintenance after successful cardioversion, and secondary, on the dynamic changes in the LA dimensions and neurohormons levels.[54] Thus, an antiarrhythmic effect of ACE-I/ARB, if any, is theoretical, rather than conclusive.

Should an ACE-I or ARB be used to prevent AF post-cardiac surgery? In experimental work, there was a positive effect of ARB candesartan in the prevention of structural atrial remodelling and atrial endocardial dysfunction, at least in hypertensive rats.[55] Nonetheless, trials in post-cardiac surgery *per se* are more limited. One recent retrospective single-centre analysis showed that ACE-I or ARB use did not significantly prevent the development of post-operative AF,[56] although there was a reduction in the odds of post-operative AF by 29%.[57] More large prospective trials are needed to clarify the true effect, if any, of RAAS inhibition on the development of post-operative AF.

Preventive strategies with antiarrhythmic drugs for post-operative atrial fibrillation

Given that post-operative AF is a major clinical problem, antiarrhythmic drugs have been used to prevent this arrhythmia (*Table 6*). In one meta-analysis, prophylactic treatment to decrease post-operative AF reduced hospital length of stay and costs, but did not significantly affect stroke and mortality.[58] A further analysis[59] evaluated 29 trials and found that the benefit of preventive strategies for shortening of hospital stay for post-operative AF was only associated with amiodarone (OR 0.60, 95% CI −0.92 to −0.29) and pacing (OR−1.3, 95% CI −2.55 to −0.08). Indeed, only amiodarone had a significant impact on reducing post-operative stroke incidence (OR 0.54, 95% CI 0.30−0.95).[59] Thus, of medical drug options, only amiodarone is an effective converter of AF to SR, whereas beta-blockers are the only effective preventive medications in the perioperative period.

Beta-blockers

Andrews *et al.*[4] published the first meta-analysis showing the beneficial effects of beta-blocker therapy in suppression of post-operative AF (34 vs. 8.7%, $P < 0.0001$). A large meta-analysis determined the benefit of beta-blocker pre-treatment and continuation post-operatively on the reduction of post-surgery AF (33 vs. 19%) with a huge heterogeneity between trials ($P < 0.00001$); there was no relation to the type of beta-blocker, regimen or pre-treatment, and trial size.[60] A further meta-analysis of 31 RCTs[59] showed broadly similar benefits for beta-blockers. In studies in which beta-blocker was withdrawn at the time of surgery, there was a much higher effect in the treatment group (OR 0.30, 95% CI 0.22−0.40) compared with trials with continuation of non-study beta-blockers in the control group (OR 0.69, 95% CI 0.54−0.87); this suggests significant heterogeneity between different studies and perhaps an underestimation of the preventive effects associated with beta-blockers.[59]

Halonen *et al.*[61] reported that intravenous metoprolol started early post-surgery was well tolerated and superior to oral administration against post-operative AF, perhaps due to diminished absorption from gastrointestinal tract very early after cardiopulmonary perfusion. Also, the pre-operative use of beta-blockers reduced perioperative mortality from 3.4 to 2.8% (OR 0.8, 95% CI 0.78−0.82).[62] Unsurprisingly, the American Heart Association guidelines strongly recommend pre-operative or early post-operative beta-blocker therapy for patients undergoing CABG.[63] The European Association for Cardio-Thoracic Surgery guidelines recommend beta-blockers as first choice for the prevention of post-operative AF in all the patients undergoing cardiac surgery, unless they are contraindicated.[64]

Sotalol

Seven randomized studies comparing the efficacy of sotalol with the conventional beta-blocker treatment in prevention of post-operative AF were described by Patel and Dunning.[65] Five of the seven studies showed a statistically significant advantage of sotalol over beta-blockers in the reduction of post-operative AF, and two other investigations did not show a significant benefit of sotalol.[65] Several trials used sotalol pre-operatively 40 mg t.d.s. or 80 mg b.d. continuing post-operatively, and this regimen was not associated with the increase in side-effects. A meta-analysis of four trials (sotalol vs. beta-blocker against post-operative AF) revealed that sotalol is more effective than beta-blocker, and the number needed to treat with sotalol over beta-blockers was

Table 6 Preventive strategies for post-operative atrial fibrillation

Author	Design, no. of subjects	Treatment studied	Type of cardiac surgery	Arrhythmia recording	Reduction of post-operative AF in the treatment group	Other variables, associated with treatment
Zimmer *et al.*[58]	Meta-analysis: 13 RCTs, *n* = 1783	Various antiarrhythmics and atrial pacing	CABG, valve, or both/on-pump		OR 0.52, 95% CI 0.41–0.65	Shortening of length of stay by 1 day ± 0.2; mean reduction in costs of $1287 ± $673;
Andrews *et al.*[4]	Meta-analysis: 24 RCTs, blinded and unblended		CABG			
	n = 1549 (13 trials);	Various beta-blockers			OR 0.28, 95% CI 0.21–0.36;	
	n = 507;	Digoxin in a various dose regimen;			OR 0.97, 95% CI 0.62–1.49;	
	n = 432	Verapamil in a various dose regimen			OR 0.91, 95% CI 0.57–1.46	
Crystal *et al.*[60]	Meta-analysis					
	27 RCTs, *n* = 3840	Various beta-blockers	CABG, valve, or both/on-pump		OR 0.39, 95% CI 0.28–0.52; NNT = 7	Second-points—length of stay and stroke reduction—NS
	8 RCTs, *n* = 1294	Sotalol			OR 0.35, 95% CI 0.26–0.49	
	9 RCTs, *n* = 1384	Amiodarone			OR 0.48, 95% CI 0.37–0.61	
	4 RCTs, *n* = 900	Sotalol vs. other beta-blockers			OR 0.50, 95% CI 0.34–0.74	
	10 RCTs,	Pacing				
	n = 581	RA			OR 0.68, 95% CI 0.39–1.19	
	n = 148	LA			OR 0.57, 95% CI 0.28–1.16	
	n = 744	Bi-atrial			OR 0.46, 95% CI 0.30–0.71	
Halonen *et al.*[61]	RCT, *n* = 240	Metoprolol i.v. 1–3 mg/h vs. oral metoprolol 25 mg t.p.d. or 50 mg b.d. for 48 h started early post-operatively	CABG, valve, or both/on-pump	Continuous ECG monitoring for 48 h or until the first AF episode	Metoprolol i.v. vs. oral: 16.8 vs. 28.1%, respectively, $P = 0.036$	
Burgess *et al.*[59]	Meta-analysis					
	31 RCTs, *n* = 4452	Beta-blocker	CABG, valve, or both/on-pump		OR 0.36, 95% CI 0.28–0.47;	
	7 RCTs, *n* = 1240	Sotalol vs. beta-blocker			OR 0.42, 95% CI 0.26–0.65;	
	18 RCTs, *n* = 3295;	Amiodarone			OR 0.48, 95% CI 0.40–0.57;	
	22 RCTs, *n* = 2896	Magnesium;			OR 0.57, 95% CI 0.42–0.77;	
	14 RCTs, *n* = 1885	Overdrive pacing			OR 0.60, 95% CI 0.47–0.77	
	9 RCTs, *n* = 723	RA			OR 0.74, 95% CI 0.48–1.12;	
	4 RCTs, *n* = 408	LA			OR 0.70, 95% CI 0.46–1.07;	
	10 RCTs, *n* = 754	Bi-atrial pacing			OR 0.44, 95% CI 0.31–0.64	

Continued

Table 6 Continued

Author	Design, no. of subjects	Treatment studied	Type of cardiac surgery	Arrhythmia recording	Reduction of post-operative AF in the treatment group	Other variables, associated with treatment
Budeus *et al.*[68]	RCT, double-blind, pacebo controlled, $n = 110$	Combined i.v. and oral amiodarone starting 1 day before and continuing to 7 days after surgery	CABG	Follow-up for 7 days by Holter monitoring	OR 0.91, 95% CI 0.036–0.235	
Mitchell *et al.*[69]	PAPABEAR RCT, double-blind, placebo controlled, $n = 601$	Oral amiodarone 10 mg/kg for 13 days starting 6 days prior to surgery	CABG, valve, or both/on-pump	Follow-up with continuous monitoring for 6 days	OR 0.52, 95% CI 0.34–0.69	
Shiga *et al.*[66]	Meta-analysis: 17 RCTs, $n = 2069$	Magnesium	CABG, valve, or both/on-pump		OR 0.77, 95% CI 0.63–0.93, $P = 0.002$; NNT = 13	No significant effect on hospital stay and post-operative MI
Reston *et al.*, 2003,[107]	Meta-analysis: 28 RCTs and cohort studies	Off-pump CABG vs. on-pump CABG	CABG, off-/ on-pump		OR 0.69, 95% CI 0.58–0.81	
Raja *et al.*[108]	Meta-analysis: 6 RCTs, $n = 1262$	Off-pump CABG vs. on-pump CABG	CABG, off-/ on-pump		OR 0.77, 95% CI 0.62–0.95; NNT = 20	
Turk *et al.*[109]	Prospective, case-matched study, $n = 267$	Off-pump CABG vs. on-pump CABG	CABG, off-/ on-pump	Continuous monitoring during the first 72 h	No significant difference	
Caló *et al.*[95]	RCT, placebo controlled, $n = 160$	PUFAs, 2 g/day, 5 days prior to surgery and continued until discharge	Elective CABG	Continuous monitoring for the first 4–5 days, then 12-lead ECG every day until discharge	Absolute risk reduction 18.1%, relative risk reduction–54.4%; NNT 5.51	Shorter hospital length of stay ($P = 0.017$)
Marin *et al.*[82]	Retrospective, cross-sectional, $n = 234$	Statin	CABG/on-pump		OR 0.52, 95% CI 0.28–0.96, $P = 0.038$	
Pati *et al.*[75]	ARMYDA-3, prospective, randomized, placebo controlled, single-centre, $n = 200$	Atorvastatin 40 mg for 7 days prior to surgery	CABG, valve, or both/on-pump	Continuous telemonitoring for at least 6 days	OR 0.39, 95% CI 0.18–085, $P = 0.017$	
Lertsburapa *et al.*[84]	A nested cohort study from AFIST I, II, and III trials, $n = 555$	Statin	CABG, valve, or both/on-pump	Continuous telemonitoring	OR 0.60, 95% CI 0.37–0.99	
Mariscalco *et al.*[86]	Retrospective, longitudinal, observational, $n = 405$	Statin, various types and regimens	Elective CABG		OR 0.58, 95% CI 0.37–0.91, $P = 0.017$	
Ozaydin *et al.*[85]	Observational, $n = 362$	Statin	CABG		Protective impact by Kaplan–Meier analysis ($P = 0.01$)	Less frequency ($P = 0.03$) and duration of AF episodes ($P = 0.0001$)
Virani *et al.*[87]	Retrospective, single-centre, $n = 4044$: 2096 with pre-treatment and 1948 without	Statin (various statins, doses and regimens)	CABG, valve or both/on-pump	Continuous telemetry during hospitalization period	OR 1.13, 95% CI 0.98–1.31, $P = 0.08$ No significance, even after propensity score analysis (OR 1.14, 95% CI 0.92–1.41, $P = 0.21$)	
Fauchier *et al.*[92]	Meta-analysis: 6 RCTs, two of them on post-operative AF, $n = 3557$	Statin	CABG		OR 0.60, 95% CI 0.27–1.37 (for primary prevention and post-operative AF); overall: OR 0.39, 95% CI 0.18–0.85	

Halonen et al.[96]	Prospective, randomized, double-blind, placebo controlled, multicentre, $n = 241$	Hydrocortisone i.v. 100 mg on the operative day followed by 100 mg every 8 h for the next 3 days	CABG, valve, or both/on-pump	Continuous ECG recording during the first 84 h after surgery	OR 0.63, 95% CI 0.45–0.87; $P = 0.003$	CRP levels in treatment group were significantly lower on the first, second, and third post-operative days compared with placebo group ($P = 0.02$, $P < 0.001$, $P < 0.001$, respectively)
Halonen et al.[96]	Meta-analysis: 3 RCTs, $n = 621$	Corticosteroids	CABG, valve, or both/on-pump		OR 0.67, 95% CI 0.54–0.84, $P = 0.001$	
Baker et al., 2007,[97]	Meta-analysis: 9 RCTs, $n = 990$	Corticosteroids	CABG, valve, or both/on-pump		OR 0.55, 95% CI 0.39–0.78	Hospital length of stay shortening by 1.6 day
Ruffin et al.[101]	A nested cohort study from AFIST I, II, and III, $n = 555$	NSAIDs	CABG, valve, or both/on-pump		OR 0.54, 95% CI 0.32–0.90	Reduced need for red blood cell transfusion (by 37%); no increase in stroke or MI incidence
Mathew et al.[5]	Retrospective, observational study from 70 centres, $n = 4657$	Perioperative ACE-I	CABG, valve, or both/on-pump		OR 0.62, 95% CI 0.48–0.79	
White et al.[57]	A nested cohort study from AFIST I, II, and III, $n = 338$	Pre-operative ACE-I or ARB	CABG, valve, or both/on-pump		OR 0.71, 95% CI 0.42–1.20	
Coleman et al., 2007,[56]	Retrospective cohort analysis, $n = 1469$	Short-term use of ACE-I or ARB post-operatively	CABG, valve, or both/on-pump		OR 0.95, 95% CI 0.57–1.56	
Anglade et al.[102]	A nested cohort study from AFIST I, II, and III, $n = 184$	Thiazolidinedione (patients with beta-blocker and amiodarone)	CABG, valve, or both/on-pump		OR 0.80, 95% CI 0.32–1.99	

ACE-I, angiotensin converting enzyme inhibitor; ARB, angiotensin II type 1 receptors blocker; AF, atrial fibrillation; CABG, coronary artery bypass grafting; CI, confidence interval; CRP, C-reactive protein; ECG, electrocardiogram; i.v., intravenous; MI, myocardial infarction; NNT, numbers needed to treat; OR, odds ratio; PUFA, n-3 polyunsaturated fatty acids; NSAIDs, non-steroidal anti-inflammatory drugs; RCT, randomized controlled trial.

10.[66] Similar results were shown by Burgess et al.[59] in their meta-analysis of seven RCTs.

Amiodarone

Amiodarone is efficacious in prophylaxis of post-operative AF compared with controls in a few large meta-analyses of RCTs, although there is a wide variety in dose, duration of treatment, and routes of delivery.[59,60] The AFIST II trial showed a benefit of combined intravenous and oral amiodarone use starting early post-operatively compared with placebo: post-operative AF occurred in 22.1 vs. 38.6% of patients, respectively; $P = 0.037$.[67] There is also a beneficial effect of combined intravenous and oral amiodarone treatment in the reduction of AF after CABG in high-risk patients identified using P-wave signal-average ECG.[68]

The largest trial of amiodarone for the prevention of post-operative AF—PAPABEAR—was published in 2005, and reported that oral amiodarone use for 13 days perioperatively was an effective and safe approach in AF prophylaxis after cardiac surgery, even in a specific subgroup of patients with perioperative use of beta-blockers (15.3 vs.25.1%, $P = 0.03$, in favour of amiodarone), although this trial was somewhat unpowered concerning safety.[69]

A recent meta-analysis of 14 RCTs ($n = 2864$) aimed to clarify an optimal dose and time of amiodarone prophylaxis for AF following cardiac surgery[70] found no significant difference in post-operative AF suppression between low (defined as $<$3000 mg), medium (3000–5000 mg) or high dose ($>$5000 mg) ($P = 0.238$), and no significant difference between the pre-operative and post-operative initiation time of amiodarone ($P = 0.862$).[70] The European Association for Cardio-Thoracic Surgery guidelines recommends amiodarone for the prevention of post-operative AF in all patients undergoing cardiac surgery when beta-blockers are contraindicated (Grade A recommendation based on level 1a and 1b studies).[64]

Temporary pacing

Studies on overdrive temporary pacing for post-operative AF prevention are small in size, with different pacing protocols. Published meta-analyses show that only bi-atrial pacing has an advantage in AF suppression after the cardiac surgery compared with controls.[59,60] With reference to recommendations of the European Association for Cardio-Thoracic Surgery guidelines, bi-atrial pacing significantly decreases the occurrence of post-operative AF.[64]

Magnesium

Magnesium is highly effective in the reduction of post-operative AF. Indeed, magnesium levels should be corrected in the same manner as potassium levels because they have definitively an impact on the incidence of AF. Magnesium is a cofactor of Na-K adenosine triphosphatase, which regulates the myocardial transmembrane sodium and potassium gradients,[71] and decreased levels of magnesium post-operatively are associated with a higher risk of AF occurrence after cardiac surgery.[72] A large meta-analysis[66] determined that magnesium is superior to traditional antiarrhythmic therapy in the prevention of post-cardiac surgery AF: the numbers needed to treat for magnesium are 13, which are lower compared with traditional antiarrhythmics (beta-blocker 7, sotalol 5, amiodarone 7). Burgess et al.[59] also found a similar overall reduction of post-operative AF by magnesium in their meta-analysis of 22 trials with various dosing strategies, time of delivery, and significant heterogeneity ($P < 0.001$). An analysis of studies that allowed post-operative beta-blocker use did not find a significant beneficial effect of magnesium for the prevention of post-operative AF (OR 0.83, 95% CI 0.60–1.16).[59]

Other drugs

Digoxin does not show any benefit for post-operative AF prophylaxis (OR 0.97, 95% CI 0.62–1.49).[73] A subgroup analysis in a meta-analysis of calcium channel blockers found that non-dihydropyridines significantly suppressed post-surgery supraventricular arrhythmias (OR 0.62, 95% CI 0.41–0.93), but with a high heterogeneity ($P = 0.03$).[74]

Non-antiarrhythmic drug approaches for the prevention of post-operative atrial fibrillation

HMG Co-A inhibitors ('statins')

A few studies have examined the use of statins in relation to the development of post-operative AF, and more studies are clearly needed. The antiarrhythmic mechanism of statins can possibly be explained by their effects on inflammation,[75–78] antioxidant effects,[79,80] antiarrhythmic effects due to ion channel stabilization,[81] a role in extracellular matrix modulation,[82] an inhibition of synthesis of isoprenoids that are significant for the post-translational modification of such signalling molecules as Rho, Rac, and Ras,[80] and an ability to reverse angiotensin II-mediated atrial structural remodelling.[83]

Many studies on statins are non-randomized and based on registry analysis. For example, Marin et al.[82] reported significant decrease in incidences of AF after elective CABG when patients were on statin therapy prior to surgery. However, the study was retrospective, included patients with a previous history of AF, and various statin pre-treatment regiments were used, and the number of subjects is too small to conclude the exact effect of statins on the reduction of post-operative AF. A retrospective analysis[84] on statins and post-operative AF among patients receiving prophylactic beta-blocker and amiodarone treatment (included from prospective randomized Atrial Fibrillation Suppression Trials I, II, and III) showed that adjunctive statin pre-treatment suppressed post-operative AF by 40%. Furthermore, Ozaydin et al.[85] reported that pre-treatment with statins was protective against the development of AF after CABG (on Kaplan–Meier analysis $P = 0.01$), but also shortened the duration of post-operative AF episodes ($P = 0.0001$). The advantage of statin pre-treatment in the suppression of AF incidence after elective CABG may not depend on type, dose, or duration of use.[86]

Nonetheless, negative studies showing no benefit of statins on post-operative AF also exist. For example, pre-treatment with statin prior to cardiac surgery did not show any significant benefit for reducing the risk in the development of post-operative AF.[87] However, this study was conducted retrospectively, and patients received different statins, variable doses were used, and there were incomplete data on the duration of statin treatment prior to cardiac surgery.

The first randomized, placebo-controlled trial on statin pre-treatment for the reduction of post-operative AF incidences was the ARMYDA-3 (Atorvastatin for Reduction of Myocardial Dysrhythmia after cardiac surgery) trial,[75] which showed a significant decrease in post-operative AF occurrences after pre-treatment with atorvastatin. Moreover, hospital length of stay was shorter in the atorvastatin group compared with placebo ($P = 0.001$). Of note, there was significantly higher post-operative peak C-reactive protein levels in AF patients compared with those who remained in SR ($P = 0.01$);[75] however, the ARMYDA-3 trial did not find any statistical association between statin use and plasma C-reactive protein levels.

A large ($n = 3829$), retrospective 8-year study showed a decreased mortality and morbidity in patients treated with statin before cardiac surgery, although this effect was not statistically significant in a subgroup of subjects after valve surgery.[88] Pre-treatment with statin prior to elective CABG surgery also decreased perioperative mortality in a large, retrospective study[89] and in an analysis from a large, prospective, longitudinal, multicentre McSPI (the MultiCenter Study of Perioperative Ischemia) trial, a significant reduction of early cardiac death (OR 0.25, 95% CI 0.07–0.87, $P < 0.03$) after CABG was seen.[90] Thus, pre-treatment with statin seems to be useful particularly prior to the CABG surgery, despite the small incidences of rhabdomyolysis caused by high doses of statin.[91] A meta-analysis of six randomized studies on the impact of statin treatment on the suppression of AF included two studies with post-cardiac surgery AF and found that statins were more beneficial in secondary AF prevention—rather in primary prevention—and their effect did not appear to be dose-related.[92]

n-3 Polyunsaturated fatty acids

The n-3 polyunsaturated fatty acids (PUFAs) are distinctive due to their antiarrhythmic effect on fatal ventricular arrhythmias,[93] and high plasma concentrations of PUFAs caused by fish consumption have been found associated with lower incidence of AF during the 12-year period.[94] In a prospective, randomized, controlled trial, pre-treatment with PUFAs decreased the development of AF after CABG surgery and shortens hospital length of stay.[95] However, the present single-centre study was not double blinded, and post-operative AF monitoring was not performed continuously in all patients. More trials are clearly needed.

Anti-inflammatory drugs

Corticosteroids are well-known anti-inflammatory agents, and inflammation has been proposed in the pathogenesis of AF post-cardiac surgery. One prospective, randomized, double-blind trial of intravenous corticosteroids administration in suppression of post-operative AF has been published.[96] This study found a significant reduction of post-operative AF in those treated with hydrocortisone compared with placebo, and when this study was included in a meta-analysis with two previous studies there was also a reduction of post-operative AF.[96] Another meta-analysis of nine randomized, controlled trials again suggested an effect of perioperative corticosteroid use on AF occurrence and on hospital length of stay after cardiac surgery, with an overall benefit of treatment with corticosteroids concerning both endpoints.[97] Also, a few prospective, randomized, controlled studies demonstrated the advantage of corticosteroid use before CABG surgery in reducing the incidence of post-operative AF, although this was not a primary endpoint of those trials.[98,99]

However, a recent randomized, double-blind study on the effects of corticosteroids on the development of AF after combined valve and CABG surgery did not reveal any differences between treatment and placebo groups on the dynamic release of plasma proinflammatory markers, but this was based on a small number of patients ($n = 78$).[100]

A positive impact of suppression of inflammatory process on the development of post-operative AF has been shown using non-steroidal anti-inflammatory drugs.[101] However, this study did not reveal any significant increase in stroke or myocardial infarction development after cardiac surgery,[101] and the study was not prospective, randomized, and controlled, and it probably underpowered concerning safety. Recently, Anglade *et al.*[102] demonstrated that the pre-operative use of thiazolidinedione, which have some anti-inflammatory properties in diabetic patients undergoing cardiac surgery, was associated with 20% reduction in post-operative AF—however, it did not reach statistical significance due to being underpowered.

As mentioned earlier, RAAS blockade decreases the risk of the new-onset AF and is beneficial in the secondary prevention of AF, particularly in heart failure patients. For example, Brull *et al.*[103] tested the effect of ACE-I use before CABG on release of IL-6 post-operatively and found that IL6 levels were significantly ($P = 0.02$) blunted with ACE-I pre-treatment compared with controls. Mathew *et al.*[5] also described this benefit in a large observational study. However, data extracted from two RCTs (AFIST II and AFIST III) did not determine any benefit of pre-operative use of ACE-I or ARB in the suppression of AF following cardiac surgery.[57] Similarly, a retrospective analysis of matched patients undergoing cardiac surgery did not find any significant effect of short-term post-operative inhibition of RAAS in reducing AF rate following cardiac surgery.[56]

Miscellaneous

Oxidative stress has been implicated in the pathogenesis of AF, and some studies tested antioxidative agents for the suppression of post-operative AF. Indeed, the possible beneficial effects of vitamin C[104] and *n*-acetylcysteine[105] have been suggested in this setting.

The American College of Chest Physicians guidelines also recommend mild hypothermia (for example, 34°C), the use of posterior pericardiotomy, and heparin-coated CPB circuits as possible intraoperative preventive strategies for the reduction of AF following cardiac surgery,[106] although robust evidence for these strategies is more limited. There is some contradictory evidence concerning the advantage of off-pump CABG over conventional CABG with CPB in reducing the rate of post-operative AF. Some meta-analyses showed that off-pump CABG significantly lower incidence of post-operative AF compared with on-pump,[107,108] but the meta-analysis by Burgess *et al.*[59] did not find a high heterogeneity ($P < 0.001$) and a lack of studies with post-operative AF as a primary endpoint. Recently, Turk *et al.*[109] reported a prospective study of off-pump CABG vs. on-pump CABG on the occurrence of post-operative AF, and did not found any significant difference between these operative techniques in the preventive strategy for preventing post-operative AF.

Despite some hopeful preliminary results of the ventral cardiac denervation by retention of anterior pericardial fat pad for the prevention of post-operative AF,[110] the recently published AFIST III trial ($n = 180$) did not find any significant benefit of such an intervention.[111]

Conclusion

The overall incidence of post-operative AF depends on arrhythmia recording method with the best diagnostic value using continuous ECG monitoring techniques. Advanced age has been shown the best predictive clinical factor, whereas other features, including ECG and echocardiographic parameters, lack a high specificity and positive prediction value. With regard to preventive options, only beta blockers, rate-limiting calcium antagonists, and amiodarone have shown a potent effect on the suppression of AF post-operatively, but not digoxin. In the prophylaxis and management of post-operative AF, the appropriate use of thromboprophylaxis and correction of identifiable precipitants (such as electrolyte imbalance or hypoxia) are recommended. The role of other drugs, such as RAAS blockers (ACE-Is, ARB) and statins in modulating the incidence of post-operative AF merits further study.

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CARDIOVASCULAR FLASHLIGHT

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Coronary artery occlusion due to lead insertion into the right ventricular outflow tract

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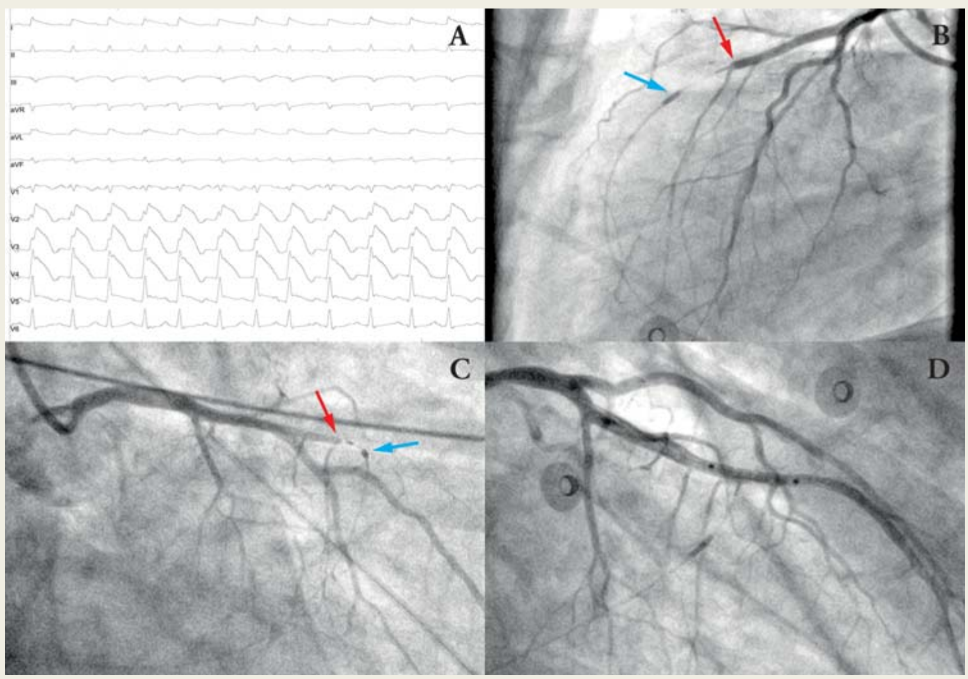

A 49-year-old male was referred to our hospital for radiofrequency (RF) ablation of recurrent, symptomatic, and drug refractory left atrial tachycardia. A non-fluoroscopic real-time three-dimensional navigation system was used for the intervention (LocaLisa, Medtronic, USA). A stable reference is crucial for the use of the device.

Therefore, a screwable temporary pacing lead (Medtronic) was directed with a sheath to the right ventricle (RV) and inserted into the septal endocardium of the RV outflow tract (RVOT). Immediately after fixation of the lead, the patient complained of chest pain. In the ECG, ST-segment elevations in leads I, aVL, and V2–V4 became overt (*Panel A*). Nitroglycerine s.l., heparin i.v., and morphine i.v. were immediately given to the patient.

An immediate coronary angiography revealed an acute occlusion of the left anterior descending (LAD) coronary artery in its mid-distal segment. This obstruction was caused by a penetration of the electrode screw into the LAD through the RVOT myocardium (*Panels B* and *C*). Removal of the lead resolved the occlusion and a covered stent prevented clinically significant bleeding from the LAD (*Panel D*). The patient symptoms improved and ECG signs normalized. The post-procedural echocardiogram showed a normal ejection fraction (50%) with a wall motion abnormality of the anterior wall. No pericardial effusion was noted.

A proper lead fixation into the RVOT can have the potential complication of inadvertent perforation into the LAD due to its proximity to the RVOT and interventricular septum. This is of relevance since many RV pacing leads are being placed in non-apical locales. Caution should be taken when implanting a screwable lead into this region.

Panel A. ECG during patients complain immediately after lead implantation: ST-segment elevation in leads I, aVL, and V2–V4.

Panels B and C. LAO and RAO view of the immediate coronary angiography during ST-segment elevation and clinical complains revealing a mid-distal LAD occlusion (red arrow) due to penetration of the screw-in electrode (blue arrow).

Panel D. A covered stent was implanted in the LAD at the effected part. The lead was removed simultaneously while stenting.