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Guideline

2023 KASNet Guidelines on Atrial Fibrillation Surgery

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Introduction

The Korea Arrhythmia Surgery Network (KASNet) was established as an official subsociety for atrial fibrillation (AF) surgery by the Korean Society of Thoracic and Cardiovascular Surgery in 2017. Since then, KASNet has provided updated knowledge, including basic science, clinical outcomes of case series and trials, as well as several guidelines. However, KASNet has not published evidence-based guidelines for the treatment of Korean patients, who constitute a different ethnicity and are believed to have distinct etiologic backgrounds compared to the populations described in other guidelines. Furthermore, there are many ways to handle aspects of the operating theater regarding the proper surgical and adjuvant management of AF. Therefore, here we provide guidelines for the clinical management of patients with AF, which is associated with various conditions, such as valvular heart disease (VHD), coronary artery disease, aortic disease, isolated AF, congenital heart disease (CHD), and ventricular arrhythmia (VA). In addition, we describe proper management of the left atrial appendage (LAA) and other available adjuvant measures. We hope that our guidelines will help professionals treat Korean patients with AF, eventually improving their long-term well-being.

Atrial fibrillation surgery in rheumatic mitral valve disease

Summary

- Concomitant AF surgery can be performed without increasing the risk of early mortality and is recommended at the time of rheumatic mitral valve (MV) surgery (class of recommendation I; level of evidence B).
- Concomitant AF surgery can effectively restore the sinus rhythm and is recommended for rheumatic MV surgery (class of recommendation I; level of evidence A).
- It is reasonable to perform concomitant AF surgery to decrease the long-term risks of thromboembolic events and mortality during rheumatic MV surgery (class IIa; level of evidence B).

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Rheumatic heart disease (RHD) remains a global health burden. Over 30 million patients are estimated to be affected by RHD, predominantly in low- and middle-income countries [1]. RHD primarily manifests as a MV disease and is known to be complicated by AF in 8% to 40% of patients [2]. Patients with rheumatic AF constitute about 30% of all AF cases [3]. From a health-economic perspective, patients with RHD pose a significant public concern because they are affected at a younger age than those with degenerative heart valve disease.

Despite the clinical and socioeconomic significance of RHD, it has not received as much attention as degenerative heart valve diseases. As such, AF accompanied by rheumatic MV disease has not been studied as extensively as AF due to degenerative MV disease, probably because of the relatively low prevalence of rheumatic MV disease in high-income countries, where major research is conducted. Consequently, existing guidelines have not sufficiently addressed the treatment of rheumatic AF [4].

Unlike other high-income countries, the Republic of Korea has a high prevalence of rheumatic MV disease and an increasing trend of degenerative MV disease due to its aging population. Cardiac surgeons in Korea encounter a unique situation in which they must provide surgical treatment for AF in patients with both rheumatic and degenerative MV disease [5]. Therefore, experts from KASNet summarized the currently available literature on the surgical treatment of AF in patients with rheumatic MV disease to develop guidelines and recommendations.

Safety of concomitant AF surgery in rheumatic MV disease

Most studies that have evaluated the efficacy and safety outcomes of concomitant AF surgery during MV surgery have not specifically addressed the etiology of degenerative or rheumatic diseases. Only a few randomized [6-9] and observational studies [10-13] have compared outcomes according to the performance of AF surgery in patients with MV diseases. Although all these studies, except 1 [13], were performed on a limited number of patients (less than 100 in each group) and thus may be underpowered to detect any clinically relevant differences, they showed that the addition of AF surgery did not increase the risk of early mortality during MV surgery.

Kim et al. reported the safety and efficacy outcomes of concomitant AF surgery in the largest number of patients (n=1,229) who underwent rheumatic MV surgery [13]. Early mortality was reported in 10 patients who had AF surgery (n=812) and in 19 patients who did not (n=417) (1.2% versus 2.4%, adjusted p=0.45). A recent meta-analysis showed that the 30-day mortality risk was comparable between patients who underwent rheumatic MV surgery with and without concomitant AF surgery [14].

Efficacy of concomitant AF surgery in rheumatic MV disease

All available randomized trials consistently showed that freedom from AF was significantly higher in patients who underwent concomitant AF surgery at the time of rheumatic MV surgery than in those who did not [6-9]. Since all these studies were underpowered due to the small cohort size, the consistently higher rate of freedom from AF in patients who underwent AF surgery across these studies may provide robust evidence that AF can be converted to sinus rhythm efficaciously by AF surgery during rheumatic MV surgery. However, all these randomized studies provided only short follow-up periods (12–44 months), thereby limiting the superior rhythm outcomes of AF surgery in the long term. An observational study by Kim et al. [13] showed that the rates of freedom from AF at 5 years were 76.5%±1.8% and 5.3%±1.1% in patients who had concomitant AF and those who did not, respectively (p<0.001), and the superior rhythm outcomes persisted up to 10 years postoperatively.

Effect of concomitant AF surgery on long-term outcome after MV surgery

It is difficult to demonstrate the efficacy of concomitant AF surgery in decreasing the risk of long-term mortality or thromboembolic events in patients with rheumatic MV disease from randomized trials because of the short follow-up periods [6-9]. A randomized trial that was performed on patients with MV disease of various etiologies also did not show a survival benefit resulting from surgical AF ablation [15]. However, 2 studies that were performed on a Korean national cohort consistently showed that concomitant surgical ablation (SA) significantly decreased the long-term risk of mortality and thromboembolic events in patients undergoing MV surgery [16,17]. Although these studies were also limited by the fact that the etiology of MV disease was not specified, a significant proportion of RHD patients was expected to be included in these studies because of the high prevalence of RHD in Korea. Furthermore, the risks of long-term mortality and thromboembolic events were found to be reduced by 38% and 51% by the addition of AF surgery in patients undergoing rheumatic MV surgery in the same study by Kim et al. [13].

Atrial fibrillation surgery in degenerative mitral valve disease

Summary

- Concomitant AF surgery for degenerative MV disease is recommended to restore sinus rhythm because it does not increase the risk of operative mortality or major complications (class of recommendation I; level of evidence A).
- Concomitant AF surgery for degenerative MV disease is a reasonable method to improve early mortality and long-term survival (class of recommendation IIa; level of evidence B).
- Concomitant AF surgery for degenerative MV disease is a reasonable method of preventing late stroke (class of recommendation IIa; level of evidence B).

Degenerative VHD is the most common type of non-rheumatic VHD. Moreover, the prevalence of degenerative VHD has increased in areas with high levels of socioeconomic development [18,19]. In Korea, socioeconomic advancements have been accompanied by an increasing incidence of degenerative VHD, especially in individuals older than 65 years [20]. We evaluated the prevalence, safety, and efficacy of concomitant AF surgery in patients with degenerative MV disease.

Prevalence of AF in degenerative MV disease

AF is a common condition in patients undergoing cardiac surgery. AF is commonly accompanied by MV surgery, and a recent study reported that 54.8% of 10,907 patients underwent MV surgery for AF [21]. However, the prevalence of AF in degenerative MV disease is lower than that in patients with other MV diseases, with reported rates of approximately 15%–20% in large retrospective studies that were performed before 2010 [22-24]. As life expectancy increases, the prevalence of AF in patients with degenerative MV disease also tends to increase, as shown in recent studies. Recent multicenter international registry data indicate that the prevalence of AF in degenerative MV disease has increased up to 32% (779/2,425), including 41% of paroxysmal AF cases and 59% of persistent AF cases [25]. A study that analyzed the Society of Thoracic Surgeons (STS) database from 2011 to 2016 also showed a 28.5% prevalence of AF in patients with degenerative MV diseases [26].

Although the prevalence of AF has increased, and accompanying AF is known to be an important risk factor for overall mortality in patients with degenerative MV diseases [25,27], concomitant AF surgery has not been performed in all patients with AF. In a report from the STS database, concomitant AF surgery was performed in only 54.4% of patients [26].

The early safety and efficacy of concomitant AF surgery in degenerative MV disease

Comparative studies are required to prove the safety and early efficacy of concomitant AF surgery for patients with degenerative MV disease. However, most studies comparing patients with MV disease according to whether they underwent AF surgery did not consider the specific etiologies. Since more than 60% of patients in the STS database had a degenerative etiology [26], studies that do not specify the etiology cannot be considered to accurately reflect the results of degenerative MV disease. Four randomized controlled trials (RCTs), in which the proportion of degenerative MV cases ranged from 20% to 70%, showed that concomitant AF surgery did not increase the risk of early surgical mortality and morbidity, but significantly increased the rate of sinus rhythm conversion [28-31]. Three retrospective studies, in which 20% to 60% of patients had degenerative MV disease, reported the same results for operative mortality and major morbidity [32-34]. Additionally, degenerative MV disease accounted for 60% of cases in the Polish National Registry data, and significantly lower rates of operative mortality, postoperative stroke, and multiorgan failure were found in the concomitant AF surgery group than in the non-AF surgery group in 1,784 matched pairs [34]. Although there was no comment on the proportion of degenerative MV cases, a propensity score matching study using the STS database registry showed that concomitant AF surgery was associated with a reduction in the relative risk of operative mortality and postoperative stroke [35].

The long-term efficacy of AF surgery in degenerative MV disease

Although several meta-analyses using only RCTs have been conducted on concomitant AF surgery, there is a limit to evaluating the long-term benefits of concomitant AF surgery in degenerative MV disease through these studies [36-38]. This is because most RCTs were performed with a limited sample size, and the follow-up duration was approximately 1 year. In addition, most meta-analyses did not focus only on patients with MV disease, but included those who underwent any cardiac surgery, including coronary bypass grafting and aortic valve (AV) replacement. In 2014, a meta-analysis was conducted, including 9 RCTs limited to patients with MV [39]; however, this meta-analysis also had an average follow-up period of 1 year, limiting the ability to draw conclusions regarding the long-term benefits of concomitant AF surgery.

Although the type of surgery was not specified for MV, a meta-analysis that was conducted in 2017, including RCTs and retrospective studies, confirmed the long-term survival and stroke preservation benefits of concomitant AF surgery [40]. Subsequently, retrospective large-sample studies showing the long-term benefits of concomitant AF surgery in MV disease were published, and the 5-year follow-up results of RCTs were also published [34,41,42]. According to an RCT with a follow-up of 5 years, in patients who underwent valve and/or coronary surgery, concomitant AF surgery was associated with significantly lower rates of the cumulative composite outcomes, including cardiovascular death and stroke. Moreover, the incidence of stroke was significantly reduced in patients who underwent concomitant AF surgery [41]. A propensity score-matched study from Washington University, in which 55% of the included cases involved MV surgery, showed that concomitant AF surgery (Cox-maze IV procedure) improved the 10-year survival by more than 50% (hazard ratio [HR], 0.47; 95% confidence interval [CI], 0.26–0.86) [42]. Additionally, the Polish National Registry data on MV demonstrated that concomitant AF surgery was significantly associated with reduced operative mortality and improved late survival [34].

Atrial fibrillation surgery in aortic valve disease

Summary

- Concomitant AF surgery is safe and recommended during AV surgery without an MV procedure (class of recommendation I; level of evidence B).
- Concomitant AF surgery is recommended to effectively restore sinus rhythm during AV surgery without an MV procedure (class of recommendation I; level of evidence B).
- Pulmonary vein isolation (PVI) is a reasonable alternative ablation strategy for patients with paroxysmal AF undergoing AV surgery without an MV procedure (class of recommendation IIa; level of evidence B).

AF is associated with poor clinical outcomes in patients undergoing AV surgery [43,44]. Even after the treatment of AV disease, AF is associated with poor outcomes [43]. Therefore, controlling AF may improve clinical outcomes in patients undergoing AV surgery. Adding AF surgery effectively restores sinus rhythm during AV replacement [45,46]. A study found that safety issues did not increase early mortality or postoperative complications except for a high requirement for postoperative pacemaker implantation [45]. Thus, PVI is an effective alternative strategy for patients with paroxysmal AF [47]. In patients with persistent and long-standing persistent AF, biatrial SA showed better rates of survival and composite adverse events than PVI in those with a high risk of SA failure, including a large left atrium (LA) (>45 mm) or persistent AF [48].

Atrial fibrillation surgery in coronary disease

Summary

- Concomitant AF surgery is recommended for patients with preexisting AF undergoing isolated coronary artery bypass grafting (CABG) (class of recommendation I; level of evidence B).
- For non-prohibited-risk patients, a biatrial Cox-maze procedure, rather than isolated PVI, is recommended (class of recommendation I; level of evidence C).
- The balance of risk benefits should be considered for patients with a CHA2DS2-VASc between 7 and 9, a history of myocardial infarction, and a higher EuroSCORE (class of recommendation I; level of evidence C).
- For patients with preexisting AF undergoing isolated CABG, surgical occlusion or exclusion of the LAA may be considered (class of recommendation IIb; level of evidence C).

When patients undergoing CABG had baseline AF, mortality was reported to increase by more than 20% up to 10 years after CABG [49], and the incidence of stroke increased by more than 2 times [50]. Recent representative guidelines have shown that concomitant SA in patients undergoing non-left atrial opening cardiac surgery has been recommended as class I, level of evidence B [4] or class IIa, level of evidence A [51]; however, SA at the time of CABG has been performed less often than it should be. In the 2017 STS database [35], concomitant SA for preexisting AF was performed in only one-third of patients undergoing isolated CABG, which was much less than the proportion of concomitant SA and accounted for more than two-thirds of MV procedures; moreover, compared to MV surgery combined with CABG, the OR of SA was only 0.4. The hesitation to perform SA may be due to a lack of confidence in the outcome of concomitant SA in a situation where a cardiac operation is performed without opening the LA and where it is a burden to lift and twist the heart before or after the graft connection, especially when grafting is being performed off-pump. There is no national database available in Korea to address this problem, but it is expected that a similar hesitation would also be found in Korea.

Based on a literature review, we propose focused recommendations for concomitant SA in patients undergoing isolated CABG.

Prevalence of preexisting AF and frequency of concomitant SA

The prevalence of preexisting AF in patients undergoing CABG has been reported as 5% to 10% [35,52], which is much lower than that in patients undergoing MV, AV, or combined valve surgery. A recent investigation of the STS database demonstrated that concomitant SA was performed in only 32.8% of the patients undergoing isolated CABG, while 68.4% of patients underwent MV surgery with or without CABG, 59.1% underwent combined MV and AV surgery, and 39.3% underwent AV with or without CABG [35]. Interestingly, according to a retrospective analysis of the data from 21 hospitals in the Providence St. Joseph Health System [53], it was found that while SA rates increased over time, they were highly variable between hospitals, regardless of the volume of surgery, and the older the surgeon who graduated from medical school, the lower the rate of SA (odds ratio [OR], 0.71; 95% CI, 0.56–0.90 for every 10-year increase).

Benefits of concomitant SA in patients undergoing CABG

In patients with preexisting AF undergoing CABG, a sinus conversion rate of up to 62% could be expected by surgical revascularization alone, but it would be difficult to anticipate that sinus rhythm can be maintained, since AF was reported to recur in most patients and the sinus rhythm was maintained in only 8% of patients [54,55]. Recent representative guidelines suggest that it is advantageous to perform concomitant SA for preexisting AF in patients undergoing CABG with or without AV surgery. The 2017 STS Clinical Practice Guidelines [4] and the 2019 JCS/JHRS (Japanese Circulation Society/Japanese Heart Rhythm Society) guidelines [56] assigned class I and level of evidence B to this practice, and the 2016 and 2020 ESC/EACTS guidelines [51,57] assigned class IIa and level of evidence A.

Several prospective randomized trials of SA have been conducted, although there have been no randomized trials with a biatrial full maze operation. These studies have compared PVI, modified mini-maze procedures, and no concomitant procedure [58]; attempted to elucidate the treatment effect of PVI in 35 patients with paroxysmal AF [59]; and a conducted prospective randomized study (the PRAGUE-12 study) to show the effect of epicardial cryoprobe with argon-based cooling [60]. When only patients undergoing isolated CABG were separated and analyzed, the sinus rhythm prevalence at 1 year was 50% in the SA group and 33.3% in the non-SA group, but this difference was not statistically significant. However, the first 2 randomized studies demonstrated statistically significant benefits of SA.

Nonrandomized studies have reported evidence that SA can contribute to reducing the incidence of long-term mortality, stroke, and systemic embolism without increasing surgical mortality. In the most recently published study comparing SA and non-ablation [61], which included the largest number of CABG cases, the 5-year mortality rate (HR, 0.89; 95% CI, 0.82–0.97; p=0.0358) and the 5-year stroke or systemic embolism incidence (HR, 0.73; 95% CI, 0.61–0.87; p=0.0006) were both significantly lower in patients who received SA and survived more than 2 years after surgery. Evidence supporting SA can be found in studies on various SA methods, which are described in the next section. With regard to costs, Rankin et al. [62] revealed that the initial admission costs were higher for SA patients; however, in the follow-up, risk-adjusted inpatient days and inpatient costs were similar 2 years after CABG due to readmission for AF and pacemaker/defibrillator implantation, while the risk-adjusted hazard for late mortality was significantly lower in patients who underwent SA.

However, several factors should not be ignored. First, in the real world, SA cannot be considered completely safe because there is still some risk of pacemaker implantation, which seems to be associated with SA. For example, in the PRAGUE-12 study, which randomized 224 patients with all types of AF [60], a pacemaker was inserted in 6% of the ablation group and 1.0% of the non-ablation group in the first month after surgery. A higher sinus conversion rate through SA seems to be associated with a higher pacemak-

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er requirement, even though there have been some rebuttals regarding unreliable device use, creation of improperly placed lesions, and unnecessary earlier insertion of a permanent pacemaker [63]. Second, SA can increase early mortality and morbidity in patients at high surgical risk. In a large-scale study including 9,771 patients that compared SA and non-SA groups, patients who underwent concomitant SA showed higher in-hospital mortality (2.5% versus 3.2%; OR, 1.27; 95% CI, 1.07–1.51), an increased rate of prolonged ventilation, and more frequent new-onset renal failure [61]. In addition, although the numbers were so small that the authors did not present a p-value or OR, they found that SA may be associated with increased initial mortality in patients with CHA2DS2-VASc between 7 and 9. Finally, it is worth noting that there may be a significant association between complete revascularization and long-term mortality in patients with preexisting AF. A database extracted from the multinational registry Heart Surgery in Atrial Fibrillation and Supraventricular Tachycardia (HEIST) [64] showed that complete revascularization resulted in a 20% lower long-term mortality rate than incomplete revascularization. Therefore, in non-prohibited risk patients with preexisting AF, it would be beneficial to aim for both SA and complete revascularization, even if this takes longer to perform.

Impact of Cox-maze III or IV on post-CABG outcomes

Among the various methods of SA concomitant with CABG, the results of Cox-maze surgery are superior, based on the data to date. Damiano et al. [65] reported the results of concomitant Cox-maze III in patients undergoing CABG, 15% of whom underwent procedures combined with MV repair. Sixty percent of the AF cases were paroxysmal, and the early mortality rate was 2%. There were no cases of AF recurrence or stroke within 10 years of surgery. However, in 9 patients (19%), postoperative pacemaker placement was required. The impact of the Cox-maze IV procedure on long-term heart rhythm has also been reported [63]. A total of 83 patients underwent Cox-maze IV procedures combined with CABG. A right atrial lesion set was not made when the AF was paroxysmal, the size was <5.0 cm, and there was no evidence of right atrial enlargement. The operative mortality rate was 3.6%, and the rate of freedom from atrial tachyarrhythmia was 98% at 1 year after surgery and 70% at 5 years.

Impact of PVI on post-CABG outcomes

Among studies investigating the impact of PVI as an SA method, 2 prospective randomized studies included patients undergoing isolated CABG. The first randomized patients with paroxysmal AF to isolated CABG (n=17) and CABG with PVI (n=18) groups and proceeded without additional connecting lines using irrigated bipolar radiofrequency [59]. Implantable loop recorders (ILRs) were used, and an AF burden of more than 0.5% over 1 month was considered failure. The 18-month rate of freedom from AF was 89% when concomitant PVI was performed, which was significantly higher than the rate of 47% in patients who did not undergo concomitant PVI. Another study [58] led by the same group randomized patients with persistent AF to a concomitant PVI group (n=31), a concomitant modified mini-maze group (n=30), and an isolated CABG group (n=34). The authors created neither box nor right atrial lesion sets for the mini-maze procedure. According to the ILR criteria, an atrial arrhythmia greater than 30 seconds by the ILR criteria was defined as failure. During an average follow-up period (14.4±9.7 months; range, 3–24 months), the rate of freedom from atrial tachyarrhythmia was 86% and 80% in the modified mini-maze and PVI groups, respectively, compared to only 44% in the group without SA.

We could not find any studies directly comparing only PVI and making additional box lesions in patients undergoing CABG; however, according to the data of research in which box lesions were made in patients undergoing CABG, we did not find a significant difference in freedom from AF compared with the data from the non-box lesion study. For example, Benussi and Alfieri [66] created box lesions using the posterior wall clamping technique and radiofrequency. Five out of 6 patients (83%) were in sinus rhythm, and 5 of 6 were off anti-arrhythmic drugs at a median follow-up of 9.8 months. In a study in which box lesions were created by epicardial laser ablation in 16 patients undergoing CABG out of a total of 52 patients, 88% (14 out of 16 patients) had a normal sinus rhythm at the median follow-up of 8.3 months [67].

Discouragement of AF ablation

SA is not always beneficial in patients undergoing isolated CABG. A recent analysis of a large-scale medical population derived from the STS database showed higher operative mortality in patients with CHA2DS2-VASc scores of 7–9. In a propensity score-matched analysis, the operative mortality of patients with CHA2DS2-VASc scores of 7–9 was 4.9% (15 out of 9,771 patients) and 10.5% (37 out of 9,771 patients) in the no-ablation and ablation groups, respectively [61]. Therefore, SA should be performed on a risk–benefit basis for these high-risk older adult patients. The PRAGUE-12 sub-analysis, a prospective randomized study sub-analysis, investigated the predictors of complete AF-free survival using a final check-up at 12 months and Holter recording [68]. A history of myocardial infarction (OR, 0.2; $p<0.05$) and a higher EuroSCORE (OR, 0.9; $p<0.05$) were independently associated with a lower probability of AF-free survival. The PRAGUE-12 subanalysis did not elucidate the number of isolated CABG cases. However, the inferred number was much lower than the 23 in the SA group and 31 in the non-SA group.

Left atrial appendage management

LAA exclusion has been considered in patients with preexisting AF who undergo CABG to prevent stroke or systemic embolization. Unfortunately, the vast majority of the data available on the beneficial effects of LAA management have been based on cardiac operations other than isolated CABG. Stollberger et al. [69] emphasized that routine LAA occlusion during CABG cannot be recommended because the LAA plays an important role in avoiding heart failure by cardiac regulation in response to hemodynamic changes such as volume or pressure overload. The pathogenesis of stroke in AF is multifactorial, and much more evidence is available regarding the treatment of patients with AF using oral anticoagulants. In a randomized controlled pilot study, 77 patients with preexisting AF undergoing CABG were randomized to LAA occlusion or control groups [70]. However, that study was not designed to evaluate stroke outcomes and, therefore, did not provide reliable data. Stroke occurred in two patients in the LAA occlusion group, but both occurred during the perioperative period, and no further embolic events occurred over 12 months. The results of the Left Atrial Appendage Occlusion Study (LAAOS) following this pilot study could not be searched online. LAAOS II was a cross-sectional study in which death and stroke data were not available for patients undergoing isolated CABG [71].

From the results of a recent large-scale retrospective study querying the US National Readmission Database, LAA exclusion in patients undergoing isolated CABG was associated with higher risks of postoperative respiratory failure (8.2% versus 6.2%), acute kidney injury (21.8% versus 18.5%), and 30-day readmission (16.0% versus 9.6%), whereas significant reductions in stroke and in-hospital mortality were not observed [72].

Isolated atrial fibrillation surgery

Summary

- Stand-alone SA, including a hybrid procedure for paroxysmal or persistent AF, is reasonable for patients for whom one or more attempts at catheter ablation have failed, those with histories of stroke, and those who prefer a surgical approach considering easy LAA closure in a minimally invasive procedure (class of recommendation IIa; level of evidence B).
- For patients with persistent and long-standing persistent AF, stand-alone SA, including a hybrid procedure, is reasonable for those for whom one or more attempts at catheter ablation have failed and for those who prefer a surgical approach (class of recommendation IIa; level of evidence B).

Surgery for isolated AF (not associated with structural heart disease) has shown better results than catheter ablation in many studies, including meta-analyses and RCTs [73-76].

There have been over 3 decades of experience with operations performed solely for the treatment of AF (stand-alone operations). The widespread use of these procedures has been limited by procedural complexity and limited data regarding outcomes. The earliest reported study on stand-alone operations for AF included 112 patients who underwent the cut-and-sew Cox-maze III procedure by Cox et al. [77]. This procedure is performed through a sternotomy on cardiopulmonary bypass on an arrested heart and physically cuts and resews the atria to create a collection of lines of blocks. Cryoablation was used to create the mitral annulus lesions. Among the 112 patients, 96% were in sinus rhythm with or without anti-arrhythmic drug (AAD) therapy, and 80% were in sinus rhythm and free of AAD therapy at the last follow-up. The only risk factor for late recurrence was preoperative AF duration. However, owing to technical difficulties and invasiveness, this procedure is rarely performed and is only performed by experienced surgeons. The primary indication for stand-alone surgery described in the 2017 Consensus Document was the presence of symptomatic AF refractory or intolerant to at least 1 class I or class III AAD [78].

The ideal patients for stand-alone AF ablation are those who have not experienced successful results after other therapies, want definitive cures, or have clots in the LAA, making other approaches not using cardiopulmonary bypass risk-prohibitive. To reduce invasiveness, new ablation technologies, including minithoracotomy, have been introduced and updated. This procedure is termed the Cox-maze IV procedure. The advantage of these approaches is their ability to reliably create endocardial lesions in a maze down to the mitral annulus. A late evaluation of this procedure in 146 stand-alone patients has shown a 72% rate of freedom from AF at 5 years of follow-up and a 59% rate of freedom from AAD [79]. To simplify the procedure, cryoablation alone has been used with safety and efficacy comparable to those of the classic maze procedure [80]. In 2005, a minimally invasive surgical approach using video-assisted pulmonary vein ablation and exclusion of the LAA was first described [81]. Although this approach can eliminate the need to open the heart and use both cardiopulmonary bypass and cardiac arrest, it limits the extent of lesions that can be created from the maze, such as mitral isthmus lesions. With respect to the safety of minimally invasive surgery for isolated AF, a review of 23 articles in 2013 showed an operative mortality rate of 0.4% and a complication rate of 3.2% [82]. Despite the aforementioned problems of minimally invasive AF surgery, it has the advantage of allowing intraoperative electrophysiological studies (EPS) because it is a beating-heart surgical procedure. This indicates that the additional treatment of residual conduction gaps and non-PVI foci based on the study results is also possible. Hybrid surgery, in which surgical epicardial ablation and percutaneous endocardial ablation are performed simultaneously (1-stage surgery) or within 6 months of each other (2-stage surgery), is a reasonable treatment strategy [78,82]. Hybrid procedures, especially when staged, have recently advanced, and safety and efficacy outcomes have greatly improved in South Korea [83].

Although additional procedures can be performed immediately based on the results of intraoperative EPS in 1-stage surgery [84], there is no evidence that the outcomes of 2-stage surgery are inferior. An RCT evaluating the usefulness of post-procedural electrophysiological confirmation after total thoracoscopic ablation showed similar 1-year rhythm outcomes [85]. A variety of hybrid surgical procedures have been reported, combining various approaches (bilateral or unilateral transthoracic approach, subxiphoid approaches, convergent procedures, etc.), lesion sets, and LAA closure [86-88]. However, the effectiveness of these methods has not been elucidated.

The maze procedure for patients with unsuccessful catheter ablation achieves a return to sinus rhythm more frequently than additional catheter ablation [73,89]. Thoracoscopic ablation for recurrent AF in patients with previous catheter ablation was also effective in a matched cohort analysis [90].

Therefore, based on the literature and the experience of the writing group members, stand-alone SA, including hybrid procedures, of paroxysmal or persistent AF is reasonable for patients who have failed one or more attempts at catheter ablation and stroke history and prefer a surgical approach (class of recommendation IIa, level of evidence B) considering easy LAA closure in a minimally invasive approach. For patients with persistent and long-standing persistent AF, stand-alone SA, including a hybrid procedure, is reasonable for those in whom 1 or more attempts at catheter ablation have failed and those who prefer a surgical approach (class IIa; level of evidence B).

Atrial fibrillation surgery in congenital heart disease

Summary

- SA is reasonable at the time of closure of the atrial septal defect (ASD) (class of recommendation IIa; level of evidence B).
- To reduce AF recurrence, biatrial rather than right-atrial ablation should be considered during ASD repair (class of recommendation I; level of evidence A).
- For symptomatic atrial tachyarrhythmia patients who undergo an atriopulmonary connection (APC) type Fontan operation, conversion to total cavopulmonary connection (TCPC) or extracardiac Fontan surgery should be considered in the management of atrial tachyarrhythmia (class of recommendation I; level of evidence C).
- SA should be added to Ebstein repair in patients with a history of AF (class I; level of evidence C).
- Biatrial SA is reasonable for minimizing recurrence during SA of persistent or long-standing persistent AF in patients with Ebstein anomalies (class of recommendation IIa; level of evidence C).
- Concomitant atrial arrhythmia surgery is reasonable in patients undergoing pulmonary valve replacement (PVR) for pulmonary regurgitation (PR) late after repair of tetralogy of Fallot (TOF) with AF (class of recommendation IIa; level of evidence B).

AF occurs frequently in patients with CHD, resulting in decreased heart function in adult patients. The clinical importance of treating patients with AF is growing, as an increasing number of patients with CHD survive with or without surgery. Recent guidelines from Japan and Europe focused on the medical and interventional management of AF in patients with CHD [51,56]. Therefore, we recommend surgical treatment for patients who require surgical AF ablation during CHD surgery.

AF surgery during ASD repair

ASD is the most common congenital cardiac anomaly diagnosed in adulthood. Because ASD in adults tends to promote the development of atrial tachycardia, repair of ASD should be considered as early as possible [91,92]. A reduction in the prevalence of AF was observed after ASD closure alone, which is mainly effective for paroxysmal AF, but not for persistent or long-standing persistent AF [93]. In addition, device closure alone in patients with persistent atrial arrhythmia is unlikely to restore sinus rhythm for patients with ASD who are above 40 years of age [94]. The risk of stroke after ASD closure is associated with the development of AF [95].

Several options exist for the treatment of AF in patients with ASD. For paroxysmal AF in patients with ASD, the combination of catheter ablation and transcatheter ASD closure appears to be a feasible treatment strategy [96]. However, repeat ablation for recurrent AF after ASD closure is challenging. Therefore, SA should be considered at the time of ASD closure to restore normal sinus rhythm in persistent AF patients [56,91,93,97-100]. To reduce AF recurrence, biatrial ablation over right-atrial ablation should be considered during surgical ASD repair [93,99-101].

AF surgery for Fontan patients

Fontan surgery is a palliative surgery used to improve cyanosis in many cases of complex CHD with uneven ventricle size. These include APC and TCPC. After the classic Fontan procedure for APC, myocardial injury with right atrial enlargement and progressive adverse atrial electrical remodeling results in the formation of an arrhythmogenic substrate [102]. The atrial arrhythmias in these patients are usually variable and refractory [56]. For patients with failed APC Fontan and atrial arrhythmias, Fontan conversion with concomitant arrhythmia surgery allows for better freedom from atrial arrhythmias and improves functional class and exercise tolerance [103-107].

AF surgery during Ebstein anomaly repair

The Ebstein anomaly is a rare CHD characterized by heart failure secondary to tricuspid regurgitation (TR) and right ventricular dysfunction. Arrhythmia is the most common presentation in adult arrhythmia [108]. An accessory pathway of Wolff-Parkinson-White syndrome may develop between the atrialized right ventricle and the right atrium, which can cause wide QRS ventricular tachycardia (VT) during AF. Given that up to 20% of patients with Ebstein anomalies have multiple accessory pathways, EPS for mapping and catheter ablation should be considered first [109]. Concomitant arrhythmia procedures should be added to Ebstein repair in all patients with supraventricular tachyarrhythmias. Surgical procedures for accessory pathway-mediated tachycardia and atrioventricular nodal reentrant tachycardia provide excellent (100%) freedom from recurrence of those arrhythmias. SA of AF is effective, with an 80% rate of freedom from late recurrence in patients undergoing surgery for Ebstein anomaly. Persistent AF may benefit from a biatrial SA [110,111].

AF surgery during corrective surgery for right-sided valvular regurgitation in repaired tetralogy of Fallot

PR is a widely recognized phenomenon that occurs following widening of the transannular right ventricular outflow tract in patients with TOF. This condition leads to the development of right ventricular dysfunction and dilatation [112,113]. Right ventricular dilatation caused by significant PR can also lead to TR. This, in turn, causes right atrial dilatation, ultimately resulting in supraventricular arrhythmia [114]. Promptly performed PVR or right ventricular to pulmonary artery conduit replacement with or without tricuspid valve repair could decrease the occurrence of these clinical results [112,113,115,116].

In certain cases where patients experience a delay in receiving treatment for volume-loading status due to PR or TR, several atrial arrhythmias have been observed. Among these arrhythmias, AF has been identified as a risk factor for decreased survival rates in patients with repaired TOF, particularly in those with TR [114,117]. The primary factor contributing to atrial arrhythmias in these patients is enlargement of the right atrium in these patients [114,118]. As right atrial dilatation is a risk factor for recurrent atrial tachyarrhythmia in patients with late repair of TOF who undergo PVR and atrial arrhythmia surgery [118], anti-arrhythmic surgery should be considered simultaneously with PVR to reduce the recurrence of atrial arrhythmia [119].

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Left atrial appendage treatment during atrial fibrillation surgery

Summary

- Elimination of the LAA is reasonable during AF surgery (class IIa; level of evidence A).
- Excision of the LAA, rather than other elimination techniques such as internal or external obliteration, is reasonable to completely eliminate communication between the LA and LAA (class of recommendation IIa; level of evidence B).
- Obliteration of the LAA with an external clipping device is a reasonable alternative to the conventional elimination technique whenever indicated (class of recommendation IIa; level of evidence C).

Elimination or preservation of the LAA during AF surgery

The LAA is where the vast majority of thrombi form in patients with AF, and over 90% of embolic infarction occurs from the LAA in non-valvular AF patients. This is an important focus of AF [120-122]. Therefore, elimination of the LAA should be a key procedure during SA for AF, and the original Cox-maze procedure included resection of the LAA as a component of the lesion sets to treat AF.

Recent large-scale retrospective studies and a meta-analysis have also demonstrated the efficacy of eliminating the LAA during cardiac surgery, with stroke rates reduced by more than 50% and a modest survival benefit [123-125]. Although a limitation of these studies is that none of the included patients underwent concomitant SA for AF, these data support the elimination of the LAA during AF surgery as a way to optimize surgical outcomes. Furthermore, better outcomes after SA of AF might be expected when a more complete LAA treatment is achieved [125,126]. A recent large-scale RCT, the LAAOS III trial [127], also revealed a significant impact of LAA elimination during cardiac surgery on stroke prevention. In that study, subgroup analyses confirmed that the benefits of LAA elimination remained significant in the subgroup of patients who underwent concomitant SA for AF (n=1,562; 33% of the study patients).

Concerns regarding the elimination of the LAA include its impact on LA contractile function and the reduced release of atrial natriuretic peptide [128,129]. A previous retrospective study demonstrated that preserving the LAA did not result in inferior long-term clinical outcomes, including stroke, but did have a benefit in terms of LA contractile function [128]. However, future studies are needed to clarify this issue.

Surgical techniques to eliminate the LAA

Review of surgical techniques

Various surgical techniques that eliminate the LAA by cavity obliteration have been introduced and can be divided into epicardial versus endocardial- and non-device-enabled versus device-enabled techniques [130].

Epicardial approaches include (1) LAA external excision with suture or stapler closure and (2) LAA external obliteration with suture or stapler closure. Endocardial techniques include internal obliteration using (1) a linear single or double layer, interrupted or running sutures, and (2) an internal purse-string suture.

One RCT showed that elimination of the LAA using 3 different techniques was unsatisfactory, and more than half of all interventions failed, leading to a need for additional sutures during surgery based on the intraoperative transesophageal echocardiographic findings to correct incomplete elimination of the LAA or findings during the early postoperative and follow-up periods, such as residual stump and gap or blood flow between the LA and the LAA [131]. However, recent studies have revealed that stapler excision may be an effective technique for eliminating the LAA [132].

A network meta-analysis comparing the efficacy of surgical elimination techniques

Data source and literature search

Following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [133], full-text articles comparing the efficacy of at least two surgical LAA elimination techniques were searched in 4 databases: Medline, Embase, Cochrane Central Register of Controlled Trials, and Web of Science on May 05, 2022. The following keywords and medical subject heading terms were searched in Medline: ("atrial fibrillation" [MeSH terms] OR "atrial fibrillation" [Title/Abstract] OR "atrial arrhythmia" [Title/Abstract] OR "atrial flutter" [Title/Abstract]) AND ("atrial appendage" [MeSH terms] OR "atrial appendage" [Title/Abstract] OR "atrial auricle" [Title/Abstract]) AND ("ligation" [MeSH terms] OR "surgical stapling" [MeSH terms] OR "excision" [Title/Abstract] OR "ligation" [Title/Abstract] OR "stapling" [Title/Abstract] OR "stapler" [Title/Abstract] OR "obliteration" [Title/Abstract]

OR "elimination" [Title/Abstract] OR "closure" [Title/Abstract] OR "occlusion" [Title/Abstract] OR "exclusion" [Title/Abstract]). The search strategies for the other databases were adapted from this strategy. Among the 4,950 articles, the full texts of 11 articles were reviewed, and 5 studies were included [70,131,132,134,135].

Statistical analysis

All statistical analyses were conducted using Review Manager Web ver. 5.4 (The Cochrane Collaboration, Oxford, UK). The primary outcome was the overall failure of LAA elimination between internal obliteration, external exclusion, and external excision. Secondary outcomes included the proportion of patients with residual stumps and flows or gaps after LAA elimination. Statistical heterogeneity between the studies was assessed using the chi-square test and the I^2 statistic. I^2 values of 25%, 50%, and 75% have been suggested to be indicators of low, moderate, and high heterogeneity, respectively [136]. Random-effects models were planned when substantial heterogeneity was found (I^2>25%); otherwise, fixed-effects models were used. Outcomes were compared as ORs with 95% CIs. Pooled estimates from RCTs and nonrandomized studies are presented.

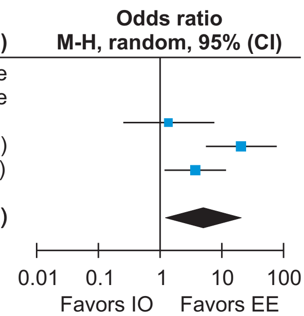
Risk of overall failure of the LAA elimination

When pooled analysis was performed for the overall LAA elimination failure rate among the internal obliteration, external exclusion, and external excision groups in 423 patients from 4 studies [131,132,134,135], it was significantly lower in the external excision group than in the other groups (Fig. 1). Pooled analyses of individual outcomes, such as residual stump and persistent gap or flow between

A

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, random, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	0	0	0	0		Not estimable
Lee et al. [132] (2016)	5	8	11	20	29.1	1.36 (0.25−7.32)
Abdeljawad et al. [136] (2021)	25	33	4	30	34.2	20.31 (5.43−76.03)
Kang et al. [133] (2021)	9	56	5	102	36.7	3.71 (1.18−11.70)
Total (95% CI)		**97**		**152**	**100.0**	**4.96 (1.15−21.40)**
Total events:	39		20			

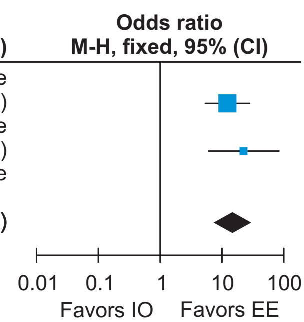
Heterogeneity: tau^2=1.18; χ^2=6.86, df=2 (p=0.03); I^2=71%
Test for overall effect: z=2.15 (p=0.03)



B

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	70	85	14	52	76.2	12.67 (5.53−29.01)
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	29	37	4	30	23.8	23.56 (6.35−87.48)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**122**		**82**	**100.0**	**15.26 (7.60−30.62)**
Total events:	99		18			

Heterogeneity: χ^2=0.62, df=1 (p=0.43); I^2=0%
Test for overall effect: z=7.66 (p<0.00001)



C

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	0	0	0	0		Not estimable
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	25	33	29	37	100.0	0.86 (0.28−2.63)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**33**		**37**	**100.0**	**0.86 (0.28−2.63)**
Total events:	25		29			

Heterogeneity: not applicable
Test for overall effect: z=0.26 (p=0.79)

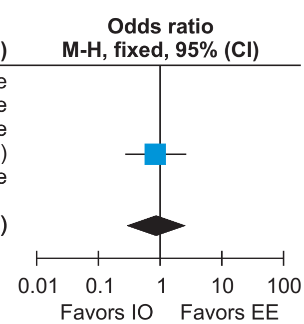


Fig. 1. Forest plots for the risk of overall elimination failure rate of left atrial appendage (LAA) using (A) internal obliteration (IO) vs. external excision (EE), (B) external obliteration (EO) vs. external excision, and (C) IO vs. EO. The pooled estimates showed that the risk was significantly lower using EE than using the other techniques. M-H, Mantel-Haenszel; CI, confidence interval; df, degrees of freedom.

the LA and LAA, showed that the superior efficacy of external excision compared with the efficacy of the other methods was due to a lower rate of persistent gap or flow despite a similar rate of residual stumps (Figs. 2, 3). Subgroup analyses also revealed that the use of sutures or staplers did not affect the efficacy of LAA elimination techniques, including external excision and external exclusion (Figs. 4, 5).

External obliteration using clip-type devices

External obliteration of the LAA using a clip-type device was recently developed, and the safety and efficacy of this device have been confirmed; however, extant studies have a limitation in that none included a comparative analysis with other elimination techniques [137]. In addition, studies have demonstrated that this clip-type device can electrically isolate the LAA and eliminate it from the bloodstream [138,139].

Adjunctive procedures in AF surgery

There is insufficient evidence to develop reasonable guidelines for SA of the ganglionic plexi or ligament of Marshall.

Surgery for ventricular tachycardia

Summary

- SA guided by preoperative and intraoperative electrophysiological mapping, performed at an experienced center, is recommended in patients with VT refractory

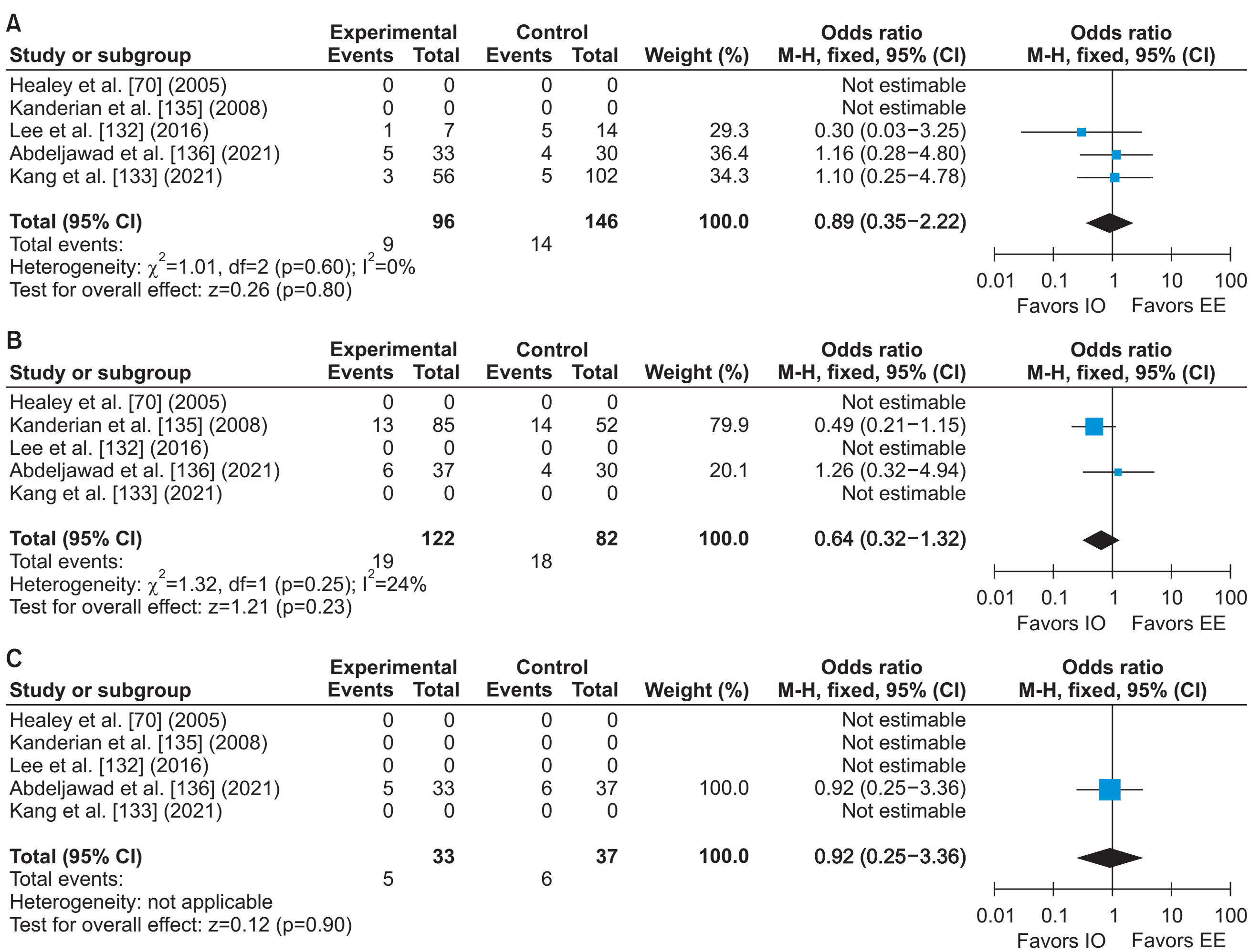
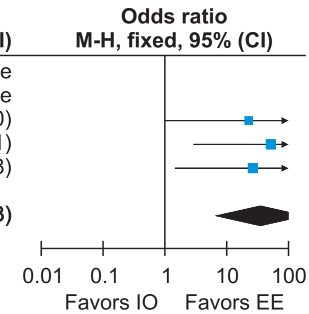


Fig. 2. Forest plots for the risk of individual outcome of residual stumps after left atrial appendage (LAA) elimination using (A) internal obliteration (IO) vs. external excision (EE), (B) external obliteration (EO) vs. external excision, and (C) IO vs. EO. The pooled estimates showed that the risk did not show statistically significant differences among the 3 techniques. M-H, Mantel-Haenszel; CI, confidence interval; df, degrees of freedom.

A

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	0	0	0	0		Not estimable
Lee et al. [132] (2016)	3	7	0	14	24.6	22.56 (0.97–524.40)
Abdeljawad et al. [136] (2021)	15	33	0	30	35.8	51.11 (2.88–905.71)
Kang et al. [133] (2021)	6	56	0	102	39.7	26.39 (1.46–477.68)
Total (95% CI)		**96**		**146**	**100.0**	**34.29 (6.13–191.83)**
Total events:	24		0			

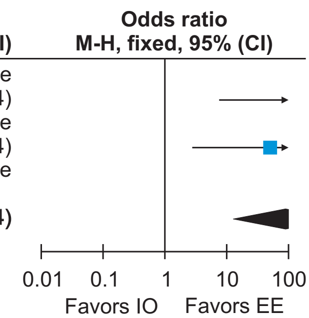
Heterogeneity: χ^2=0.17, df=2 (p=0.92); I^2=0%
Test for overall effect: z=4.02 (p<0.0001)



B

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	47	85	0	52	46.2	129.55 (7.74–2,167.34)
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	17	37	0	30	51.8	52.07 (2.96–915.04)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**122**		**82**	**100.0**	**89.45 (12.13–659.54)**
Total events:	64		0			

Heterogeneity: χ^2=0.20, df=1 (p=0.65); I^2=0%
Test for overall effect: z=4.41 (p<0.0001)



C

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	0	0	0	0		Not estimable
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	15	33	17	37	100.0	0.98 (0.38–2.52)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**33**		**37**	**100.0**	**0.98 (0.38–2.52)**
Total events:	15		17			

Heterogeneity: not applicable
Test for overall effect: z=0.04 (p=0.97)

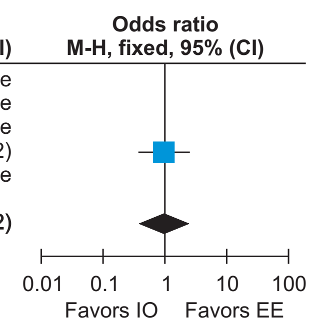


Fig. 3. Forest plots for the risk of individual outcome of persistent gap or flow after left atrial appendage (LAA) elimination using (A) internal obliteration (IO) vs. external excision (EE), (B) external obliteration (EO) vs. external excision, and (C) IO vs. EO. The pooled estimates showed that the risk did not show statistically significant differences among the 3 techniques. M-H, Mantel-Haenszel; CI, confidence interval; df, degrees of freedom.

to AAD therapy after failure of catheter ablation by experienced electrophysiologists (class of recommendation I; level of evidence B).

- SA is recommended in patients with recurrent sustained monomorphic VT or frequent implantable cardioverter-defibrillator (ICD) shock events for whom anti-arrhythmic medications are ineffective or for whom catheter ablation is not successful (class of recommendation I; level of evidence C).
- SA during cardiac surgery (bypass or valve surgery) may be considered in patients with clinically documented VT or ventricular fibrillation after catheter ablation failure (class of recommendation IIb; level of evidence C).
- SA may be considered in patients with sustained monomorphic VT after MI who have heart failure or thromboembolism associated with a left ventricular aneurysm, dyskinesia, or akinesia (class of recommendation IIb; level of evidence C).
- SA may be considered in patients with sustained monomorphic VT originating from the left ventricular assist device (LVAD) insertion site (class of recommendation IIb; level of evidence C).
- SA may be considered in patients with sustained monomorphic VT associated with cardiac tumors (class of recommendation IIb; level of evidence C).

In the era of transvascular catheter ablation for the treatment of VT and implantable ICD as standard therapy, the requirement for SA has become rare. Anatomically guided left ventricular aneurysmectomy was first described 50

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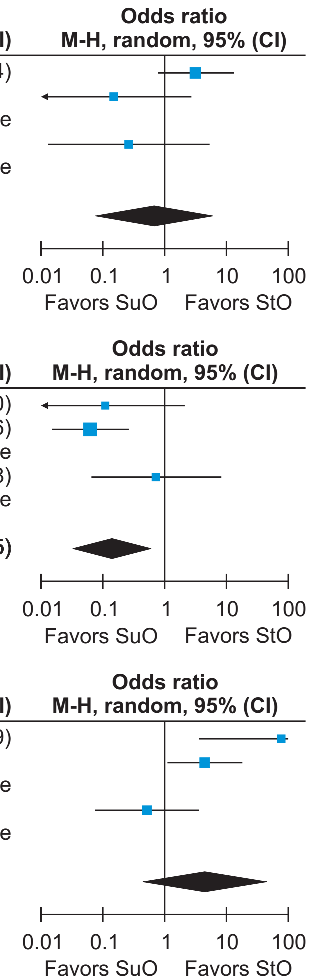


A

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, random, 95% (CI)
Healey et al. [70] (2005)	6	11	9	33	44.3	3.20 (0.78−13.14)
Kanderian et al. [135] (2008)	58	73	12	12	28.4	0.15 (0.01−2.69)
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	24	32	5	5	27.3	0.26 (0.01−5.25)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**116**		**50**	**100.0**	**0.68 (0.07−6.33)**
Total events:	88		26			

Heterogeneity: tau^2=2.41; χ^2=5.27, df=2 (p=0.07); I^2=62%
Test for overall effect: z=0.34 (p=0.73)

B

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, random, 95% (CI)
Healey et al. [70] (2005)	0	11	9	33	20.7	0.11 (0.01−2.10)
Kanderian et al. [135] (2008)	6	73	7	12	51.2	0.06 (0.02−0.26)
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	5	32	1	5	28.0	0.74 (0.07−8.08)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**116**		**50**	**100.0**	**0.14 (0.03−0.65)**
Total events:	11		17			

Heterogeneity: tau^2=0.64; χ^2=3.03, df=2 (p=0.22); I^2=34%
Test for overall effect: z=2.52 (p=0.01)

C

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, random, 95% (CI)
Healey et al. [70] (2005)	6	11	0	33	26.0	79.18 (3.89−1,613.59)
Kanderian et al. [135] (2008)	44	73	3	12	39.2	4.55 (1.14−18.24)
Lee et al. [132] (2016)	0	0	0	0		Not estimable
Abdeljawad et al. [136] (2021)	14	32	3	5	34.8	0.52 (0.08−3.54)
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**116**		**50**	**100.0**	**4.49 (0.43−46.98)**
Total events:	64		6			

Heterogeneity: tau^2=3.16; χ^2=8.15, df=2 (p=0.02); I^2=75%
Test for overall effect: z=1.25 (p=0.21)

Fig. 4. Forest plots for the risks of (A) overall elimination failure rate of left atrial appendage (LAA), (B) individual outcome of residual stump, and (C) individual outcome of persistent gap or flow after LAA elimination using external suture obliteration (SuO) vs. stapler obliteration (StO). The pooled estimates showed that the risk of residual stump was lower after SuO than after StO, while the other outcomes were not significantly different between the 2 techniques. M-H, Mantel-Haenszel; CI, confidence interval; df, degrees of freedom.

years ago [140]. Akinetic left ventricular walls with huge aneurysms may be accompanied by VA, and map-guided resection of the aneurysm improves left ventricular function and eliminates VA. Subendocardial resection for the management of VA was first described by Josephson et al. [140]. More recent studies have demonstrated that perisurgical EPS after subtotal endocardiectomy and cryoablation has a VT recurrence rate of approximately 10%–20%, predominantly within the first 90 days [141].

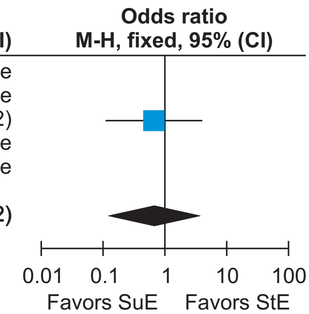
From the viewpoint of implementing a life-saving procedure, SA for VT is indicated in cases monomorphic sustained VT if pharmacotherapy or catheter ablation is ineffective, frequent VT attacks are not suppressed, or there is frequent activation of an ICD associated with the above condition, irrespective of whether the patient has an underlying heart disease [142-145].

For patients with deep intramural circuits, standard endocardial approaches combined with percutaneous epicardial catheter ablation remain ineffective in VT control. For patients with prior pericarditis or cardiac surgery, percutaneous epicardial access might not be feasible, and epicardial VT might not be easily targeted using standard ablation approaches. Alternative surgical VT control is acceptable for difficult catheterization approaches.

This surgical approach can be easily considered in cases involving concomitant surgical procedures. In addition, in cases with an inaccessible epicardial space (e.g., left ventricular summit), percutaneous catheter ablation can be facilitated by a subxiphoidal incision or thoracotomy, allowing entry into the pericardial space. This approach is most straightforward in patients with an apical, inferior, or left ventricular summit VT substrate because the area of the

A

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	0	0	0	0		Not estimable
Lee et al. [132] (2016)	5	10	6	10	100.0	0.67 (0.11–3.92)
Abdeljawad et al. [136] (2021)	0	0	0	0		Not estimable
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**10**		**10**	**100.0**	**0.67 (0.11–3.92)**
Total events:	5		6			
Heterogeneity: not applicable						
Test for overall effect: z=0.45 (p=0.65)						



B

Study or subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight (%)	Odds ratio M-H, fixed, 95% (CI)
Healey et al. [70] (2005)	0	0	0	0		Not estimable
Kanderian et al. [135] (2008)	0	0	0	0		Not estimable
Lee et al. [132] (2016)	2	8	3	6	100.0	0.33 (0.03–3.20)
Abdeljawad et al. [136] (2021)	0	0	0	0		Not estimable
Kang et al. [133] (2021)	0	0	0	0		Not estimable
Total (95% CI)		**8**		**6**	**100.0**	**0.33 (0.03–3.20)**
Total events:	2		3			
Heterogeneity: not applicable						
Test for overall effect: z=0.95 (p=0.34)						

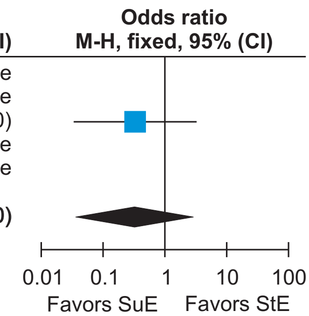


Fig. 5. Forest plots for the risks of (A) overall elimination failure rate of left atrial appendage (LAA) and (B) individual outcome of residual stump after LAA elimination using external suture excision (SuE) vs. stapler excision (StE). The pooled estimates showed that the risks were not significantly different between the 2 techniques. M-H, Mantel-Haenszel; CI, confidence interval.

heart closest to the window is most easily accessed, and pericardial adhesions can limit extensive mapping. Thoracotomy is the preferred approach for lateral and posterior substrates, whereas sternotomy is often required for anterior and partially inferior substrates. Portable electroanatomic mapping can help localize the substrate, and VT can be performed during beating heart-assisted cardiopulmonary bypass.

Resection and cryoablation of the left ventricular endocardium with white fibrosis are performed together with left ventricular reconstruction and thrombectomy in VT with heart failure, thromboembolism caused by a ventricular aneurysm, or left ventricular wall asynergy after myocardial infarction. Even in VT involving the part of an LVAD with blood drainage, the boundary between the scar and normal myocardium is considered an arrhythmic substrate, and cryoablation is performed in this area [146,147]. VT attacks associated with cardiac tumors are reportedly suppressed by surgical treatments, including tumor resection.

Executive summary

The executive summary is as follows (Fig. 6A–H).

A Atrial fibrillation surgery in rheumatic mitral valve disease	COR	LOE
· Concomitant AF surgery can be performed without increasing the risk of early mortality and is recommended at the time of rheumatic MV surgery (class of recommendation I; level of evidence B).	I	B
· Concomitant AF surgery can effectively restore the sinus rhythm and is recommended for rheumatic MV surgery (class of recommendation I; level of evidence A).	I	A
· It is reasonable ro perform concomitant AF surgery to decrease the long-term risks of thromboembolic events and mortality during rheumatic MV surgery (class IIa; level of evidence B).	IIa	B

Fig. 6. Recommendations regarding (A) atrial fibrillation (AF) surgery in rheumatic mitral valve (MV) disease, (B) AF surgery in degenerative MV disease, (C) AF surgery in aortic valve (AV) disease, (D) AF surgery in coronary disease, (E) isolated AF surgery, (F) AF surgery in congenital heart disease, (G) left atrial appendage (LAA) treatment during AF surgery, and (H) surgery for ventricular tachycardia (VT). CABG, coronary artery bypass grafting; SA, surgical ablation;ASD, atrial septal defect. (Continued on next page.)

B Atrial fibrillation surgery in degenerative mitral valve disease

Recommendation	COR	LOE
Concomitant AF surgery for degenerative MV disease is recommended to restore sinus rhythm because it does not increase the risk of operative mortality or major complications (class of recommendation I; level of evidence A).	I	A
Concomitant AF surgery for degenerative MV disease is a reasonable method to improve early mortality and long-term survival (class of recommendation IIa; level of evidence B).	IIa	B
Concomitant AF surgery for degenerative MV disease is a reasonable method of preventing late stroke (class of recommendation IIa; level of evidence B).	IIa	B

C Atrial fibrillation surgery in aortic valve disease

Recommendation	COR	LOE
Concomitant AF surgery is safe and recommended during AV surgery without an MV procedure (class of recommendation I; level of evidence B).	I	B
Concomitant AF surgery is recommended to effectively restore sinus rhythm during AV surgery without an MV procedure (class of recommendation I; level of evidence B).	I	B
Pulmonary vein isolation is a reasonable alternative ablation strategy for patients with paroxysmal AF undergoing AV surgery without an MV procedure (class of recommendation IIa; level of evidence B).	IIa	B

D Atrial fibrillation surgery in coronary disease

Recommendation	COR	LOE
Concomitant AF surgery is recommended for patients with preexisting AF undergoing isolated CABG (class of recommendation I; level of evidence B).	I	B
For non-prohibited-risk patients, a biatrial Cox-maze procedure, rather than isolated pulmonary vein isolation, is recommended (class of recommendation I; level of evidence C).	I	C
Risk venefits should be considered for patients with CHA2DS2-VASc, 7−9, history of myocardial infarction, and higher EuroSCORE. (class of recommendation I; level of evidence C).	I	C
For patients with preexisting AF undergoing isolated CABG, surgical occlusion or exclusion of the left atrial appendage may be considered (class of recommendation IIb; level of evidence C).	IIb	C

E Isolated atrial fibrillation surgery

Recommendation	COR	LOE
Stand-alone SA, including a hybrid procedure for paroxysmal or persistent AF, is reasonable for patients for whom one or more attempts at catheter ablation have failed, those with histories of stroke, and those who prefer a surgical approach considering easy left atrial appendage closure in a minimally invasive procedure (class of recommendation IIa; level of evidence B).	IIa	B
For patients with persistent and long-standing persistent AF, stand-alone SA, including a hybrid procedure, is reasonable for those for whom one or more attempts at catheter ablation have failed and for those who prefer a surgical approach (class of recommendation IIa; level of evidence B).	IIa	B

Fig. 6. (Continued; caption shown on previous page).

F After fibrillation surgery in congenital heart disease	COR	LOE
SA is reasonable at the time of closure of the ASD (class of recommendation IIa; level of evidence B).	IIa	B
To refuce AF recurrence, biatrial rather than right-atrial ablation should be considered during ASD repair (class of recommendation I; level of evidence A).	I	A
For symptomatic atrial tachyarrhythmia patients who undergo an atriopulmonary connection type Fontan operation, conversion to total cavopulmonary connection or extracardiac Fontan surgery should be considered in the management of atrial tachyarrhythmia (class of recommendation I; level of evidence C).	I	C
SA should be added to Ebstein repair in patients with a history of AF (class I; level of evidence C).	I	C
Biatrial surgical ablation is reasonable for minimizing recurrence during surgical ablation of persistent or long-standing persistent AF in patients with Ebstein anomalies (class of recommendation IIa; level of evidence C).	IIa	C
Concomitant atrial arrhythmia surgery is reasonable in patients undergoing pulmonary valve replacement for pulmonary regurgitation late after repair of tetralogy of Fallot with atrial fibrillation (class of recommendation IIa; level of evidence B).	IIa	B

G Left atrial appendage treatment during atrial fibrillation surgery	COR	LOE
Elimination of the LAA is reasonable during AF surgery (class of recommendation IIa; level of evidence A).	IIa	A
Excision of the LAA, rather than other elimination techniques such as internal or external obliteration, is reasonable to completely eliminate communication between the left atrium and LAA (class of recommendation IIa; level of evidence, B).	IIa	B
Obliteration of LAA with external clip device is reasonable as an effective alternative to conventional elimination technique whenever indicated (class of recommendation IIa; level of evidence C).	IIa	C

H Left atrial appendage treatment during atrial fibrillation surgery	COR	LOE
SA guided by preoperative and intraoperative electrophysiological mapping, performed at an experienced center, is recommended in patients with VT refractory to anti-arrhythmic drug therapy after failure of catheter ablation by experienced electrophysiologists (class of recommendation I; level of evidence B).	I	B
SA is recommended in patients with recurrent sustained monomorphic VT or frequent implantable cardioverter-defibrillator shock events for whom anti-arrhythmic medications are ineffective or for whom catheter ablation is not successful (class of recommendation I; level of evidence C).	I	C
SA during cardiac surgery (bypass or valve surgery) may be considered in patients with clinically documented VT or ventricular fibrillation after catheter ablation failure (class of recommendation IIb; level of evidence C).	IIb	C
SA may be considered in patients with sustained monomorphic VT after myocardial in farction who have heart failure or thromboembolism associated with an left ventricular aneurysm, dyskinesia, or akinesia (class of recommendation IIb; level of evidence C).	IIb	C
SA may be considered in patients with sustained monomorphic VT originating from the left ventricular assist device insertion site (class of recommendation IIb; level of evidence C).	IIb	C
SA may be considered in patients with sustained monomorphic VT associated with cardiac tumors (class of recommendation IIb; level of evidence C).	IIb	C

Fig. 6. (Continued; caption shown on previous page).

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Conflict of interest

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