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2023 APHRS expert consensus statements on surgery for AF

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1 | INTRODUCTION

A variety of surgical procedures for atrial fibrillation (AF) with different approaches have become available during the last quarter century, starting with the Maze procedure to the minimally invasive procedures. Asia-Pacific region is an active region in surgical treatment of AF; however, there is a diversity in the region in terms of health care and insurance systems, which can affect the indication and outcome of surgery for AF. The Asia Pacific Heart Rhythm Society (APHRS) and the surgery subcommittee organized a task force group to develop the APHRS Expert Consensus Statement on Surgery for AF (hereafter Statement). The purpose of the Statement is to describe the evidence and recommendation of various surgical treatments for AF patients with or without structural heart disease.

Contents in each chapter include a brief outline of the procedure, followed by a comparative outcome of the procedure based on clinical evidence. The evidence includes freedom from AF, short- and long-term survivals, and morbidities or complications. Freedom from AF is a function of time after intervention. Clinical studies do not necessarily come into the line align with guidelines in regard to the timing and method for evaluation of postoperative arrhythmia, which may influence the objective assessment of surgical procedures.[1–4] A classified recommendation of the procedure is described with a level of evidence. A recommended lesion set and a device is

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also described, if appropriate. Definitions of classes of recommendations and levels of evidence are referred to the ESC Guidelines.[5]

2 | SURGICAL AF ABLATION WITH OTHER CARDIOVASCULAR PROCEDURES

2.1 | Concomitant with left atrial (LA) open procedures

- Impact of concomitant AF ablation with LA open procedures

Patients undergoing LA open procedures, such as mitral valve surgery, frequently have atrial fibrillation (AF). Untreated AF has been shown to increase the risk of morbidities, such as stroke, and affect the long-term survival. Therefore, concomitant procedures for AF have been recommended to improve the postoperative outcomes.[6–8]

Meta-analyses of randomized controlled trials (RCT) and non-RCTs showed concomitant AF surgery to be safe without increasing operative mortality.[1,9–23] The analyses of the United States (US) Society of Thoracic Surgeons (STS) AF database[21] with a propensity matching showed that surgical ablation was associated with a reduction of 30-day mortality.

Previous studies,[8–21] including several meta-analyses, RCT and non-RCT clinical trials and the US STS AF database, on patients undergoing surgical AF ablation concomitant with LA open procedures, demonstrated a superior sinus rhythm restoration and maintenance rates than those without undergoing AF ablation.

A meta-analysis of several nonrandomized[1,22,23] clinical trials and one RCT[24] of concomitant surgical AF ablation in patients undergoing LA open procedures showed a reduction of stroke rate at 5-year postoperatively.

Although there has been no RCT examining the long-term (>12 months) outcome after concomitant surgical AF ablation, several retrospective and propensity-matched studies[25–27] have demonstrated the performance of surgical AF ablation concomitant with other cardiac procedures, such as valve surgery or combined valve surgery and CABG, were associated with improved long-term survival. An LA open procedure was performed in the majority of the patients in these studies, and two studies[25,26] demonstrated not only the improved survival in the treated AF group compared to the untreated AF group without treating AF, but also showed similar survival to the group of patients without a history of AF.

Several studies have shown that the quality of life (QOL) in the long term is also improved in the patients who restored sinus rhythm postoperatively, especially in those who were symptomatic from AF preoperatively.[28–31]

- Complications of surgical procedures for AF

Besides the common complications of cardiac surgical procedures, there are two specific complications potentially related to surgical procedures for AF: postoperative atrial tachycardia (AT) and new permanent pacemaker (PPM) implantation. Inappropriate lesion sets or surgical techniques, including inappropriate use of ablation devices, have been shown to be the mechanism for a part of postoperative AF recurrence and the majority of AT.[32] Even in the original cut-and-sew maze procedure, incomplete cryothermia at the CS or the atrioventricular annulus lesions results in postoperative AT. Conduction block between the LA and each PV can be tested by PV pacing intraoperatively. Intraoperative verification of complete conduction block created on the atria, the atrioventricular annuli, and the coronary sinus is feasible,[33,34] but not practical as a routine procedure.

An increased incidence of new PPM implantation after the maze procedure has been demonstrated in many studies.[21,35–39] There are nonsurgical and surgical factors for the PPM implantation after the maze procedure. Nonsurgical factors for the PPM implantation include preexisting dysfunction of the sinoatrial node (SAN) or postoperative progressive dysfunction of SAN, and other electrophysiologic abnormalities of intra-atrial/ inter-atrial conduction or atrioventricular node (AVN) conduction. SAN dysfunction requiring PPM implantation can occur in up to 10% of patients after the maze procedure for nonparoxysmal AF, and it is mainly caused by unmasking of preexisting sick sinus syndrome.[40] Mechanical or thermal injuries to the cardiac pulse generating (SAN) or conduction system, such as the SAN, intra-atrial conduction tracts and AVN, and interruption of the blood flow to the above system are the most likely intraoperative reasons for postoperative bradycardia and in-hospital PPM implantation.[41] The evidence that LA surgical ablation alone did not increase the incidence of PPM implantation[42] and the modified maze procedure with omission of an ablation line adjacent to the SAN have reduced the incidence of PPM implantation,[43] suggesting that the ablation lines of the right atrium (RA) may affect the SAN function. However, a retrospective study[44] showed the incidence of PPM implantation for SAN dysfunction was comparable between the biatrial and LA ablation. A recent study on robotic Cox-Maze procedure demonstrated that an anatomically precise placement of the posterolateral RA incision behind the SAN region reduced the incidence of PPM implatation.[45]

- Optimal lesion set for AF ablation in patients undergoing LA open procedure

Although the electrophysiologic mechanism of AF is diverse and not fully understood, the maze procedure, consisting of isolation of all four pulmonary veins and the posterior LA to block the propagation of the abnormal repetitive activations, and of the lines of conduction block on the RA and LA to block all potential macro-reentrant circuits, frequently converts AF back to sinus rhythm. Thus, the biatrial maze procedure is the standard procedure for AF ablation in patients undergoing LA open procedures. One randomized trial[17] on nonparoxysmal AF patients undergoing mitral valve surgery reported equivalent results of PVI to biatrial maze procedure. However, the assessment method in this trial did not follow the guidelines and the follow-up study with a more accurate method showed a lower prevalence of postoperative atrial tachyarrhythmias after biatrial maze procedure

compared with PVI.[46] The low rate of success of the biatrial maze procedure and a high incidence of PPM implantation in this study could be attributed to either incorrectly performed surgery or inadequate lesion sets.[47] Incidences of postoperative atrial tachycardia or AF recurrence because of inappropriate lesion set or incomplete surgical technique in biatrial maze procedure might have masked the superiority of biatrial maze procedure. Actual situations that the lesion set of the procedures for AF is not uniform among institutions or surgeons and each lesion is not necessarily performed properly should be kept in mind when we interpreting the results of comparative studies, particularly of multicenter studies, of different procedures and discuss the optimal lesion set of surgical AF ablation. Because the LA is already opened for intra-LA procedures, the additional ablation of the mitral isthmus and the CS is technically easy and safe. In addition, the patients undergoing LA open surgery frequently have mitral valve disease with persistent or long-standing persistent AF, PVI alone may not be adequate as an AF ablation procedure concomitant with LA open surgery.[46,48]

LA ablation without RA ablation can be indicated in patients whose AF mechanism is strongly presumed to be confined within the LA, and without RA dilatation or a need for tricuspid valve surgery. There are conflicting conclusions regarding sinus rhythm restoration rates between biatrial ablation and LA ablation, especially in patients with nonparoxysmal AF. Several meta-analyses of small RCTs and retrospective trials described that biatrial ablation were associated with increased freedom from AF compared with LA ablation alone,[35,36,49] but other studies suggested the risk of AF recurrence was comparable between the two procedures.[37,38,42] All are retrospective studies and there may be inherent weakness because of unconfounded factors, biasness, and patient selection. Most retrospective studies on biatrial ablation tend to include more patients with a longer duration of AF, a larger LA diameter, and more frequent association with tricuspid valve disease than those on LA ablation only.[42] No large-scale randomized trial between the biatrial ablation and LA ablation has ever been done and may be difficult because of the diverse nature of structural remodeling of the RA, but should be encouraged.

Since clear scientific evidence does not exist yet, the following factors should be considered and taken into account when selecting the biatrial ablation or LA ablation as a concomitant AF ablative procedure in patients undergoing LA open procedures. It should also be mentioned that the duration of AF or other factors are not clearly recorded or recognized in many patients.

a. patients' comorbidities and safety factors
b. types of AF; paroxysmal, persistent, or long-standing persistent
c. durations of AF
d. hemodynamics and LA performance, such as viability and compliance
e. extent of RA enlargement, remodeling or cardiomyopathy
f. association of tricuspid regurgitation

- Recommendation of energy source used for AF ablation

Energy sources used for surgical AF ablation should create a transmural and continuous necrosis of the atrial tissue to block abnormal activations to propagate and prevent reentrant activations while avoiding collateral damage to surrounding vessels and other important structures. The only two currently available energy sources or technologies that have been able to fulfill these requirements are the bipolar radiofrequency (RF) ablation and cryoablation. Transmurality created by the devices using these energy sources has been extensively examined and confirmed by experimental, histological and clinical studies.[2,50–54] The Cox-Maze IV using the bipolar RF or cryoablation that creates transmural lesion set is the only operation and technology with an FDA-approved indication for the treatment of AF.

- **Recommendation with Level of Evidence**

a. Surgical AF ablation is recommended in patients with AF undergoing a surgical procedure requiring an opening of the left atrium, such as mitral valve surgery. (Class I, Level of Evidence: B)
b. Education, training, and proctoring are recommended to enhance uptake and improve outcomes. (Class I, Level of Evidence: C)

The class of recommendation for surgical AF ablation is divided between class I and class IIa among the guidelines.[2,28,55] Although a statistically significant improvement of long-term survival after concomitant AF ablation has not been demonstrated by meta-analyses or RCT, the analyses have demonstrated a significant improvement of short-term survival and the analyses of non-RCT have demonstrated a significant improvement of long-term survival. In addition, one RCT has demonstrated a significant reduction in stroke risk after surgical AF ablation.[24] These evidence indicate that a concomitant AF ablation with an LA open procedure is safe and effective in the management of AF, and along with LAA resection or occlusion, improves the patient outcomes. Education of patients, surgeons, and physicians with training and proctoring of surgeons is desired to improve outcomes of surgical AF ablation.[1,2,21]

2.2 | Concomitant with nonatriotomy procedure

Less patients with AF undergoing a nonatriotomy cardiac procedure, such as AVR or CABG, receive a concomitant ablation when compared to those undergoing open-atriotomy procedures. Preoperative AF has been shown to be associated with an increased risk of early and late mortality and morbidity in AVR patients.[56] While rapid and multiple PV or LA focal activations with decremental and irregular conduction toward the RA are the primary mechanism of AF determined by intraoperative mapping in patients with mitral valve disease,[57] the electrophysiology of AF

in aortic valvular heart or coronary artery disease has not been examined in detailed. Nonetheless, biatrial Cox-Maze procedure concomitant to either atriotomy and nonatriotomy procedures yields similarly excellent conversion rate to sinus rhythm, and successful ablation in either group predicts favorable early and late outcomes,[58–61] and has been proven to be safe.[59,62] However, an addition of atriotomies for the biatrial ablation in patients undergoing nonatriotomy procedures increases the cardiac arrest and pulmonary bypass times and may increase the risks associated with atriotomies, such as bleeding. PV isolation (PVI) can be performed without atriotomies, avoiding these risks. One has to trade the decreased surgical risks in return for a lower possibility of sinus restoration rate when performing a simplified ablation procedure such as PVI, instead of biatrial Cox-Maze procedure that has been proven to result in higher successful rate for AF.

The optimal AF ablative procedure concomitant with nonatriotomy procedures; whether biatrial Cox-Maze procedure, PVI alone, or others has been controversial. Heterogeneity of patient demographics, ablation techniques and follow-up method have made it challenging to compare the outcomes between the different procedures. Although biatrial maze procedure should theoretically provide a superior rhythm outcome compared to PVI alone, unbiased comparison of biatrial maze procedure and PVI in patients may not be straightforward. PVI has been performed in AF patients undergoing nonatriotomy procedures more often and this may be driven by misleading data that points to equivocal results with biatrial ablation.[38] However, careful analysis of published data confirms that biatrial ablation following the Maze principles yields better rhythm restoration, particularly in the patients with a dilated LA, and is not an independent predictor of higher PPM implantation.[37,48,63–65]

Bipolar radiofrequency and cryoablation devices remain the only proven energy sources other than cut-and-sew technique that can fulfil the principles of the Maze procedure.[1] A combined use of bipolar radiofrequency and cryoablation compensates each device and may shorten the time for completion of the Maze procedure.[66] The perception that the conduct of surgery must be altered to accommodate concomitant ablation and the burden of adding time and complexity to an already challenging operation may have deterred many surgeons from performing concomitant ablation during nonatriotomy surgery. These issues can be overcome with adequate training, education, and proctoring.[1] Cost-effective data supporting concomitant AF ablation are still lacking but emerging.[67]

- **Recommendations with Level of Evidence**

a. Surgical ablation for AF can be performed without additional risk of operative mortality or major morbidity and is recommended to restore sinus rhythm and improve patient outcome during nonatriotomy cardiac surgery. (Class I, Level of Evidence: B)
b. Education, training, and proctoring are recommended to enhance uptake and improve outcomes. (Class I, Level of Evidence: C)

2.3 | Concomitant with off-pump procedures

Symptomatic AF patients who undergo cardiac surgical procedures should be treated for AF at the same time, however, concomitant surgical AF ablation in the patients undergoing surgical procedures without using cardiopulmonary bypass and cardiac arrest, such as off-pump CABG,[68,69] is challenging because of technical difficulties of ensuring a transmural and continuous ablation on the atria, coronary sinus, and atrioventricular annuli. AF ablation on a beating heart may result in a nontransmural or noncontinuous atrial necrosis because of heat sink effect by blood flow in the atria, and resulting in even a small gap in the ablation lesions line, can increasing the likelihood of AF recurrence and emergence of reentrant atrial tachycardia.[70]

Bilateral PVI without ablation of the atrial free wall and coronary sinus can be safely and effectively performed by using a clamp-type bipolar radiofrequency device as an off-pump beating heart procedure. Off-pump bilateral PVI is recommended in patients with symptomatic AF and a small LA who have failed medical and percutaneous treatment,[1] as it has been shown to provide better freedom from AF compared with percutaneous catheter ablation in stand-alone AF patients.[5] However, the patients with severely symptomatic AF refractory to medical therapies should undergo standard on-pump Maze procedure that may provide a higher success rate for AF than PVI.[71]

- **Recommendation with Level of Evidence**

a. Off-pump bilateral PVI should be considered in medically refractory symptomatic AF patients with a small LA. (Class IIa, Level of Evidence: B-R)

2.4 | Surgical AF ablation concomitant with MICS procedures

Minimally invasive cardiac surgery (MICS) is an approach to perform a surgery by direct vision or using a thoracoscope through small incisions, avoiding a full sternotomy, intending to reduce wound pain and to lead a quicker recovery postoperatively. The MICS approach has been increasingly applied in a variety of procedures, such as CABG or valve surgeries.[72] Revolution of endoscopic technology, ablation technology, and surgical instrumentation enabled the maze procedure to be performed via the MICS approach.

The selection of approaches for MICS should be based on the concomitant cardiac pathology, patient-specific anatomy, and the experience of the surgeon. A right mini-thoracotomy is a widely used approach for MICS to perform the biatrial Cox-Maze IV procedure as a stand-alone AF ablation or as a concomitant procedure with mitral or tricuspid valve surgery, as well as with most aortic valve replacement and coronary artery bypass grafting.[73]

Cox-Maze III/IV procedure by MICS demonstrated lesser bleeding amount and blood transfusion, diminished postoperative pain, lesser intubation time, a shorter hospital stay, compared to median sternotomy approach, while the early and late outcomes are similar.[73,74]

- **Recommendation with Level of Evidence**

a. Biatrial Cox-Maze procedure by experienced surgeons should be recommended in surgical ablation of AF concomitant with MICS procedures. (Class IIb, Level of Evidence: B-NR)

3 | STAND-ALONE SURGICAL AF ABLATION

3.1 | Thoracoscopic AF surgery

The maze procedure has been shown to result in a high conversion rate of AF in patients with stand-alone AF. To reduce the invasiveness of sternotomy and CPB, minimally invasive approaches have been developed. The initial approach involved bilateral mini-thoracotomies and has now evolved into a totally thoracoscopic approach.[75] Totally thoracoscopic surgery for AF includes bilateral PVI and exclusion or removal of the LAA. Additional ablations may include LA roof and floor lesions between the right and left PVI lesions to isolate the LA posterior wall, a linear ablation extended to the LAA line, a trigone line from the roof line, and ganglionated plexus ablation. The trigone line is called a "Dallas lesion", aiming to block reentrant activations conducting around the mitral valve annulus, which reentrant activations are blocked by the ablation of the mitral isthmus and CS in the conventional maze procedure through a median sternotomy.[76–78]

A meta-analysis of 1171 totally thoracoscopic maze patients, largely for paroxysmal AF, evaluated in conformity with the HRS/EHRA/ECAS expert consensus statement,[3] has demonstrated a 1 year off antiarrhythmic drugs (AAD) success rate of 78% and a 1 year on AAD success rate of 84%.[79] Compared to catheter ablation, patients with drug-refractory AF, a dilated LA or a previously failed catheter ablation who underwent thoracoscopic maze procedure had significantly higher freedom from LA arrhythmia without antiarrhythmic drugs at 12 months (65.6% vs. 36.5%).[80,81] AF free survival (single procedure success) 5 years after thoracoscopic PVI and LA ganglionic plexi ablation was 38% and AF free rate was 80% with or without additional interventions including antiarrhythmic drugs (31%), catheter ablation (21%), and electrical cardioversion (19%).[82]

There has been a continuous refinement of the thoracoscopic procedure with a progressive decrease of the procedure-related complication rate during the past decade. A two-center randomized clinical trial demonstrated a significantly higher procedural adverse event rate of 23% after surgical bilateral PV isolation using a video-assisted thoracoscopy compared to that after catheter ablation of 3.2%.[80] Actually, the surgical procedure examined in this trial was a mini-thoracotomy procedure supported by a video-assisted thoracoscopy that was widely performed in the early days of minimally invasive cardiac procedures. The above-quoted meta-analysis of 14 papers showed in-hospital complication rate of 2.9%, no perioperative deaths, and in-hospital mortality of 0.26%.[79] More recently, the review of the database of surgical ablation for stand-alone AF using the Society of Thoracic Surgeons Adult Cardiac Surgical Database (STS-ADCS) of the US demonstrated an overall 30-day mortality of 0.8%.[81] These incidences are sufficiently lower than those of other cardiac procedures, including the standard Cox-Maze IV procedure.

It is important to specify the appropriate patient population indicated for the minimally invasive thoracoscopic procedure for stand-alone AF. It has been shown that surgical ablation results in a better rhythm outcome as compared to catheter ablation in patients with failed prior catheter ablation.[80,83,84] Patients with a dilated left atrium with or without hypertension were also included in the comparative study; however, no significant efficacy of surgical ablation was demonstrated over catheter ablation.[80] Other comparative studies of the propensity score-matched population of thoracoscopic ablation or radiofrequency catheter ablation performed for persistent atrial fibrillation as the first ablative procedure have shown that there is no significant deference in the long-term incidence of tachyarrhythmia recurrence between the two procedures.[85–87]

Hybrid ablation approach, defined as a bilateral PVI with LAA closure to be performed surgically combined with percutaneous catheter-base endocardial ablation,[3] has been shown to provide better results compared with percutaneous catheter ablation alone in symptomatic AF patients who have failed medical and percutaneous treatment.[88] The procedure may be indicated in a subgroup of symptomatic paroxysmal AF patients with a small LA in whom pharmacological therapy and percutaneous ablation have failed, while the optimal ablation device and approach, the timing of catheter ablation, and other factors are still controversial. Recently, minimally invasive hybrid converge procedure was developed by combining epicardial ablation and map-guided endocardial ablation.[89] The procedure consists of epicardial ablation of the posterior LA and the antrum around the right and left PVs by vacuum-assisted unipolar radiofrequency device which is introduced through a transdiaphragmatic or subxiphoid port guided by a pericardioscope, followed by endocardial catheter ablation to touch up a conduction gap through the epicardial ablation lesions to complete the isolation of the posterior LA and PVs. A multicenter randomized trial for persistent and long-standing persistent AF demonstrated superior effectiveness compared to catheter ablation alone.[90] A heart-team hybrid approach using selected epicardial thoracoscopic surgical ablations and completion endocardial ablations to replicate the Cox-maze IV lesion set has been shown to provide promising results, particularly in nonparoxysmal AF patients.[91]

- **Recommendation with Level of Evidence**

a. Stand-alone surgical ablation with minimally invasive thoracoscopic approach should be considered in patients who have failed one or more sessions of catheter ablation, after careful consideration of relative safety and efficacy of therapeutic options. (Class IIa, Level of Evidence: B)
b. Stand-alone surgical ablation with minimally invasive thoracoscopic approach may be considered in patients with a dilated LA or intolerant or refractory to antiarrhythmic drug therapy and prefer a surgical approach, after careful consideration of relative safety and efficacy of therapeutic options. (Class IIb, Level of Evidence: B)
c. Hybrid ablation consisting of surgical ablation with LAA closure combined with catheter-based ablation should be considered in symptomatic AF patients. (Class IIa Level of Evidence: B)

3.2 | Robotic Cox-Maze procedure

Robotic surgery is beneficial for patients with respect to smaller incisions, resulting in reduced pain, discomfort, blood loss and transfusions, and risk of infection, allowing faster recovery time and return to normal activities, and shorter hospitalization. There are advantages also for surgeons including greater visualization and precision, enhanced dexterity, educative effect on training, and others. Robotic-assisted Cox-Maze procedure has been undertaken for stand-alone AF[92] as well as a concomitant procedure with other robotic-assisted cardiac procedures, such as mitral valve surgery.[93] The procedure utilizes single lung ventilation and a CPB with a femoral artery and peripheral venous cannulation guided by transesophageal echocardiography. The surgical procedures are performed through a single 3–5 cm rib-sparing incision on the right chest and with robotic ports inserted via stab incisions on the chest. The ablation is performed on the arrested heart using cryothermia or other ablation technologies.[94] The lesion set remains basically identical to the open chest Cox-Maze IV.

Recently, a longitudinal follow-up study on patients who underwent a robotic-assisted maze procedure using cryothermia for nonparoxysmal AF, as a stand-alone procedure or concomitant with other cardiac procedures, demonstrated an excellent rhythm control with satisfactory surgical outcome.[45] Robotic procedure is a minimally invasive surgical approach with rapidly progressing technologies. Further studies, including a comparative study with catheter ablation, are desired to determine the optimal minimal and effective treatment for AF patients, particularly with one or more history of failed catheter ablation.

- Recommendation with Level of Evidence

There exists only a limited number of published studies at the time of writing of the Statement to draw a recommendation with sufficient evidence.

4 | LAA CLOSURE

4.1 | Concomitant with other cardiovascular procedures

- Importance of LAA closure

Approximately 10%–20% of patients undergoing cardiovascular surgery have AF and carry risks of associated morbidities such as thromboembolic stroke, impaired long-term survival, and others.[6–8,95] Maze procedure is a gold standard therapy for these patients and the recommendation is supported by evidence of decreased incidence of thromboembolic stroke and improved long-term survival, which effects may be attributed to prevention of thrombus formation in the left atrial appendage (LAA) by resection of the LAA and restoration of atrial contraction by the maze procedure.

Thrombi formed in the LAA have been shown to be the most frequent source of ischemic stroke in AF patients. In patients with rheumatic AF or nonrheumatic AF without anticoagulant therapy, 7% or 16% of the patients have been shown to have thrombi in the LAA, respectively.[96] Vitamin K antagonist or direct oral anticoagulants effectively prevent thrombus formation in the LAA and subsequent thromboembolism. However, a continuous anticoagulant therapy does not necessarily prevent ischemic stroke and potentially increases the risk of hemorrhagic complications in postoperative patients.[97] From the early era of cardiac surgery, back in the 1950s, closure of the LAA has been performed during cardiac procedures to prevent stroke in AF patients.[98] A retrospective cohort study of Medicare patients with AF undergoing cardiac surgery demonstrated that concomitant LAA occlusion significantly reduced the risk of readmission for thromboembolism at 3 years postoperatively (adjusted hazard ratio, 0.67).[99] A multicenter RCT (LAAOS III) examined the impact of LAA occlusion during cardiac surgery in patients with AF and a CHA2DS2-VASc score of at least 2 and demonstrated the concomitant LAA occlusion reduced the incidence of ischemic stroke by 33% as compared to no-LAA occlusion group during an average follow-up of 3 years.[100]

- Indication of LAA closure

LAA closure is indicated in patients in whom the maze procedure or other rhythm-control procedures are not indicated or not strongly recommended for various reasons as follows:

a. Patients who are assumed to retain AF after the maze procedure.

Severely dilated LA, long duration of AF, or other parameters have been shown as predictors for retained AF after the maze procedure.[98] Increased incidence of postoperative permanent pacemaker implantation has also been demonstrated in these patients.[35,39]

b. Patients with severe comorbidities that may deter the maze procedure to be safely performed.

Although concomitant maze procedure does not increase the operative mortality in general,[101] the surgical risk may be increased in very old patients, patients with pulmonary or renal dysfunction, and/or other comorbidities.

c. Patients undergoing off-pump cardiovascular procedures.

Patients undergoing off-pump cardiovascular procedures, such as off-pump coronary artery bypass graft (CABG), occasionally have AF and carry a risk of postoperative ischemic stroke similar to those undergoing on-pump cardiovascular procedures.[102] Performing Maze procedure without cardiopulmonary bypass is feasible but technically challenging.[103,104] LAA closure is indicated in these patients and may reduce the risk of ischemic stroke and addition of PV isolation may increase the chance of AF conversion.

Prophylactic LAA closure in non-AF patients during routine cardiac surgery is not recommended, because there has been no sufficient evidence to support it at the time of writing. While indeed, some studies have demonstrated no reduction of stroke and, on the contrary, increased incidence of postoperative AF,[105,106] although one RCT showed concomitant LAA closure reduced the risk of postoperative ischemic brain injury regardless of a previous AF diagnosis.[107] More precise studies and discussion are needed to determine the impact and indication of prophylactic LAA closure.

Postoperative closure of the LAA by a percutaneous LAA closure device[108,109] is an optional strategy for AF patients undergoing cardiovascular procedures. The incidence of device-related thrombus after percutaneous LAA closure with endovascular devices is reportedly high, particularly in patients with predictors, such as hypercoagulability disorder, periprocedural pericardial effusion, renal insufficiency, implantation depth >10 mm from the pulmonary vein limbus, and nonparoxysmal AF.[110] As patients undergoing cardiovascular surgeries frequently have many of these predictors, concomitant LAA closure with cardiovascular procedures is recommended rather than postoperative percutaneous LAA closure.

- Recommended techniques for LAA closure

Cut-and-sew technique, which has long been used for LAA closure from the early days of cardiac surgery and shown to be a reliable technique for prevention of ischemic stroke,[95] is recommended in the on-pump setting with cardiac arrest procedures. Various techniques alternative to cut-and-sew technique have been tested for safety and reliability to be used in the off-pump setting or on a beating heart. A simple ligation and external suture closure techniques have been shown to frequently result in incomplete closure of the LAA, followed by thrombus formation and thromboembolic events,[111–114] and thus these techniques are not recommended. Stapling tools, which have been widely used in lung lobectomy, gastrectomy, or colectomy, have been applied in LAA closure. A study with transesophageal echocardiography of patients after LAA closure demonstrated the incidence of patent LAA was 29% after staple exclusion, while no patients with patent LAA after staple amputation.[115] A randomized comparison of internal ligation, stapled excision, and surgical excision of LAA demonstrated high incidences of incomplete closure after internal ligation (43%) and of residual LAA stump after stapled excision (25%) or surgical excision (50%) assessed by transesophageal echocardiography at a mean of 0.4 years postoperatively and recommended intraoperative assessment of the closed LAA by transesophageal echocardiography. An endocardial longitudinal double-layer obliteration has been proposed for the LAA closure based on the anatomical and pathological considerations.[115]

An LAA exclusion clip made of titanium core frame and nitinol springs was developed and a multicenter FDA trial with 3-month follow-up with computed tomography angiography or transesophageal echocardiography demonstrated greater than 95% success of LAA closure.[116] LAA closure in minimally invasive cardiac surgery or off-pump procedures has been a technical challenging procedure. The LAA clip has enabled safe and successful closure of the LAA in these procedures.[117,118]

- **Recommendations with Level of Evidence**

a. The LAA closure is recommended in patients with AF undergoing on-pump cardiovascular procedures in whom the maze procedure or other rhythm-control procedures are not indicated. (Class I, Level of Evidence: A)
b. The LAA closure is recommended in patients with AF undergoing off-pump cardiovascular procedures in whom the maze procedure or other rhythm-control procedures are not indicated. (Class IIa, Level of Evidence: B)

4.2 | Thoracoscopic LAA closure

Thoracoscopic LAA closure has been performed as a stand-alone procedure in AF patients without structural heart diseases, aiming at prevention of thromboembolic stroke caused by thrombi in the LAA.[109,119,120] Thoracoscopic LAA closure is a less invasive approach that eliminates the risks related to open chest procedures and a use of CPB, while effectively prevents thromboembolic events because of AF.

The indication of thoracoscopic LAA closure should be determined by the comparisons of safety and effective prevention of stroke with percutaneous endocardial or epicardial LAA closure devices,[109,120,121] and anticoagulant therapy. Clinical experience with thoracoscopic LAA closure using stapler-and-loop technique performed in AF patients at a high risk of cardiogenic thromboembolism or bleeding complications because of anticoagulant therapy without any hospital mortality and major complications, demonstrated complete closure of the LAA confirmed by intraoperative

transesophageal echocardiography and cardiogenic thromboembolisms occurred in 0.25 patients per 100 patient-years during an average follow-up period of 24 months without anticoagulant therapy.[122] The incidence of ischemic stroke was 0.78 patients per 100 patient-years after a total thoracoscopic ablation with LAA closure using a stapler or a clip.[123]

Criteria for discontinuation of anticoagulant therapy after thoracoscopic LAA closure are not fully elucidated. In addition to history of stroke, CHA_2DS_2-VASc score, LA size, and LVEF, the postoperative assessment of the closed LAA whether any remnant or pouch remains should be taken into account when anticoagulant medicines are discontinued after LAA closure.[114,123]

- Recommended techniques and approach for thoracoscopic LAA closure

The current techniques for LAA exclusion include surgical resection and suture closure, internal obliteration, epicardial closure using a stapler or a clip, and others. A recent randomized trial of internal ligation, surgical excision, and stapled excision reported that all these three techniques left either a stump or a gap at least 50% of the time.[114] An external clip approved by the FDA in 2011 is a promising device for occlusion of the LAA. Excellent results of thoracoscopic epicardial closure of the LAA using the clip have been reported in nonvalvular AF patients with a high risk of thromboembolism or bleeding[124,125] A heart-team approach may be important for decision-making process for percutaneous or thoracoscopic LAA occlusion in patients who are contraindicated for oral anticoagulants and indicated for LAA closure.[126] Because the techniques and devices for the thoracoscopic LAA closure are continuously being innovated and improved, the procedure is recommended to be performed by experienced surgeons.

- **Recommendation with Level of Evidence**

a. Thoracoscopic LAA closure is recommended in AF patients who are at a high risk of thromboembolism or bleeding events despite optimal anticoagulation therapy and not indicated for percutaneous LAA closure. The procedure is recommended to be performed by experienced surgeons after a careful discussion by a heart team. (Class IIa, Level of Evidence: B)

5 | EDITOR'S POSTSCRIPT

It has been more than a quarter century since the first patient underwent the maze procedure, the first in history nonpharmacological rhythm-control therapy of AF that is invented by Dr Cox and his research group of Washington University in St. Louis, MO, USA. Since then, we have witnessed and experienced rapid strides and advancements in surgery as well as in catheter ablation. The advancements involve a variety of aspects in the treatment of AF, from basic electrophysiology to minimally invasive hybrid approaches.

A number of guidelines and consensus statements have been published based on objective evidence and expertise to support the clinical practice of surgery for AF. We have developed the APHRS expert consensus statement on surgery for AF, in which indication or recommendation of surgical procedures is tailored to regional specificity and updated in response to the recent advancements in electrophysiology and technology in AF treatment. Task force and internal reviewers are applied from the APHRS surgery subcommittee members. External reviewers are the expert cardiac surgeons in AF surgery and expert cardiologists in AF ablation, nominated by other societies. I would appreciate all the task force members for preparing the manuscript, and internal and external reviewers for providing invaluable comments and suggestions. We all hope these statements will help surgeons to perform an appropriate procedure on AF patients with a various condition and improve outcome of patients.

Takashi Nitta, MD, PhD.

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CONFLICT OF INTEREST STATEMENT

Takashi Nitta is a consultant for AtriCure. Michael Yii is a consultant for AtriCure as a proctor. Mark La Meir is a consultant for AtriCure. Christoph T Starck declares payment to his institution related to his activity as speaker fees, honoraria, consultancy, advisory board fees, investigator, committee member from AngioDynamics, Abiomed, AtriCure, Medtronic, Spectranetics, Biotronik, Liva Nova (Sorin) and Cook Medical and departmental or institutional research funding from Cook Medical, Hylomorph.

DECLARATIONS

The manuscript describes expert consensus statements and there is nothing to declare.

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REFERENCES

1. Ad N, Damiano RJ, Badhwar V, Calkins H, La Meir M, Nitta T, et al. Expert consensus guidelines: examining surgical ablation for atrial fibrillation. J Thorac Cardiovasc Surg. 2017;153:1330–54.
2. Badhwar V, Rankin JS, Damiano RJ Jr, Gillinov AM, Bakaeen FG, Edgerton JR, et al. The Society of Thoracic Surgeons 2017 clinical practice guidelines for the surgical treatment of atrial fibrillation. Ann Thorac Surg. 2017;103:329–41.

3. Calkins H, Hindricks G, Cappato R, Kim YH, Saad EB, Aguinaga L, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation. Heart Rhythm. 2017;14:e275–444.
4. January CT, Wann LS, Calkins H, Chen LY, Cigarroa JE, Cleveland JC Jr, et al. 2019 AHA/ACC/HRS focused update of the 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: a report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines and the Heart Rhythm Society. J Am Coll Cardiol. 2019;74:104–32.
5. McMurray JJ, Adamopoulos S, Anker SD, Auricchio A, Böhm M, Dickstein K, et al. ESC guidelines for the diagnosis and treatment of acute and chronic heart failure 2012. Eur Heart J. 2012;33:1787–847.
6. Gammie JS, Haddad M, Milford-Beland S, Welke KF, Ferguson TB Jr, O'Brien SM, et al. Atrial fibrillation correction surgery: lessons from the Society of Thoracic Surgeons National Cardiac Database. Ann Thorac Surg. 2008;85:909–14.
7. Ngaage DL, Schaff HV, Mullany CJ, Sundt TM III, Dearani JA, Barnes S, et al. Does preoperative atrial fibrillation influence early and late outcomes of coronary artery bypass grafting? J Thorac Cardiovasc Surg. 2007;133:182–9.
8. Quader MA, McCarthy PM, Gillinov AM, Alster JM, Cosgrove DM III, Lytle BW, et al. Does preoperative atrial fibrillation reduce survival after coronary artery bypass grafting? Ann Thorac Surg. 2004;77:1514–22.
9. Jessurun ER, Van Hemel NM, Defauw JJ, Brutel De La Rivière A, Stofmeel MA, Kelder JC, et al. A randomised study of combining maze surgery for atrial fibrillation with mitral valve surgery. J Cardiovasc Surg (Torino). 2003;44:9–18.
10. Akpinar B, Guden M, Sagbas E, Sanisoglu I, Ozbek U, Caynak B, et al. Combined radiofrequency modified maze and mitral valve procedure through a port access approach; early and midterm results. Eur J Cardiothorac Sur. 2003;24:223–30.
11. Schuetz A, Schulze C, Sarvanakis KK, Mair H, Plazer H, Kilger E, et al. Surgical treatment of permanent atrial fibrillation using microwave energy ablation; a prospective randomised clinical trial. Eur J Cardiothorac Surg. 2003;24:475–80.
12. Vasconcelos JT, Scanavacca MI, Sampaio RO, Grinberg M, Sosa EA, Oliveira SA. Surgical treatment of atrial fibrillation through isolation of the left atrial posterior wall in patients with chronic rheumatic mitral valve disease: a randomized study with control group. Arq Bras Cardiol. 2004;83:211–8.
13. de Lima GG, Kalil RA, Leiria TL, Hatem DM, Kruse CL, Abrahão R, et al. Randomized study of surgery for patients with permanent atrial fibrillation as a result of mitral valve disease. Ann Thorac Surg. 2004;77:2089–94.
14. Doukas G, Samani NJ, Alexiou C, Oc M, Chin DT, Stafford PG, et al. Left atrial radiofrequency ablation during mitral valve surgery for continuous atrial fibrillation; a randomized controlled trial. JAMA. 2005;294:2323–9.
15. Abreu Filho CA, Lisboa LA, Dallan LA, Spina GS, Grinberg M, Scanavacca M, et al. Effectiveness of the maze procedure using cooled-tip radiofrequency ablation in patients with permanent atrial fibrillation and rheumatic mitral valve disease. Circulation. 2005;112:120–5.
16. Blomstrom-Lundqvist C, Johansson B, Berglin E, Nilsson L, Jensen SM, Thelin S, et al. A randomized double-blind study of epicardial left atrial cryoablation for permanent atrial fibrillation in patients undergoing mitral valve surgery: the SWEDish multicentre atrial fibrillation study (SWEDMAF). Eur Heart J. 2007;28:2902–8.
17. Gillinov AM, Gelijns AC, Parides MID, DeRose JJ Jr, Moskowitz AJ, Voisine P, et al. Surgical ablation of atrial fibrillation during mitral valve surgery. N Engl J Med. 2015;372:1399–409.
18. Budera P, Straka Z, Osmančík P, Vaněk T, Jelínek Š, Hlavička J, et al. Comparison of cardiac surgery with left atrial surgical ablation vs cardiac surgery without atrial ablation in patients with coronary and/or valve heart disease plus atrial fibrillation; final results of the PRAGUE-12 randomised multicentre study. Eur Heart J. 2012;33:2644–52.
19. Khargi K, Deneke T, Haardt H, Lemke B, Grewe P, Müller KM, et al. Saline-irrigated, cool tip radiofrequency ablation in a effective technique to perform the maze procedure. Ann Thorac Surg. 2001;72:S1090–5.
20. Nashef SAM, Fynn S, Abu-Omar Y, Spyt TJ, Mills C, Everett CC, et al. Amaze: a randomized controlled trial of adjunct surgery for atrial fibrillation. Eur J Cardiothorac Surg. 2018;54:729–37.
21. Badhwar V, Rankin J, Ad N, Grau-Sepulveda M, Damiano RJ, Gillinov AM, et al. Surgical ablation of atrial fibrillation in the United States: trends and propensity matched outcomes. Ann Thorac Surg. 2017;104:493–500.
22. Wong JWW, Mak KH. Impact of maze and concomitant mitral valve surgery on clinical outcomes. Ann Thorac Surg. 2006;82:1938–47.
23. Reston JT, Shuhaiber JH. Meta-analysis of clinical outcomes of maze-related surgical procedures for medically refracting atrial fibrillation. Eur J Cardiothorac Surg. 2005;28:724–30.
24. Osmancik P, Budera P, Talavera D, Hlavicka J, Herman D, Holy J, et al. Five-year outcomes in cardiac surgery patients with atrial fibrillation undergoing concomitant surgical ablation versus no ablation. The long-term follow-up of the PRAGUE-12 study. Heart Rhythm. 2019;16:1334–40.
25. Lee R, McCarthy PM, Wang EC, Vaduganathan M, Kruse J, Malaisrie SC, et al. Midterm survival in patients treated for atrial fibrillation. A propensity-matched comparison to patients without a history of atrial fibrillation. J Thorac Cardiovasc Surg. 2012;155:159–70.
26. Musharbash F, Schill M, Sinn L, Schuessler RB, Maniar HS, Moon MR, et al. Performance of the Cox-maze IV procedure in associated with improved long-term survived in patients with atrial fibrillation undergoing cardiac surgery. J Thorac Cardiovasc Surg. 2018;155:159–70.
27. Iribane A, Discipio A, McCullogh J, Quinn R, Leavitt BJ, Westbrook BM, et al. Surgical atrial fibrillation ablation improves long-term survival: a multi-centre analysis. Ann Thorac Surg. 2019;107:133–41.
28. Nogami A, Kurita T, Abe H, Ando K, Ishikawa T, Imai K, et al. JCS/JHRS 2019 guideline on non-pharmacotherapy of cardiac arrhythmias. Circ J. 2021;85:1104–244.
29. Johansson B, Houltz B, Berglin E, Brandrup-Wognsen G, Karlsson T, Edvardsson N. Short term sinus rhythm predicts long-term sinus rhythm and clinical improvement after intraoperative ablation of AF. Europace. 2008;10:610–7.
30. Grubitzsch H, Dushe S, Beholz S, Dohmen PM, Konertz W. Surgical ablation of AF in patients with congestive cardiac failure. J Card Fail. 2007;13:509–16.
31. Maesen B, van der Heijden CAJ, Bidar E, Vos R, Athanasiou T, Maessen JG. Patient-reported quality of life after standalone and concomitant arrhythmia surgery: a systematic review and meta-analysis. Interact Cardiovasc Thorac Surg. 2022;34:339–48.
32. Takahashi K, Miyauchi Y, Hayashi M, Iwasaki YK, Yodogawa K, Tsuboi I, et al. Mechanisms of postoperative atrial tachycardia following biatrial surgical ablation of atrial fibrillation in relation to the surgical lesion sets. Heart Rhythm. 2016;13:1059–65.
33. Ishii Y, Nitta T, Kambe M, Kurita J, Ochi M, Miyauchi Y, et al. Intraoperative verification of conduction block in atrial fibrillation surgery. J Thorac Cardiovasc Surg. 2008;136:998–1004.
34. Nitta T, Wakita M, Watanabe Y, Ohmori H, Sakamoto SI, Ishii Y, et al. Double potential mapping: a novel technique for locating the site of incomplete ablation. Innovations. 2012;7:429–34.

35. McClure GR, Belley-Cote EP, Jaffer IH, Dvirnik N, An KR, Fortin G, et al. Surgical ablation of atrial fibrillation; a systemic review and meta-analysis of randomised controlled trials. Europace. 2018;20:1442–50.
36. Phan K, Xie A, Tsai YC, Kumar N, La Meir M, Yan TD. Biatrial ablation vs left atrial concomitant surgical ablation for treatment of atrial fibrillation: a meta-analysis. Europace. 2015;17:38–47.
37. Bogachev-Prokophiev AV, Afanasyev AV, Pivkin AN, Ovcharov MA, Zheleznev SI, Sharifulin RM, et al. A left atrial versus a biatrial lesion set for persistent atrial fibrillation ablation during open heart surgery. Eur J Cardiothorac Surg. 2018;54:738–44.
38. Li H, Lin X, Ma X, Tao J, Zou R, Yang S, et al. Biatrial versus isolated left atrial ablation in atrial fibrillation: a systematic review and meta-analysis. Biomed Res Int. 2018;2018:3651212. https://doi.org/10.1155/2018/3651212
39. Soni LK, Cedola SR, Cogan J, Jiang J, Yang J, Takayama H, et al. Right atrial lesions do not improve the efficacy of a complete lesion atrial lesion set in the surgical treatment of atrial fibrillation, but they do increase procedure morbidity. J Thorac Cardiovasc Surg. 2013;145:356–63.
40. Cox JL, Ad N, Churyla A, Malaisrie SC, Pham DT, Kruse J, et al. The maze procedure and postoperative pacemakers. Ann Thorac Surg. 2018;106:1561–9.
41. Nitta T. Commentary: many things remain unlearned and undetermined. J Thorac Cardiovasc Surg. 2021;166:767–8. https://doi.org/10.1016/j.jtcvs.2021.10.027
42. Wang X, Wang C, Ye M, Lin J, Jin J, Hu Q, et al. Left atrial concomitant surgical ablation for treatment of atrial fibrillation in cardiac surgery: a meta-analysis of randomized controlled trials. PloS One. 2018;13:e0191354. https://doi.org/10.1371/journal.pone.0191354
43. Kakuta T, Fukushima S, Minami K, Kawamoto N, Tadokoro N, Saiki Y, et al. Incidence of and risk factors for pacemaker implantation after the modified Cryo-maze procedure for atrial fibrillation. J Thorac Cardiovasc Surg. 2021;166(3):755–66. https://doi.org/10.1016/j.jtcvs.2021.10.064
44. Kim HJ, Kim JB, Kim SO, Cho MS, Kim JK, Kim WK, et al. Long-term outcomes of surgical ablation for atrial fibrillation. Impact of ablation lesion sets. *JACC*. Asia. 2021;1:203–14.
45. Almousa A, Mehaffey JH, Wei LM, Simsa A, Hayanga JWA, Cook C, et al. Robotic-assisted cryothermic Cox maze for persistent atrial fibrillation: longitudinal follow-up. J Thorac Cardiovasc Surg. 2022;165(5):1828–1836.e1. https://doi.org/10.1016/j.jtcvs.2022.05.012
46. Blackstone EH, Chang HL, Rajeswaran J, Parides MK, Ishwaran H, Li L, et al. Bilateral maze procedure verses pulmonary vein isolation for atrial fibrillation during mitral valve surgery: new analytical approaches and end points. J Thorac Cardiovasc Surg. 2019;157:234–43.
47. Cox JL. Surgical ablation for atrial fibrillation. N Engl J Med. 2015;373:483–4.
48. Barnet SD, Ad N. Surgical ablation as treatment for the elimination of atrial fibrillation: a meta-analysis. J Thorac Cardiovasc Surg. 2006;131:1029–35.
49. Prasad SM, Maniar HS, Diodato MD, Schuessler RB, Damiano RJ Jr. Physiological consequences of bipolar radiofrequency energy on the atrial pulmonary veins: a chronic animal study. Ann Thoracic Surg. 2003;76:836–41.
50. Prasad SM, Maniar HS, Schuessler RB, Damiano RJ Jr. Chronic transmural atrial ablation by using bipolar radiofrequency energy on the beating heart. J Thorac Cardiovasc Surg. 2002;124:708–13.
51. Ventosa-Fernández G, Sandoval E, Ninot S, Ribalta T, Castellá M. Histological evidence of transmurality four years after bipolar radiofrequency Cox-maze IV. Ann Thorac Surg. 2015;100:328.
52. Doll N, Kiaii BB, Fabricius AM, Bucerius J, Kornherr P, Krakor R, et al. Intraoperative left ablation (for atrial fibrillation) using a new argon cryocatheter; early clinical experience. Ann Thorac Surg. 2003;76:1711–5.
53. Vrital B, Kuliniski A. Cryotherapy of cardiac arrhythmic from basic science to bedside. Heart Rhythm. 2015;12:2195–203.
54. Cox J, Malaisrie S, Churyla A, Mehta C, Kruse J, Kislitsina ON, et al. Cryosurgery for atrial fibrillation: physiological basis for creating optimal cryolesions. Ann Thorac Surg. 2021;112:354–62.
55. Vahanian A, Beyersdorf F, Praz F, Milojevic M, Baldus S, Bauersachs J, et al. 2021 ESC/EACTS guidelines for the management of valvular heart disease: developed by the task force for the management of valvular heart disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2022;43:561–632.
56. Saxena A, Dinh DT, Reid CM, Smith JA, Shardey GC, Newcomb AE. Does preoperative atrial fibrillation portend a poorer prognosis in patients undergoing isolated aortic valve replacement? A multicentre Australian study. Can J Cardiol. 2013;29:697–703.
57. Nitta T, Ishii Y, Miyagi Y, Ohmori H, Sakamoto SI, Tanaka S. Concurrent multiple left atrial focal activations with fibrillatory conduction and right atrial focal or reentrant activation as the mechanism in atrial fibrillation. J Thorac Cardiovasc Surg. 2004;127:770–8.
58. Khargi K, Hutten BA, Lemke B, Deneke T. Surgical treatment of atrial fibrillation; a systematic review. Eur J Cardiothorac Surg. 2005;27:258–65.
59. Yoo JS, Kim JB, Ro SK, Jung Y, Jung SH, Choo SJ, et al. Impact of concomitant surgical atrial fibrillation ablation in patients undergoing aortic valve replacement. Circ J. 2014;78:1364–71.
60. Damiano RJ Jr, Gaynor SL, Bailey M, Prasad S, Cox JL, Boineau JP, et al. The long-term outcome of patients with coronary disease and atrial fibrillation undergoing the Cox maze procedure. J Thorac Cardiovasc Surg. 2003;126:2016–21.
61. Raissouni K, Petrosyan A, Malapert G, Jazayeri S, Morgant MC, Bouchot O. Concomitant cardiac surgery and radiofrequency ablation of atrial fibrillation: a retrospective single center study. J Cardiothorac Vasc Anesth. 2020;34:401–8.
62. Phan K, Xie A, La Meir M, Black D, Yan TD. Surgical ablation for treatment of atrial fibrillation in cardiac surgery: a cumulative meta-analysis of randomised controlled trials. Heart. 2014;100:722–30.
63. Kim HJ, Kim JB, Kim SO, Cho MS, Kim JK, Kim WK, et al. Long term outcome after surgical ablation for AF: impact of lesion sets. J Am Coll Cardiol. 2021;1:203–14.
64. Kainuma S, Mitsuno M, Toda K, Funatsu T, Nakamura T, Miyagawa S, et al. Dilated left atrium as a predictor of late outcome after pulmonary vein isolation concomitant with aortic valve replacement and/or coronary artery bypass grafting. Eur J Cardiothorac Surg. 2015;48:765–7.
65. Kainuma S, Mitsuno M, Toda K, Miyagawa S, Yoshikawa Y, Hata H, et al. Surgical ablation concomitant with nonmitral valve surgery for persistent atrial fibrillation. Ann Thorac Surg. 2021;112:1909–20.
66. Yii M, Yap CH, Nixon I, Chao V. Modification of the Cox maze III procedure using bipolar radiofrequency ablation. Heart Lung Circ. 2007;16:37–49.
67. Rankin JS, Lerner DJ, Braid-Forbes MJ, McCrea MM, Badhwar V. Surgical ablation of atrial fibrillation concomitant to coronary-artery bypass grafting provides cost-effective mortality reduction. J Thorac Cardiovasc Surg. 2020;160:675–86.
68. La Meir M, Gelsomino S, Nonneman B. The problem with concomitant atrial fibrillation in non-mitral valve surgery. Ann Cardiothorac Surg. 2014;3:124–9.
69. Khiabani AJ, Adademir T, Schuessler RB, Melby SJ, Moon MR, Damiano RJ Jr. Management of atrial fibrillation in patients undergoing coronary artery bypass grafting: review of the literature. Innovations (Phila). 2018;3:383–90.
70. Melby SJ, Lee AM, Zierer A, Kaiser SP, Livhits MJ, Boineau JP, et al. Atrial fibrillation propagates through gaps in ablation lines:

implications for ablative treatment of atrial fibrillation. Heart Rhythm. 2008;5:1296–301.
71. de Maat GE, van Gelder I, Rienstra M, Quast AF, Tan ES, Wiesfeld AC, et al. Surgical vs. transcatheter pulmonary vein isolation as first invasive treatment in patients with atrial fibrillation: a matched group comparison. Europace. 2014;16:33–9.
72. Iribarne A, Easterwood R, Chan EY, Yang J, Soni L, Russo MJ, et al. The golden age of minimally invasive cardiothoracic surgery: current and future perspectives. Future Cardiol. 2011;7:333–46.
73. Lancaster TS, Melby SJ, Damiano RJ. Minimally invasive surgery for atrial fibrillation. Trends Cardiovasc Med. 2016;26:268–77.
74. Chaiyaroj S, Lertsitthichai P. Comparative early and long term results of mitral valve surgery between right mini thoracotomy and full sternotomy approach. J Med Assoc Thai. 2021;104:133–9.
75. Wolf RK. Minimally invasive surgical treatment of atrial fibrillation. Semin Thorac Cardiovasc Surg. 2007 Winter;19(4):311–8.
76. Edgerton JR, Jackman WM, Mack MJ. A new epicardial lesion set for minimal access left atrial maze: the Dallas lesion set. Ann Thorac Surg. 2009;88:1655–7.
77. Yilmaz A, Geuzebroek GS, Van Putte BP, Boersma LV, Sonker U, De Bakker JM, et al. Completely thoracoscopic pulmonary vein isolation with ganglionic plexus ablation and left atrial appendage amputation for treatment of atrial fibrillation. Eur J Cardiothorac Surg. 2010;38:356–60.
78. Sirak JH, Schwartzman D. Interim results of the 5-box thoracoscopic maze procedure. Ann Thorac Surg. 2012;94:1880–4.
79. van Laar C, Kelder J, van Putte BP. The totally thoracoscopic maze procedure for the treatment of atrial fibrillation. Interact Cardiovasc Thorac Surg. 2017;24:102–11.
80. Boersma LV, Castella M, van Boven W, Berruezo A, Yilmaz A, Nadal M, et al. Atrial fibrillation catheter ablation versus surgical ablation treatment (FAST): a 2-center randomized clinical trial. Circulation. 2012;125:23–30.
81. Ad N, Holmes SD, Roberts HG Jr, Rankin JS, Badhwar V. Surgical treatment for stand-alone atrial fibrillation in North America. Ann Thorac Surg. 2020;109:745–52.
82. Saini A, Hu YL, Kasirajan V, Han FT, Khan MZ, Wolfe L, et al. Long-term outcomes of minimally invasive surgical ablation for atrial fibrillation: a single-center experience. Heart Rhythm. 2017;14:1281–8.
83. Castellá M, Kotecha D, van Laar C, Wintgens L, Castillo Y, Kelder J, et al. Thoracoscopic vs. catheter ablation for atrial fibrillation: long-term follow-up of the FAST randomized trial. Europace. 2019;21:746–53.
84. Pokushalov E, Romanov A, Elesin D, Bogachev-Prokophiev A, Losik D, Bairamova S, et al. Catheter versus surgical ablation of atrial fibrillation after a failed initial pulmonary vein isolation procedure: a randomized controlled trial. J Cardiovasc Electrophysiol. 2013;24:1338–43.
85. Adiyaman A, Buist TJ, Beukema RJ, Smit JJJ, Delnoy PPHM, Hemels MEW, et al. Randomized controlled trial of surgical versus catheter ablation for paroxysmal and early persistent atrial fibrillation. Circ Arrhythm Electrophysiol. 2018;11:e006182. https://doi.org/10.1161/CIRCEP.118.006182
86. Haldar S, Khan HR, Boyalla V, Kralj-Hans I, Jones S, Lord J, et al. Catheter ablation vs. thoracoscopic surgical ablation in long-standing persistent atrial fibrillation: CASA-AF randomized controlled trial. Eur Heart J. 2020;41:4471–80.
87. Kim J, Kim JY, Jeong DS, Chung TW, Park SJ, Park KM, et al. Long-term outcome of thoracoscopic ablation and radiofrequency catheter ablation for persistent atrial fibrillation as a de novo procedure. Europace. 2023;25:euad096. https://doi.org/10.1093/europace/euad096
88. Je HG, Shuman DJ, Ad N. A systematic review of minimally invasive surgical treatment for atrial fibrillation: a comparison of the Cox-maze procedure, beating-heart epicardial ablation, and the hybrid procedure on safety and efficacy. Eur J Cardiothorac Surg. 2015;48:531–40.
89. Kiser AC, Landers M, Horton R, Hume A, Natale A, Gersak B. The convergent procedure: a multidisciplinary atrial fibrillation treatment. Heart Surg Forum. 2010;13:E317–21.
90. DeLurgio DB, Crossen KJ, Gill J, Blauth C, Oza SR, Magnano AR, et al. Hybrid convergent procedure for the treatment of persistent and long-standing persistent atrial fibrillation: results of CONVERGE clinical trial. Circ Arrhythm Electrophysiol. 2020;13:e009288. https://doi.org/10.1161/CIRCEP.120.009288
91. Dunnington GH, Pierce CL, Eisenberg S, Bing LL, Chang-Sing P, Kaiser DW, et al. A heart-team hybrid approach for atrial fibrillation: a single-centre long-term clinical outcome cohort study. Eur J Cardiothorac Surg. 2021;60:1343–50.
92. Roberts HG, Wei LM, Dhamija A, Cook CC, Badhwar V. Robotic assisted cryothermic biatrial Cox-maze. J Cardiovasc Electrophysiol. 2021;32:2879–83.
93. Kuo CC, Chang HH, Hsing CH, Hii HP, Wu NC, Hsu CM, et al. Robotic mitral valve replacements with bioprosthetic valves in 52 patients: experience from a tertiary referral hospital. Eur J Cardiothorac Surg. 2018;54:853–9.
94. Henry L, Ad N. The surgical treatment for atrial fibrillation: ablation technology and surgical approaches. Rambam Maimonides Med J. 2013;4(3):e0021. https://doi.org/10.5041/RMMJ.10121
95. Ad N, Suri RM, Gammie JS, Sheng S, O'Brien SM, Henry L. Surgical ablation of atrial fibrillation trends and outcomes in North America. J Thorac Cardiovasc Surg. 2012;144:1051–60.
96. Blackshear JL, Odell JA. Appendage obliteration to reduce stroke in cardiac surgical patients with atrial fibrillation. Ann Thorac Surg. 1996;61:755–9.
97. Hassan K, Bayer N, Schlingloff F, Oberhoffer M, Wohlmuth P, Schmoeckel M, et al. Bleeding complications after use of novel oral anticoagulants in patients undergoing cardiac surgery. Ann Thorac Surg. 2018;105:702–8.
98. Madden JL. Resection of the left auricular appendix; a prophylaxis for recurrent arterial emboli. JAMA. 1949;140:769–72.
99. Friedman DJ, Piccini JP, Wang T, Zheng J, Malaisrie SC, Holmes DR, et al. Association between left atrial appendage occlusion and readmission for thromboembolism among patients with atrial fibrillation undergoing concomitant cardiac surgery. JAMA. 2018;319:365–74.
100. Whitlock RP, Belley-Cote EP, Paparella D, Healey JS, Brady K, Sharma M, et al. Left atrial appendage occlusion during cardiac surgery to prevent stroke. N Engl J Med. 2021;384:2081–91.
101. Saint LL, Damiano RJ Jr, Cuculich PS, Guthrie TJ, Moon MR, Munfakh NA, et al. Incremental risk of the Cox-maze IV procedure for patients with atrial fibrillation undergoing mitral valve surgery. J Thorac Cardiovasc Surg. 2013;146:1072–7.
102. Böning A, Diegeler A, Hilker M, Zacher M, Reents W, Faerber G, et al. Preoperative atrial fibrillation and outcome in patients undergoing on-pump or off-pump coronary bypass surgery: lessons learned from the GOPCABE trial. Interact Cardiovasc Thorac Surg. 2015;20:74–8.
103. Lee R, Nitta T, Schuessler RB, Johnson DC, Boineau JP, Cox JL. The closed heart MAZE: a nonbypass surgical technique. Ann Thorac Surg. 1999;67:1696–702.
104. Ninet J, Roques X, Seitelberger R, Deville C, Pomar JL, Robin J, et al. Surgical ablation of atrial fibrillation with off-pump, epicardial, high-intensity focused ultrasound: results of a multicenter trial. J Thorac Cardiovasc Surg. 2005;130:803–9.
105. Melduni RM, Schaff HV, Lee HC, Gersh BJ, Noseworthy PA, Bailey KR, et al. Impact of left atrial appendage closure during cardiac surgery on the occurrence of early postoperative atrial fibrillation, stroke, and mortality: a propensity score-matched analysis of 10 633 patients. Circulation. 2017;24:366–78.

106. Yao X, Gersh BJ, Holmes DR Jr, Melduni RM, Johnsrud DO, Sangaralingham LR, et al. Association of surgical left atrial appendage occlusion with subsequent stroke and mortality among patients undergoing cardiac surgery. JAMA. 2018;319:2116–26.
107. Park-Hansen J, Holme SJV, Irmukhamedov A, Carranza CL, Greve AM, Al-Farra G, et al. Adding left atrial appendage closure to open heart surgery provides protection from ischemic brain injury six years after surgery independently of atrial fibrillation history: the LAACS randomized study. J Cardiothorac Surg. 2018;13:53.
108. Reddy VY, Sievert H, Halperin J, Doshi SK, Buchbinder M, Neuzil P, et al. Percutaneous left atrial appendage closure vs warfarin for atrial fibrillation a randomized clinical trial. JAMA. 2014;312:1988–98.
109. Holmes DR Jr, Kar S, Price MJ, Whisenant B, Sievert H, Doshi SK, et al. Prospective randomized evaluation of the watchman left atrial appendage closure device in patients with atrial fibrillation versus long-term warfarin therapy: the PREVAIL trial. J Am Coll Cardiol. 2014;64:1–12.
110. Simard T, Jung RG, Lehenbauer K, Piayda K, Pracoń R, Jackson GG, et al. Predictors of device-related thrombus following percutaneous left atrial appendage occlusion. J Am Coll Cardiol. 2021;78:297–313.
111. Katz E, Tsiamtsiouris T, Applebaum R, Schwartzbard A, Tunick PA, Kronzon I. Surgical left atrial appendage ligation is frequently incomplete: a transesophageal echocardiographic study. J Am Coll Cardiol. 2000;36:468–71.
112. Aryana A, Singh SK, Singh SM, O'Neill PG, Bowers MR, Allen SL, et al. Association between incomplete surgical ligation of left atrial appendage and stroke and systemic embolization. Heart Rhythm. 2015;12:1431–7.
113. Cullen MW, Stulak JM, Li Z, Powell BD, White RD, Ammash NM, et al. Left atrial appendage patency at cardioversion after surgical left atrial appendage intervention. Ann Thorac Surg. 2016;101:675–81.
114. Lee R, Vassallo P, Kruse J, Malaisrie SC, Rigolin V, Andrei AC, et al. A randomized, prospective pilot comparison of 3 atrial appendage elimination techniques: internal ligation, stapled excision, and surgical excision. J Thorac Cardiovasc Surg. 2016;152:1075–80.
115. Badhwar V, Scott Rankin J, Lee R, McCarthy PM, Wei LM. Contemporary left atrial appendage management during adult cardiac surgery. J Thorac Cardiovasc Surg. 2023;1(4):1398–404. https://doi.org/10.1016/j.jtcvs.2022.02.029
116. Ailawadi G, Gerdisch MW, Harvey RL, Hooker RL, Damiano RJ Jr, Salamon T, et al. Exclusion of the left atrial appendage with a novel device: early results of a multicenter trial. J Thorac Cardiovasc Surg. 2011;142:1002–9.
117. Rosati F, de Maat GE, Valente MAE, Mariani MA, Benussi S. Surgical clip closure of the left atrial appendage. J Cardiovasc Electrophysiol. 2021;32:2865–72.
118. Yoshimoto A, Suematsu Y, Kurahashi K, Kaneko H, Arima D, Nishi S. Early and middle-term results and anticoagulation strategy after left atrial appendage exclusion using an Epicardial clip device. Ann Thorac Cardiovasc Surg. 2021;20:185–90.
119. Ohtsuka T, Ninomiya M, Nonaka T, Hisagi M, Ota T, Mizutani T. Thoracoscopic stand-alone left atrial appendectomy for thromboembolism prevention in nonvalvular atrial fibrillation. J Am Coll Cardiol. 2013;62:103–7.
120. Massumi A, Chelu MG, Nazeri A, May SA, Afshar-Kharaghan H, Saeed M, et al. Initial experience with a novel percutaneous left atrial appendage exclusion device in patients with atrial fibrillation, increased stroke risk, and contraindications to anticoagulation. Am J Cardiol. 2013;111:869–73.
121. Landmesser U, Schmidt B, Nielsen-Kudsk JE, Lam SCC, Park JW, Tarantini G, et al. Left atrial appendage occlusion with the AMPLATZER amulet device: periprocedural and early clinical/echocardiographic data from a global prospective observational study. EuroIntervention. 2017;13:867–76.
122. Ohtsuka T, Nonaka T, Hisagi M, Ninomiya M, Masukawa A, Ota T. Thoracoscopic stapler-and-loop technique for left atrial appendage closure in nonvalvular atrial fibrillation: mid-term outcomes in 201 patients. Heart Rhythm. 2018;15:1314–20.
123. Kim JY, Jeong DS, Park SJ, Park KM, Kim JS, On YK. Long-term efficacy and anticoagulation strategy of left atrial appendage occlusion during total thoracoscopic ablation of atrial fibrillation to prevent ischemic stroke. Front Cardiovasc Med. 2022;31(9):853299. https://doi.org/10.3389/fcvm.2022.853299
124. Emmert MY, Puippe G, Baumüller S, Alkadhi H, Landmesser U, Plass A, et al. Safe, effective and durable epicardial left atrial appendage clip occlusion in patients with atrial fibrillation undergoing cardiac surgery: first long-term results from a prospective device trial. Eur J Cardiothorac Surg. 2014;45:126–31.
125. Branzoli S, Marini M, Guarracini F, Pederzolli C, Pomarolli C, D'Onghia G, et al. Epicardial standalone left atrial appendage clipping for prevention of ischemic stroke in patients with atrial fibrillation contraindicated for oral anticoagulation. J Cardiovasc Electrophysiol. 2020;31:2187–91.
126. Branzoli S, Guarracini F, Marini M, D'Onghia G, Penzo D, Piffer S, et al. Heart team for left atrial appendage occlusion: a patient-tailored approach. J Clin Med. 2021;11:176.

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APPENDIX

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