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.

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**Keywords**

- Atrial fibrillation
- Cardiac surgery
- Clinical predictive factors
- Prevention

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**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 asymptomatic7 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 settings7—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...
by Almassi et al., but these factors were not significantly associated with post-operative AF in other work. 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, which coincides with a peak of systemic inflammation caused by surgery. 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, and prolonged...
Table 3 Peak of atrial fibrillation occurrences and activation of inflammation following cardiac surgery

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<td>Second day, &gt;70% of episodes within the first 3 days</td>
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<td>Second day, &gt;95% of episodes before the fifth day</td>
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<td>Aouifi et al.</td>
<td>Second day of CRP peak</td>
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AF, atrial fibrillation; CRP, C-reactive protein.

hospital length of stay. 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, persistent congestive heart failure (CHF) symptoms, respiratory failure, various infectious complications, renal failure, severe hypotension and shock, multisystemic failure, and cardiopulmonary arrest. 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. 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. 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. In contrast to the study by Chandy et al., 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. In a small study of 95 patients, Hayashida et al. found that signal-averaged P-wave duration together with older age and left atrial enlargement was an independent predictor for AF following cardiac surgery.

Chandy et al. 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.

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 and clinical studies. 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. 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. 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. 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.

In their study of 300 patients, Chandy et al. investigated electrocardiographic signs of pericarditis in 8 subjects, and only 2 experienced post-operative AF. A study by Leung et al. 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 (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 (Table 5). For example, Tsang et al. reported that diastolic LV dysfunction and its severity were independent predictors for the development of future non-valvular AF. Benedetto et al. used tissue Doppler
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<th>In-hospital mortality: post. AF vs. no post. AF</th>
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<td>Aranki et al.</td>
<td>570, CABG</td>
<td>3.9 vs. 1.8%, $P = 0.15$</td>
<td>NS</td>
<td>$15.3 \pm 28.6$ vs. $9.3 \pm 19.6$, $P = 0.001$</td>
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<td>Almassi et al.</td>
<td>3794, CABG, valvular, combined</td>
<td>$5.95$ vs. $2.95%$, $P = 0.001$ (30 days)</td>
<td>$9.36$ vs. $4.17%$, $P = 0.001$ (6 months)</td>
<td>Median ICU: $3.6$ vs. $2$, $P &lt; 0.001$; Hospital: $10$ vs. $7$, $P &lt; 0.001$; Re-admission to the ICU: $13.49$ vs. $3.52%$, $P &lt; 0.001$</td>
<td>$5.3$ vs. $2.4%$, $P &lt; 0.001$</td>
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<td>Borzak et al.</td>
<td>436, CABG</td>
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<td>NS</td>
<td>Adjusted multivariate analysis: $9.2 \pm 5.3$ vs. $6.4 \pm 5.3$, $P &lt; 0.001$</td>
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<td>Tamis and Steinberg</td>
<td>216, elective CABG</td>
<td>NS</td>
<td>NS</td>
<td>$15.1 \pm 9.0$ vs. $10.0 \pm 4.6$, $P &lt; 0.001$; Adjusted multivariate analysis: AF patients stayed $3.2 \pm 1.7$ days longer, $P &lt; 0.001$</td>
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<td>Stamou et al.</td>
<td>969, off-pump CABG</td>
<td>$3$ vs. $1%$, $P = 0.009$ (in-hospital)</td>
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<td>$9 \pm 6$ vs. $6 \pm 5$, $P &lt; 0.001$</td>
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<td>Stamou et al.</td>
<td>16,528, CABG</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>Likosky et al.</td>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>$2.7%$ vs. $1.2%$, $P &lt; 0.001$; Post. AF as a predictor for stroke: OR $1.82$, $P &lt; 0.001$</td>
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<td>Villareal et al.</td>
<td>6475, CABG</td>
<td>$7.4$ vs. $3.4%$, $P = 0.0007$ (in-hospital)</td>
<td>Post. AF as independent predictor: adjusted OR $1.5$, $P &lt; 0.001$ in the retrospective cohort, and OR $3.4$, $P = 0.0018$ in the case-matched group (mean follow-up $5 \pm 2$ years)</td>
<td>Median: $14$ vs. $10$, $P &lt; 0.0001$</td>
<td>$5.2$ vs. $1.7%$, $P &lt; 0.001$; No significant association</td>
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<td>Mathew et al.</td>
<td>4657, CABG</td>
<td>$4.7$ vs. $2.11%$, $P &lt; 0.001$</td>
<td>NS</td>
<td>Median (IQR): ICU, hours: $36.3$ (21.7–68.2) vs. $25.5$ (21.0–47.3), $P &lt; 0.001$; Hospital, days: $9$ (7–12) vs. $7$ (6–10), $P &lt; 0.001$</td>
<td>No significant association</td>
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<td>Auer et al.</td>
<td>253, CABG, valvular, combined</td>
<td>NS</td>
<td>NS</td>
<td>Adjusted multivariate analysis: $14.2 \pm 5.3$ vs. $10.8 \pm 3.8$, $P &lt; 0.01$</td>
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<td>Ahmadi et al.</td>
<td>11,183, CABG</td>
<td>$33.3$ vs. $1.07%$, $P &lt; 0.05$ (24 h)</td>
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Post. AF, post-operative atrial fibrillation; CABG, coronary artery bypass grafting; ICU, intensive care unit; IQR, interquartile range; NS, not stated; OR, odds ratio.
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<td>Caravelli et al.</td>
<td>n = 129; CABG</td>
<td>fPWD on the SAECG pre-operatively; RMSV10; RMSV20</td>
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<td>LV EF; LA posteroanterior diameter</td>
<td>NS</td>
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<td>Aytemir et al.</td>
<td>n = 53; CABG</td>
<td>fPWD on the SAECG pre-operatively</td>
<td>fPWD &gt; 22.3 ms predicted post-operative AF (sensitivity of 68%, specificity of 88%, negative predictive value of 83%, positive predictive value of 76%)</td>
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<td>Hayashida et al.</td>
<td>n = 95; CABG or aortic valve replacement</td>
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<td>LA diameter</td>
<td>Larger LA diameter in post-operative AF patients ($P = 0.003$)</td>
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<td>fPWD on the SAECG pre-operatively; RMSV20</td>
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<td>Gang et al.</td>
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<td>fPWD &gt; 40 ms predicted post-operative AF (sensitivity of 77%, specificity of 55%, negative predictive value of 87%, positive predictive value of 37%)</td>
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<td>Chandy et al.</td>
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<tr>
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<td>CABG</td>
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<td>Amar et al.</td>
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<td>Thoracic surgery</td>
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<td>Leung et al.</td>
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<td>CABG</td>
<td>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</td>
<td>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</td>
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<td>Roshanali et al.</td>
<td>355</td>
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<td>LV EF; max transmitral A-wave Doppler flow velocity; LA volume; atrial electromechanical interval</td>
<td>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</td>
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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.
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.\(^5\)\(^,\)\(^6\) 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 neuromodulation.\(^4\) Thus, an antirhythmic 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.\(^5\)\(^,\)\(^6\) 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,\(^6\) although there was a reduction in the odds of post-operative AF by 29%.\(^7\) 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.\(^5\)\(^,\)\(^6\) A further analysis\(^5\)\(^,\)\(^7\) 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).\(^5\) 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 in 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.\(^6\)\(^,\)\(^7\) A further meta-analysis of 31 RCTs\(^5\) 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.\(^5\)

Halonen et al.\(^6\) 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).\(^6\) Unsurprisingly, the American Heart Association guidelines strongly recommend pre-operative or early post-operative beta-blocker therapy for patients undergoing CABG.\(^6\) 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.\(^6\)

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.\(^6\) 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.\(^6\) 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...
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<td>Meta-analysis: 13 RCTs, n = 1783</td>
<td>Various antiarrhythmics and atrial pacing</td>
<td>CABG, valve, or both/on-pump</td>
<td>OR 0.52, 95% CI 0.41–0.65</td>
<td>Shortening of length of stay by 1 day ± 0.2; mean reduction in costs of $1287 ± $673;</td>
<td></td>
</tr>
<tr>
<td>Andrews et al.</td>
<td>Meta-analysis: 24 RCTs, blinded and unblended</td>
<td>Various beta-blockers</td>
<td>CABG</td>
<td>OR 0.28, 95% CI 0.21–0.36; OR 0.97, 95% CI 0.62–1.49; OR 0.91, 95% CI 0.57–1.46</td>
<td></td>
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<tr>
<td>Crystal et al.</td>
<td>Meta-analysis</td>
<td>Various beta-blockers</td>
<td>CABG</td>
<td>OR 0.39, 95% CI 0.28–0.52; NNT = 7</td>
<td>Second-points—length of stay and stroke reduction—NS</td>
<td></td>
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<tr>
<td>Halonen et al.</td>
<td>RCT, n = 240</td>
<td>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</td>
<td>CABG, valve, or both/on-pump</td>
<td>Continuous ECG monitoring for 48 h or until the first AF episode</td>
<td>Metoprolol i.v. vs. oral: 16.8 vs. 28.1%, respectively, $P = 0.036$</td>
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<tr>
<td>Burgess et al.</td>
<td>Meta-analysis</td>
<td>Beta-blocker</td>
<td>CABG, valve, or both/on-pump</td>
<td>OR 0.36, 95% CI 0.28–0.47;</td>
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<tr>
<th>Author</th>
<th>Design, no. of subjects</th>
<th>Treatment studied</th>
<th>Type of cardiac surgery</th>
<th>Arrhythmia recording</th>
<th>Reduction of post-operative AF in the treatment group</th>
<th>Other variables, associated with treatment</th>
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<tr>
<td>Budeus et al.</td>
<td>RCT, double-blind, placebo controlled, n = 110</td>
<td>Combined i.v. and oral amiodarone starting 1 day before and continuing to 7 days after surgery</td>
<td>CABG</td>
<td>Follow-up for 7 days by Holter monitoring</td>
<td>OR 0.91, 95% CI 0.036–0.235</td>
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<td>Mitchell et al.</td>
<td>PAPABEAR RCT, double-blind, placebo controlled, n = 601</td>
<td>Oral amiodarone 10 mg/kg for 13 days starting 6 days prior to surgery</td>
<td>CABG, valve, or both/on-pump</td>
<td>Follow-up with continuous monitoring for 6 days</td>
<td>OR 0.52, 95% CI 0.34–0.69</td>
<td>No significant effect on hospital stay and post-operative MI</td>
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<tr>
<td>Shiga et al.</td>
<td>Meta-analysis: 28 RCTs and cohort studies, n = 1262</td>
<td>Magnesium</td>
<td>CABG, valve, or both/on-pump</td>
<td></td>
<td>OR 0.77, 95% CI 0.63–0.93, P = 0.002; NNT = 13</td>
<td>No significant difference</td>
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<td>Reston et al.</td>
<td>Retrospective, case-matched study, n = 267</td>
<td>Off-pump CABG vs. on-pump CABG</td>
<td>CABG, off-/on-pump</td>
<td>Continuous monitoring during the first 72 h</td>
<td>OR 0.77, 95% CI 0.62–0.95; NNT = 20</td>
<td>No significant difference</td>
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<tr>
<td>Caló et al.</td>
<td>RCT, placebo controlled, n = 160</td>
<td>Off-pump CABG vs. on-pump CABG</td>
<td>CABG, off-/on-pump</td>
<td>Continuous monitoring for the first 4–5 days, then 12-lead ECG every day until discharge</td>
<td>Absolute risk reduction 18.1%, relative risk reduction 54.4%; NNT 5.51</td>
<td>Shorter hospital length of stay (P = 0.017)</td>
</tr>
<tr>
<td>Marin et al.</td>
<td>Retrospective, cross-sectional, n = 234</td>
<td>Statin</td>
<td>CABG/on-pump</td>
<td></td>
<td>OR 0.52, 95% CI 0.28–0.96, P = 0.038</td>
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<td>Pati et al.</td>
<td>ARMYDA-3, prospective, randomized, placebo controlled, single-centre, n = 200</td>
<td>Atorvastatin 40 mg for 7 days prior to surgery</td>
<td>CABG, valve, or both/on-pump</td>
<td>Continuous telemonitoring for at least 6 days</td>
<td>OR 0.39, 95% CI 0.18–0.85, P = 0.017</td>
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<td>Lertsburapa et al.</td>
<td>A nested cohort study from AFIST I, II, and III trials, n = 555</td>
<td>Statin</td>
<td>CABG, valve, or both/on-pump</td>
<td>Continuous telemonitoring</td>
<td>OR 0.60, 95% CI 0.37–0.99</td>
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<td>Mariscalco et al.</td>
<td>Retrospective, longitudinal, observational, n = 405</td>
<td>Statin, various types and regimens</td>
<td>Elective CABG</td>
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<td>OR 0.58, 95% CI 0.37–0.91, P = 0.017</td>
<td>Protective impact by Kaplan–Meier analysis (P = 0.01)</td>
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<td>Ozaydin et al.</td>
<td>Observational, n = 362</td>
<td>Statin</td>
<td>CABG</td>
<td></td>
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<td>Less frequency (P = 0.03) and duration of AF episodes (P = 0.0001)</td>
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<tr>
<td>Virani et al.</td>
<td>Retrospective, single-centre, n = 404: 2096 with pre-treatment and 1948 without</td>
<td>Statin (various statins, doses and regimens)</td>
<td>CABG, valve or both/on-pump</td>
<td>Continuous telemetry during hospitalization period</td>
<td>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)</td>
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<tr>
<td>Fauchier et al.</td>
<td>Meta-analysis: 6 RCTs, two of them on post-operative AF, n = 3557</td>
<td>Statin</td>
<td>CABG</td>
<td></td>
<td>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</td>
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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 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 OR 0.67, 95% CI 0.54–0.84, P = 0.001 Hospital length of stay shortening by 1.6 day

Baker et al., 200797 Meta-analysis: 9 RCTs, n = 990 Corticosteroids OR 0.55, 95% CI 0.39–0.78 Reduced need for red blood cell transfusion (by 37%); no increase in stroke or MI incidence

Ruffin et al.101 A nested cohort study from AFIST I, II, and III, n = 555 NSAIDs OR 0.54, 95% CI 0.32–0.90

Mathew et al.5 Retrospective, observational study from 70 centres, n = 4657 Perioperative ACE-I OR 0.62, 95% CI 0.48–0.79

White et al.17 A nested cohort study from AFIST I, II, and III, n = 338 Pre-operative ACE-I or ARB OR 0.71, 95% CI 0.42–1.20

Coleman et al., 200756 Retrospective cohort analysis, n = 1469 Short-term use of ACE-I or ARB post-operatively 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) 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.
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. Amiodarone use starting early post-operatively compared with placebo: post-operative AF occurred in 22.1 vs. 38.6% of patients, respectively; \( P = 0.037 \). 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 surgery59 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).71

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 tri-phosphatase, 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-analysis66 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 nondihydropyridines 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,83 and an ability to reverse angiotensin II-mediated atrial structural remodelling.84

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 analysis84 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, which showed a significant decrease in post-operative AF occurrences after pre-treatment 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 ($P = 0.01$); 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. Pre-treatment with statin prior to elective CABG surgery also decreased perioperative mortality in a large, retrospective study 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. 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. 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.

**n-3 Polyunsaturated fatty acids**

The n-3 polyunsaturated fatty acids (PUFAs) are distinctive due to their antiarrhythmic effect on fatal ventricular arrhythmias and high plasma concentrations of PUFAs caused by fish consumption have been found associated with lower incidence of AF during the 12-year period. In a prospective, randomized, controlled trial, pre-treatment with PUFAs decreased the development of AF after CABG surgery and shortened hospital length of stay. 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. 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. 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. 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.

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 ($n = 78$).

A positive impact of suppression of inflammatory process on the development of post-operative AF has been shown using non-steroidal anti-inflammatory drugs. However, this study did not reveal any significant increase in stroke or myocardial infarction development after cardiac surgery, and the study was not prospective, randomized, and controlled, and it probably underpowered concerning safety. Recently, Anglade et al. 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. tested the effect of ACE-I use before CABG on release of IL-6 post-operatively and found that IL-6 levels were significantly ($P = 0.02$) blunted with ACE-I pre-treatment compared with controls. Mathew et al. 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. 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.

**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 and n-acetylcysteine have been suggested in this setting.

The American College of Chest Physicians guidelines also recommend mild hypothermia (for example, $34^\circ$C), the use of posterior pericardiotomy, and heparin-coated CPB circuits as possible intraoperative preventive strategies for the reduction of AF following cardiac surgery, 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, but the meta-analysis by Burgess et al. did not
find a high heterogeneity ($I^2 < 0.001$) and a lack of studies with post-operative AF as a primary endpoint. Recently, Turk et al.\textsuperscript{109} reported a prospective study of off-pump CABG vs. on-pump CABG on the occurrence of post-operative AF, and did not find 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,\textsuperscript{110} the recently published AFIST III trial ($n = 180$) did not find any significant benefit of such an intervention.\textsuperscript{111}

**Conclusion**

The overall incidence of post-operative AF depends on arrhythmia prevention of post-operative AF,\textsuperscript{110} the recently published AFIST III trial, but not 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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Atrial fibrillation following cardiac surgery


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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 became overt (Panel A). Nitroglycerine s.l., heparin i.v., and morphine i.v. were immediately given to the patient.

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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.