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Management of Atrial Fibrillation in Patients Undergoing Coronary Artery Bypass Grafting: Review of the Literature

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Summary

Untreated atrial fibrillation(AF) is associated with an increased risk of all-cause mortality and morbidity. Despite the current guidelines recommending surgical ablation(SA) of AF at the time of coronary artery bypass(CABG) surgery, the majority of patients with concomitant AF and coronary artery disease do not receive SA for their AF. This review reports the efficacy of different SA techniques used for the treatment of AF during CABG. PubMed was systematically searched for studies reporting outcomes of concomitant SA in CABG patients between January 2002 and March 2018. Data were independently extracted and analyzed by two investigators. Twenty-four studies were included. Twelve studies exclusively reported outcomes of SA in patients undergoing CABG, while the remaining 12, reported outcomes of concomitant cardiac surgery with subgroup analysis(Table-1). Only 4 studies performed the concomitant Cox-Maze procedure(CMP). Freedom from atrial tachyarrhythmia(ATA) was reported as high as 98% at one year and 76% at five years with CMP, while lesser lesion sets had more variable outcomes, ranging from 35% to 93%. In most studies, the addition of SA was not associated with increased morbidity and mortality. While the CMP had the greatest short- and long-term success rates, the majority of the studies comprising the evidence documenting the safety and efficacy of adding SA were of low or moderate quality. There was a great deal of heterogeneity among study populations, follow up times, methods, and definition of failure. To establish a consensus regarding a SA technique for AF in CABG population, larger multicenter randomized controlled studies need to be designed.

Keywords

Coronary Artery Bypass Grafting (CABG); Atrial Fibrillation; Surgical Ablation; Cox Maze Procedure; Surgical Revascularization

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Introduction

Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia with increasing incidence and prevalence in North America (1). It frequently presents in association with other cardiovascular complications and is a marker of higher risk for morbidity and mortality (2, 3). Concomitant left atrial (LA) enlargement is a known predisposing mechanism among patients with mitral valve disease, but AF can also result from atrial ischemia, fibrosis, or preexisting atrial disease (4). Several surgical studies have shown that patients who present for cardiac surgery with a history of AF have reduced survival over time if their AF is left untreated (5–7). Moreover, recent information suggests that performance of surgical ablation (SA) is accompanied by a reduction in 30-day operative mortality and possibly a reduction in the incidence of late stroke/transient ischemic attack (>1 year of follow up after surgery) (8, 52). Strong evidence showing an association between preoperative AF and increased morbidity and mortality has led to the 2017 Society of Thoracic Surgeons Guidelines for the Surgical Treatment of Atrial Fibrillation and the 2017 AATS Expert Consensus Guidelines to recommend surgical ablation at the time of concomitant operations (mitral valve surgery, aortic valve surgery, coronary bypass graft operations, etc.) to restore sinus rhythm with a Class I or IIa indication (9, 52).

A recent Society of Thoracic Surgeons' database analysis demonstrated that the likelihood of a concomitant SA in mitral patients with AF approached 70%, far exceeding the 33% observed for isolated coronary artery bypass grafting (CABG). There has been an increasing trend for contemporary utilization of SA, but surgeons in North America remain hesitant to add SA to CABG operations leaving more than 65% of patients untreated, despite a history of AF (8).

The mechanism of AF in patients with coronary artery disease (CAD) has not been well-defined and may be different than that seen in patients with valvular pathology or without organic heart disease. Extracardiac risk factors such as increased age, hypertension and obesity are common for both AF and CAD. Patients without known CAD and new-onset AF have an increased risk for subsequent new coronary ischemic events and mortality during follow-up (10). Studies have shown that atrial ischemia can cause AF due to inhomogeneities in conduction and repolarization (4, 11). Up to 10% of patients undergoing isolated CABG have preexisting atrial fibrillation (12) and surgical revascularization alone has been found to be insufficient for stable sinus rhythm (SR). Surgery-related spontaneous cardioversion which may be seen in up to 62% of patients, have been transient as few of these patients (as low as 8%) were still in sinus rhythm at the end of 6 months (13, 14). Additionally, untreated AF at the time of CABG is a risk factor for increased in-hospital mortality, postoperative morbidity and reduced long-term survival (2, 3, 5, 7, 13, 15). In a propensity-matched group of patients undergoing coronary artery bypass with or without baseline AF, Quader et. al, showed a greater than 20% increase in mortality by ten years after CABG in patients with baseline AF (5). Among patients undergoing isolated CABG, the presence of preoperative AF was associated with significantly higher rates of all major postoperative complications including two times greater incidence of stroke as documented in another study (15). These findings support strong consideration for surgical AF ablation

to be performed at the time of CABG, with the aim to reduce both postoperative short- and long-term mortality and late morbidities.

The single most effective surgical ablation technique in the management of AF has been the Cox-Maze procedure (CMP), introduced by James L. Cox and colleagues in 1987. The final version of his cut-and-sew technique was termed the CM-III procedure. This procedure proved to be highly efficacious, with as high as 100% freedom from AF at 10 years and no late strokes in the concomitant CABG patients, as reported by Damiano et al. in 2003 (16). In that series, there was one late recurrence 10.5 years after surgery (16). However, due to its technical complexity, few surgeons performed this operation. In 2002, Cox-Maze IV (CMIV) procedure was introduced using bipolar radiofrequency (RF) and cryoablation devices to replace most of the atrial incisions (17, 18). This has resulted in more widespread adoption of SA in patients undergoing concomitant surgery. The freedom from AF between the Cox-Maze III and IV groups have been similar. However, the CMP-IV has had significantly shorter operative times and lower complication rates (19). More recently, Schill et al. reported a single institution outcome of concomitant CMPIV and CABG with 98% freedom from atrial tachyarrhythmias at 1 year, with 88% off antiarrhythmic drugs (20).

Ad and colleagues previously showed that addition of the CMP to primary nonatriotomy operations such as AVR or CABG did not convey an increase in either morbidity or mortality (21). Despite these findings, only 33% of patients receive surgical ablation for AF at the time of isolated CABG (8), leaving AF untreated in 2 out of 3 patients. The Cox-Maze procedure, which has the highest success rate, requires atriotomies, and many surgeons are reluctant to add this to a standard CABG procedure, where these incisions are not required. Instead, many surgeons prefer either a more limited LA lesion set (e.g., epicardial pulmonary vein isolation) or choose not to take advantage of this opportunity to treat AF in these patients.

Presently, there is no established consensus regarding ablation strategy (i.e. patient selection, lesion set, energy selection) at the time of CABG. This review will discuss the results of SA with different lesion sets for the treatment of AF during CABG.

Methods

PubMed search was conducted for studies published between January 2002 and March 2018. Keywords used for the search included: (“atrial fibrillation”) and (“surgical ablation”, “ablation”, “Cox maze procedure”, “maze”, or “pulmonary vein”) and (“coronary artery bypass surgery”). Journals known to publish data relevant to this research were also searched. Additionally, the reference lists of all retrieved articles and those of relevant review articles were cross-referenced. The literature search was performed in duplication by two independent reviewers (A.J.K, T.A.).

Human studies written in English language, were included if they had data directly related to outcomes of SA in patients undergoing CABG. Studies where the sample size were small, had inadequate follow-up (under 6 months), or surgical outcomes was ambiguous, mainly due to reporting of mixed surgical operations, were excluded. When institutions published

duplicate studies with accumulating numbers of patients or increased lengths of follow up, only the most recent reports were included. Abstracts, case reports, editorials, and reviews were also excluded.

Two reviewers independently extracted data from relevant studies (A.J.K, T.A.). The following information was extracted: publication information (first author's name, publication year, institution, study period), characteristics of participants (mean age of participants, gender, sample size), type of surgery (on pump, off pump), details of surgical ablation (energy source, lesion set, left atrial appendage (LAA) treatment), primary endpoint (sinus rhythm, AF free survival), type of rhythm monitoring (ECG, Holter, Pacemaker interrogation), atrial fibrillation outcome information (type of AF, method of AF detection, freedom from atrial fibrillation, freedom from atrial fibrillation and antiarrhythmic drugs and follow-up time) and general outcome information (early and late mortality, stroke rate, etc.). Discrepancies between the two reviewers were resolved by discussion and consensus.

Results

Search Outcome

A total of 984 records were retrieved after the primary search. After screening the title and abstracts, 768 studies were excluded. 216 potentially relevant full-text articles were reviewed and finally, 24 were included for analysis. Of the 24 included studies, 12 of them were dedicated to reporting the surgical treatment of AF in patients undergoing CABG (16, 20, 22–33). Data about CABG patients were extracted from the subgroup analysis of the remaining 12 studies, which were principally reported concomitant cardiac surgery outcomes (34–46). The full Cox-Maze lesion set was used only in 4 (17%) studies. Six (25%) studies used only pulmonary vein isolation (PVI). Fifteen (63%) studies used extra LA ablation lesions to treat atrial fibrillation, in which three (3/24, 13%) of them isolated the posterior LA by creating a box surrounding all four pulmonary veins. One study (32) compared PVI to a non-box LA lesion set (called a modified mini-maze procedure). In 8 of 24 (33%) studies, lesions were created without the use of cardiopulmonary bypass (CPB). Three (13%) studies reported outcomes of only paroxysmal AF patients, 9 (37%) studies reported non-paroxysmal (characterized as persistent, long-standing persistent, chronic, permanent, continuous) and 12 (50%) studies reported outcomes in a mixed patient population. The majority of studies used RF energy to create lesions (63%, n=15), followed by combination of RF and cryothermy (13%, n=3), cryothermy alone (8%, n=2), ultrasound (8%, n=2), microwave (4%, n=1), and laser (4%, n=1) energies.

A complete list of the studies that were included in this review are summarized in Table-1. Studies were grouped based on the type of SA performed at the time of CABG.

Outcomes of concomitant Cox-Maze III/IV and CABG

There were no prospective randomized trials in this group. A total of 4 studies were included which reported the outcomes of concomitant CMIII/IV lesion set during CABG. Damiano et al. published one of the earliest series regarding surgical treatment of AF in CABG patients in 2003 using the "cut and sew" CM-III technique. Nine patients (19%) required placement

of a pacemaker postoperatively. In this series, the overall, freedom from symptomatic atrial fibrillation was 100% at 10 years follow up. There was only one documented recurrence of AF that occurred 10.5 years after the index surgery. Unfortunately, follow up was only based on symptoms and sporadic ECGs (16). The same group recently reported the outcomes of concomitant CABG and the ablation-assisted Cox-Maze IV (CMIV) procedure, using bipolar RF and cryoablation devices to replace most of the atrial incisions (20). In this study, recurrence of atrial tachyarrhythmias (ATAs) was defined according to the guidelines in the consensus statement as any episode of AF, atrial flutter, or tachycardia of at least 30 seconds duration that occurred after the 3 months blanking period (53). The majority of patients had prolonged 24-hour Holter monitoring. Freedom from ATAs was reported as 98% and 76% at 1 and 5 years, respectively (20). The incidence of postoperative pacemaker implantation decreased from 19% to 10% with the CMIV procedure.

In the remaining 2 studies, outcomes of CMIII/IV lesion sets were from the subgroup analysis of concomitant cardiac surgery operations. Dr. Ad used RF clamps and cryoablation devices to create the non-box Cox-maze lesions. Nine of twelve patients in that series were concomitant SA and CABG, and freedom from atrial arrhythmia was 83% at 1 year postoperatively (37). The majority of patients underwent prolonged monitoring at some point during the follow up period. It was, however, unclear how recurrence of AF/ATAs were defined. A more recent paper by Tsai et al. used RF and cryothermy in 23 concomitant CABG patients and reported 91% freedom from AF at a mean follow up of 3.2 years (44).

Outcomes of concomitant PVI and CABG

Six studies were included to report the outcomes of pulmonary vein isolation (PVI) for the treatment of atrial fibrillation in this patient population. Subgroup analysis was used to extract data in 1 of 6 papers (46).

There were 2 prospective, randomized studies reporting the outcome data of PVI with CABG (31, 32). Pokushalov et al. reported a trial in patients with a history of paroxysmal AF referred for CABG. Patients were randomized to CABG alone (n=17) or CABG with PVI (n=18) (31). Implantable loop recorders (ILR) were used to follow patients and an AF burden of more than 0.5% over one month was considered failure. At 18 months, 16 (89%) of 18 patients in the CABG + PVI group were free from AF compared to 47% of the CABG (8 of 17) only group (p=0.007) (31). In another study by the same group, Cherniavsky et al. randomized 95 patients with persistent atrial fibrillation into three groups: CABG+PVI (n=31), CABG+modified Mini-Maze procedure (non-box, LA only, n=30), and isolated CABG (n=34). Lesions were done using an irrigated bipolar RF device and failure was defined according to the consensus statement with documentation of atrial arrhythmia greater than 30 seconds by ILR (53). At a mean follow up time of 14.4±9.7 months (range 3–24 months), the freedom from ATAs was 86% in the CABG + modified Mini-Maze group, 80% in the CABG+PVI group and 44% in the lone CABG group (32). In another report, Pokushalov et al. reported the outcomes of 72 patients with paroxysmal atrial fibrillation (30). An irrigated bipolar radiofrequency system was used to isolate pulmonary veins during cardiopulmonary bypass on the beating heart. The freedom from atrial fibrillation was reported as 72% at 1 year. Unfortunately, as opposed to the recommended definition of AF

recurrence (i.e. documented ATA duration of ≥30 seconds), procedural success was defined as AF burden <0.5% (30).

All studies in this group used bipolar RF energy to isolate pulmonary veins. Electrical isolation of pulmonary veins was checked in 67% of the studies (23, 30, 31, 46), and LAA exclusion was reported in only 33% (23, 24). Two studies (33%) performed isolation without CPB (23, 24), 3 (50%) studies performed on-CPB PVIs with a beating heart (30–32) and one study (17%) used both techniques (46). Three (50%) studies reported outcomes of only paroxysmal atrial fibrillation patients with freedom from atrial fibrillation ranges from 72% to 93% with mean follow up periods ranging from 12 months up to 47 months (30, 31, 46). None of these studies used the consensus statement definition of failure. The longest follow-up data were reported by Kainuma et al. (46). In this paper, 54 of 160 patients underwent pulmonary vein isolation and CABG for paroxysmal AF with a mean follow-up of 47±25 months. Freedom from atrial fibrillation was reported as 88%, 84% and 93% at 12, 24 and 36 months respectively (46). In this study, freedom from atrial fibrillation was ascertained from patient history and sporadic 12-lead ECG. Prolonged monitoring (e.g., 24-hr Holter) was only used in patients with symptoms or irregular heart rates (46).

Two studies compared PVI in patients with paroxysmal and non-paroxysmal AF (23, 24). Freedom from AF was reported as 83% in paroxysmal and 59% in the non-paroxysmal group at 1 year by Akpinar et al. (23). Lastly, pacemaker implantation following PVI was reported to be as low as 0% in one study (32), and as high as 13% in another study (24).

Outcomes of concomitant PVI with additional lesions (non-box) and CABG

Twelve studies reported additional left and/or right atrial lesions combined with pulmonary vein isolation. Five of twelve studies reported results of surgical ablation in CABG patients (22,27,29,32,33), and the data were extracted from the subgroup analysis of the remaining 7 papers (34,35,38,40,42,43,45). All of these studies had only one or no lesions connecting the isolated right and left pulmonary veins, which meant that they all failed to isolate the entire posterior LA. Additionally, electrical isolation of pulmonary veins was checked in only one (8%) study (33). Routine closure of the LAA was reported in 75% (9 of 12) (22,27,29,33,34,35,38,42,43).

Two prospective randomized studies were included. As discussed previously, Cherniavsky et al. randomized 95 patients with persistent atrial fibrillation into three groups: CABG+PVI (n=31), CABG+modified Mini-Maze procedure (non-box, LA only, n=30), and isolated CABG (n=34). At a mean follow up time of 14.4±9.7 months (range 3–24 months), PVI with concomitant CABG eliminated AF in 80% of patients, and the effectiveness of the CABG + modified Mini-Maze procedure reached 86% (p=0.27), while isolated CABG eliminated AF in only 44% of patients (p=0.008) (32). In another randomized study, the PRAGUE-12 study, 224 patients with AF requiring valve and/or CABG operation were randomized into two groups: left atrial surgical ablation (n = 117) vs. no ablation (n = 107) (43). Twenty-three patients in the ablation group underwent CABG+SA. A cryoprobe with an argon-based cooling system was used to create left-sided lesions epicardially. After 1 year, a 24-hr Holter monitoring revealed sinus rhythm in 50% of patients undergoing CABG + SA vs. 33% in CABG with no SA (p=0.342) (43). Unfortunately, this study was limited by

the fact that rhythm monitoring was done by sporadic ECGs and a single 24-hr Holter at one year. This may have failed to detect certain recurrences of AF. Additionally, it was unclear how recurrence of AF/ATAs was defined.

In this group, 35 to 86 percent freedom from atrial fibrillation were reported within a range of 12 to 36 months follow-up time. Sie et al. reported 200 concomitant surgical ablation cases, 13 of which were CABG patients. Monopolar irrigated RF energy was used to create non-box endocardial lesions and 42% of patients (5 of 13) were free from AF at a mean of 3.3 years after their operations (34). Jiang et al. used a bipolar RF clamp and a monopolar RF pen to create lesions without cardiopulmonary bypass and reported a 90% freedom from AF in paroxysmal and 83% in non-paroxysmal patients within a mean follow up time of 29.8±10.2 months (33).

Surgical ablation in this group was performed using other energy sources including microwave by Knaut et al. (35), and high intensity focused ultrasound (HIFU) by Groh et al. (40). Freedom from AF at 12 months was reported at 72% when microwave was used (35), while the use of HIFU epicardially led to 85% freedom from AF at 12 months after surgery (40). A wide range of pacemaker implantation was reported, ranging from 0% to 24%.

Outcomes of concomitant PVI with additional connecting lesions (box) and CABG

Isolation of the entire posterior LA by creating a box lesion set in addition to pulmonary veins was reported in 3 studies (25, 39, 41). Electrical isolation was confirmed only in one study (41) and none of the studies reported routine LAA closure. Usage of laser energy, HIFU, or RF to create epicardial off-pump lesions resulted in 88%, 79%, and 83% freedom from atrial fibrillation respectively. None of these studies used the consensus statement definition of failure (53).

Discussion

Preoperative AF is associated with an increased risk of all-cause (including perioperative) morbidity and mortality in patients referred for CABG. Concomitant surgical ablation of AF at the time of coronary artery bypass surgery should be strongly considered (2,3,5,7,13,15). The most recent STS guidelines for the treatment of atrial fibrillation recommended surgical ablation at the time of concomitant isolated CABG as a Class I indication (level of evidence B, non-randomized) (9). The authors of the guidelines were critical of the fact that many surgeons have preferred less invasive approaches, such as epicardial ablation, occasionally without full consideration for the pathophysiology of AF (9). In our review, only 17% (4 of 24) of the reports on concomitant surgical ablation of AF in patients undergoing CABG used a complete biatrial maze lesion set.

According to a recent STS database analysis done by Badhwar et al., only 33% of CABG patients with pre-operative AF received concomitant surgical ablation, with PVI being the most common preferred surgical ablation procedure (8). This propensity-matched analysis revealed that the addition of surgical ablation to cardiac surgery was associated with the reduction in the relative risk (RR) of 30-day mortality [RR 0.92] and stroke [0.84] offset by an increase in renal failure [RR 1.12] and pacemaker implantation [RR 1.33]. In support of

this observation, and based on the literature review and meta-analyses, the American Association of Thoracic Surgery Expert Consensus Guidelines also showed that the addition of concomitant SA for AF improved 30-day operative mortality (52). Furthermore, except for a higher rate of pacemaker implantation, no major postoperative morbidity or mortality differences were detected in a propensity analysis comparing patients undergoing primary non-atriotomy operations (AVR, CABG, AVR+CABG) with or without concomitant CMP surgical ablation as shown by Ad and colleagues (21). None of the reports in this review showed an increase in the operative risk by adding the surgical ablation to CABG. In addition, in three randomized studies, comparing concomitant surgical ablation (PVI or "modified mini maze") to isolated CABG, no differences in in-hospital mortality and morbidity were reported (31, 32, 43).

One of the earliest reports on the outcomes of the concomitant surgical ablation of AF and CABG showed excellent results with over 95% freedom from symptomatic AF in a mean follow up time of 5.7 years by using the gold standard CM III (cut and sew) technique in 2003 (16). However, its' technical complexity prevented this procedure from becoming widely performed, especially for concomitant CABG patients. Replacing most of the atrial incisions with lesions created by bipolar RF and cryothermy, the Cox-maze IV (CMIV) procedure, has significantly shortened operative time and lowered complication rates (17–19), leading to increased procedural adoption rates.

This review showed that concomitant surgical ablation using the CM III/IV lesion set has been successful in this population. In general, more limited ablation procedures had worse 1-year efficacy, but there was significant variability in outcomes. Schill et al. reported 98% and 76% freedom from atrial arrhythmia at 1 and 5-years follow-up by using a Cox-maze IV lesion sets (20). Ad and colleagues used argon cryoablation energy to create a CM lesion set and reported a 94% freedom from atrial arrhythmia at 1 year in patients with primary non-atriotomy operations like AVR or CABG (21).

Creation of proper and transmural lesion sets has been one of the keys to success in AF surgery. Henn et al. have previously shown that omitting only one lesion from the original CMP, the superior connecting lesion on the LA, which resulted in an incomplete posterior LA isolation (box-lesion), had a significantly higher rate of AF recurrence compared to those with complete posterior LA isolation (78% vs 45% freedom from atrial tachyarrhythmias (ATAs) at 5 years, p=0.005) (48).

Studies have shown that even a 1-mm gap with viable myocardium may be enough to initiate arrhythmias (49). AATS Clinical Guidelines on surgical AF ablation recommended the use of bipolar radiofrequency clamps and cryoablation devices only (52). Outside of clinical trials, the use of devices that have difficulty creating transmural lesions are not recommended (52). These include unipolar RF, laser, and microwave, all of which have had lower late success rates (54–57). Sie at al. used a unipolar irrigated RF pen to create CM III/IV lesion sets with only a 43% freedom from AF in a mean follow-up time of 3.3 years (34). Non-box lesion sets and non-transmural lesions with a unipolar RF pen would explain this low success rate.

In 1998, Haissaguerre et al. demonstrated that AF episodes can be induced by focal triggers with most located in and around the orifices of the pulmonary veins, and other sites were in the right atrium, the crista terminalis, and the LAA (50). This finding resulted in what has become the dominant strategy of catheter ablation, isolation of the pulmonary veins. While this has yielded good results in patients with paroxysmal “lone AF”, patients with long-standing and persistent AF have required more complex interventions (47). Also, Haissaguerre’s observation that most paroxysmal atrial fibrillation is due to pulmonary vein triggers may not be applicable to surgical patients, as there have been very few analyses of the distribution of AF triggers in the atria in patients with concomitant cardiac pathology. Haissaguerre’s findings, in addition to the reluctance of adding atriotomies by surgeons, have resulted in the creation of many surgical techniques focusing only on isolation of pulmonary veins with or without additional LA lesions which have been termed “modified Maze lesion sets”. This review showed that 83% of the reports (20 of 24) used a more limited lesion set as a surgical ablation technique for concomitant CABG patients. In selected patients, particularly with paroxysmal AF, this approach has yielded acceptable outcomes.

This literature review showed that freedom from atrial fibrillation ranges from 72% to 88% for paroxysmal AF patients undergoing concomitant PVI and CABG at short-term follow-up. However, late success rates may be much worse. In our series, performing a non-box CMP-IV, which included complete PVI and documentation of exit block in every case, had less than 45% freedom from ATAs at 5 years (48). This was true for both paroxysmal and non-paroxysmal AF, suggesting that there may be a high late failure rate with PVI alone. Further studies are needed to clarify this observation.

Unfortunately, the comparison of outcomes of surgical ablation in patients undergoing coronary artery bypass surgery is difficult because of the variability in lesion sets, study populations, energy sources, definitions of failure, and follow-up time and methodology. Transmurality of the lesions is critically important in ensuring procedural success. At our institution, we use a combination of bipolar radiofrequency and cryothermy to create CMP-IV lesion sets (48). This has been based on their efficacy in the experimental laboratory (54, 57–60). Based on our experience and the recent AATS Clinical Guidelines, we recommend the use of bipolar radiofrequency clamps and/or cryoablation devices only (52).

Summary and Clinical Recommendations:

This review was most remarkable for the variability in clinical outcomes in this patient population, the lack of prospective randomized trials and the paucity of late follow up. It revealed the need for multi-institutional studies and, ideally, randomized controlled trials, to delineate the risks and benefits of concomitant surgical ablation and the appropriate lesion set in different subsets of patients. However, the best outcomes were achieved with the CMP III/IV, and it is the only procedure with late follow up available. In contrast, PVI has had more variable early outcomes. PVI may be an acceptable strategy in paroxysmal AF, though further studies with late follow up are needed.

Based on this review, we would make the following recommendations for clinical practice. In patients undergoing cardiopulmonary bypass for CABG, our group would recommend a

complete biatrial CMP lesion set in most patients, as it has been proven efficacious with durable results at 5 to 10 years. Moreover, large database studies, propensity-matched analyses, and prospective randomized trials have failed to detect any increased morbidity or mortality with concomitant SA.

At our institution, we perform PVI only in patients who are deemed to be high risk for CPB and are undergoing off-pump CABG, and have symptomatic paroxysmal AF with a LA diameter less than 5.0 cm. In patients who are on CPB, we occasionally perform left-sided only CM lesion sets on very selected patients with paroxysmal AF, LA diameter <5.0 cm, and those with no evidence of right atrial enlargement or tricuspid valve pathology.

We routinely perform SA prior to performing the CABG portion of the operation. Pulmonary vein isolation using a bipolar RF clamp is the first step of the operation and surgeons should always check for exit block from all isolated pulmonary veins. The right atrial lesion set is done on the beating heart on CPB, while the LA lesion set is performed on the arrested heart. This usually can be performed in 10–15 minutes with ablation devices. Exclusion of the LAA is extremely important and is accomplished either by amputating or clipping. When clipping the LAA, our bypass grafts are performed first, and the clip is applied at the end of the procedure to avoid manipulation and possible dislodgement. We usually avoid using a clip in patients who may need redo operation as adhesions occurring around the clip can fix the heart to nearby structures.

LAA closure/exclusion is an integral component of the Cox-Maze procedure. Obliteration of LAA reduces early and late stroke rates by more than 50% and has modest survival benefits (51). In our review of the literature, only 45% (9 of 20) of the reports of more limited procedures, routinely addressed the LAA. Four of the eight (50%) papers performed ablations without the use of cardiopulmonary bypass and routinely closed the LAA. The use of LAA closure devices such as the clip should allow surgeons to safely address the appendage in this situation. We highly recommend LAA management at the time of surgical ablation in all patients.

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Table 1.

Major Studies Reporting Outcomes of Concomitant Surgical Ablation of Atrial Fibrillation and Coronary Artery Bypass Grafting

Procedure/Author	Type of AF (n)			Energy Source							CPB Use	Prolonged Monitoring ¥¥	Postoperative PM Implant (%)	Follow-up (Months)	Freedom from ATA (%)
	Paroxysmal	Non-paroxysmal	Total	Cut + Sew	RF	Cryoablation	Cryoablation + RF	Microwave	Laser	HIFU					
Cox-Maze Procedure															
Damiano et al.[16] *	28	19	47	X							X		19	Mean: 68±40	98 #
Schill et al.[20] **	37	46	83				X				X	X	10	12	98
													10	60	76
Ad[37] ***	0	9	9				X				X	X	17	12	83 #
Tsai et al. [44]	0	23	23				X				X		NR	Mean: 38 Range: 12–96	91
PVI															
Akpinar et al.[23]	12	21	33		X							X	NR	12	71 #
Wudel et al.[24]	11	4	15		X								13	Mean: 7.6±4.4	80 #
Pokushalov et al.[30]	72	0	72		X						X	X	NR	12	72 #
Pokushalov et al.[31] ##	18	0	18		X						X	X	NR	18	89 #
Chemiavsky et al.[32] ##	0	31	31		X						X	X	0	Mean: 14±10	80
Kainuma et al.[46]	54	0	54		X						X		6	36	93 #
PVI + "non-box" additional lesions															
Khargi et al.[22]	0	36	36		X						X		3	12	75 #
Houltz et al.[27] ¥	19	16	35		X	X					X	X	NR	Mean: 28±5	69
Mariani et al.[29]	0	12	12		X							X	NR	12	75 #
Cherniavsky et al.[32] ##	0	30	30		X						X	X	0	Mean: 14±10	86
Jiang et al.[33]	9	36	45		X							X	0	Mean: 30±10	84 #
Sie et al.[34] ***	0	13	13		X						X		4	Mean: 40 Range: 12 – 80	42 #
Knaut et al.[35]	0	42	42					X			X	X	24	12	72 #
Deneke et al.[38]	0	52	52		X						X	X	5	12	80
Groh et al.[40]			51							X		X	4	12	85

Procedure/Author	Type of AF (n)			Energy Source							CPB Use	Prolonged Monitoring¥¥	Postoperative PM Implant (%)	Follow-up (Months)	Freedom from ATA (%)
	Paroxysmal	Non-paroxysmal	Total	Cut + Sew	RF	Cryoablation	Cryoablation + RF	Microwave	Laser	HIFU					
Geidel et al.[42]	0	65	65		X						X	X	5	36	78#
Budera et al.[43]##			23			X					X	X	10	12	50#
Tischer et al.[45]			26		X						X	X	NR	Mean: 23±11	35
"Box lesion"															
Benussi et al.[25]	4	2	6		X								NR	Mean: 8.5±2.6	83#
Groh et al.[39]			41							X		X	2	12	79#
Poa et al.[41]	0	16	16						X				10	Median: 8.3	88#

*RF (n=5), and microwave (n=1) was used to replace several of the atrial lesions.

**9 out of 83 patients underwent a non-box CMP-IV.

***All patients in these two studies underwent non-box CMP.

¥RF energy source was used in 8 out of 35 patients.

¥¥A study was considered to have prolonged monitoring when at least 50% of patients in that study underwent continuous rhythm monitoring of > 24 hours using ILR, Holter, PM interrogation, etc. during the follow-up period.

#These studies did not define recurrence of ATA based on the HRS/EHRA/ECAS consensus statement (>30 seconds duration of ATA that is documented by an ECG or device recording system following the 3 months blanking period).

##Randomized control studies.

AF, Atrial Fibrillation; RF, Radiofrequency; HIFU, High-Intensity Focused Ultrasound; CPB, Cardiopulmonary Bypass; ATA, Atrial Tachyarrhythmia; PVI, Pulmonary Vein Isolation; ILR, Implantable loop recorder; PM, Pacemaker; NR, Not Reported.