Practical Approaches to Concomitant Surgical Ablation of Atrial Fibrillation: Matching the Ablation to the Patient

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Central Picture:

Central Picture Legend:
The CryoMaze-III lesion set is efficient and effective with mitral valve surgery.

Central Message:
A variety of tools, lesion sets, and goals are appropriate to treat AF and the left atrial appendage concomitant to other cardiac surgeries. We present options to suit several clinical situations.

Perspective statement:
Studies have shown that concomitant surgical ablation and left atrial appendage closure improve late survival and reduce stroke in patients with pre-operative AF. We offer practical approaches for various clinical scenarios to minimize peri-operative risk and achieve high effectiveness. Lesions sets, technologies, and goals of therapy should match the patient.

Key words:
Surgical ablation; atrial fibrillation; Left atrial appendage occlusion

Introduction
Atrial Fibrillation (AF) is common before cardiac surgery, especially for older patients and when
the left atrium is enlarged such as with mitral valve (MV) operations. The frequency of AF
before concomitant operations in a Medicare population was 28.4%. In the STS database,
which includes younger patients, it was 13.4%. AF places the patient at increased late risk for
stroke, heart failure, rehospitalization, and death. Fortunately, the surgeon can address these
late complications at the same time as most other cardiac operations. The randomized LAAOS
III trial of 4,770 AF patients who had a CHA₂DS₂-VASc score of at least 2 showed a 33%
reduction in late stroke or systemic embolism for the group of patients with preexisting AF who
had concomitant surgical left atrial appendage occlusion (S-LAAO) when compared to the
control group who did not have LAA closure. This contributed to a Class I Level of Evidence A
Guideline in the 2023 American Heart Association/American College of Cardiology AF
Guidelines and in the 2023 STS Guidelines. Several small randomized trials in patients with
preoperative AF demonstrated reduced late AF with surgical ablation (SA) compared to
untreated controls. But the short follow-up and small numbers of patients did not allow
meaningful comparison of late clinical outcomes such as stroke or death. However, large
matched single center, multi center, registry, and Medicare studies have shown improved late
survival for AF patients who had concomitant SA compared to patients with no ablation and
these recent studies are included in the 2023 STS Guidelines.

The data supporting concomitant AF ablation and LAAO are clear. But despite a Class I
indication, concomitant SA is not performed often (22% in the Medicare population and 48.3% in
the STS database). The obstacles to concomitant ablation include the perception of greatly
increased cross clamp and cardiopulmonary bypass time; the complexity of many lesion sets;
and risks such as renal dysfunction and increased need for a permanent pacemaker
(PPM). The benefits of a perfect, complete, highly-effective SA operation have to be
balanced with the reality of adding risk in complex surgical procedures in patients with co-
morbidities.
This paper summarizes our pragmatic approach to a variety of operations and factors that we consider in the risk/benefit decision (Figure 1). We try to offer the benefits of ablation and S-LAAO to as many patients as we can, including 100% of mitral operations. We strive for high efficacy, but do not deny SA to patients with risk factors for failure (such as long AF duration or enlarged atria) even though including such patients may reduce our reported efficacy. We focus on achieving 30-day safety and optimal late survival and freedom from stroke. Numerous randomized trials have uniformly, convincingly, and unequivocally demonstrated that AF patients have a higher late return to sinus rhythm with concomitant ablation than those whose AF is untreated. Therefore, in this paper we focus on minimizing the 30-day risk of adding ablation, and maximizing the late benefits of improved survival and freedom from stroke as discussed in the most recent STS Guidelines concerning concomitant AF ablation. Both STS and AHA Guidelines recognize the benefits of concomitant LAAO which is a Class I Recommendation, LOE A.5,6

Left Atrial Appendage Occlusion Should be Considered in All Patients with Preoperative AF

S-LAAO should be performed in as many patients with pre-operative AF as possible.4,19 We prefer a Clip due to the ease of use, safety, and reliability. After the LA is opened the LAA is empty, so no Clip measuring tool is necessary; we use a 35mm Clip in all patients. We don’t divide the Ligament of Marshall as it is not necessary to place the Clip at the base of the LAA. The surgeon lifts the heart, places the Clip with an assistant’s help, visually confirms there is no impingement of the Circumflex artery and the Clip is near the LAA base, the assistant cuts the suture, the surgeon removes the Clip holder, then places the heart back in the pericardium (Video 1). The Clip electrically isolates the LAA so the additional ablation line into the LAA used in the CM III and CM IV lesion set is eliminated.20 Recently we began timing how long it takes to place a Clip on the LAA and it can easily be done in less than 2 minutes. It is simple. The
“learning curve” should be 5 procedures or less. Technically there is no reason to omit this procedure, except in reoperations or extensive pericarditis in which adhesions may make this impossible (example, patent LIMA-LAD). Surgeons should recognize that the magnitude of the patient benefit is similar to our one quality metric involving a procedure, LIMA-LAD grafting, but with a small fraction of the effort. There is no other procedure in cardiac surgery with the high safety and effectiveness of Clip placement that takes less than 2 minutes and reduces the patients late stroke risk by 33%. But excision is another option. Suture and staple closure have been successful for some surgeons, but in most reports have been associated with a significant rate of incomplete closure or residual LAA stump over 10mm. Complete internal closure with two layers of occlusion has been reported by Badhwar. S-LAAO with surgical ablation increases late survival more than just S-LAAO alone, so both should be performed for the best late outcome.

Surgical Ablation with the Left Atrium Open (mitral valve operations)

The most common concomitant surgical ablation is performed with mitral valve surgery. For mitral surgery we aim to occlude the LAA, and perform an ablation that creates a “box lesion” encompassing all 4 pulmonary veins and the posterior LA wall, and mitral isthmus and coronary sinus ablation to prevent peri-mitral flutter that can be very symptomatic (Figure 1).

Today there are several lesion sets and technologies used in SA. Cryoablation, alone or in combination with bipolar radiofrequency, is a fundamental technology. Our preferred approach is the CryoMaze III procedure. Step one: the LA is opened and we “clip” the LAA (Figure 2), which electrically isolates the LAA. Step two: the box lesion is created with two applications of the disposable cryoprobe (3-minute freezes for each ablation line) when using the CryoFlex™ probe. This probe is longer than other commercial probes and is almost always able to accomplish these lesions with two applications, whereas shorter probes may require a third application to complete the box. The probe is placed across the base of the LAA (Figure 3A).
The second application of the probe includes a bend that creates the mitral isthmus line. Step three: a short segment of cryoablation is also applied on the epicardial surface of the coronary sinus (two-minute freeze). The LAA clip and 3 ablations recreate the essential lesions of the Cox Maze III procedure (the box lesion, LAA lesion, mitral isthmus line, and coronary sinus ablation).

To achieve successful transmural cryoablation there are certain tips and tricks to keep in mind. The cryo lines must overlap without a gap. With the CryoMaze III lesion set there is only one overlapping line, where the second box line overlaps the first line (approximately at P2). A short period (< 60 seconds) of thawing the first line may help the second line to cross and continue to the mitral annulus. Occasionally a small gap (typically from a small fold of atrial tissue) is identified when the probe is thawed and removed. In this case an additional freeze needs to be placed to fill in the gap and complete the line. The ablations must be transmural. Good contact of the probe can be assured by pushing the probe against the tissue with pickups or the sucker tip, and/or pushing atrial tissue against the probe. Two minutes of cryoablation may not have been sufficient to create a transmural freeze for thick left atrial tissue as we found in our earliest experience with the two-minute box lesion. We switched from a 2-minute freeze to a 3-minute box ablation in 2018. Endocardial RA lesions through thick Crista Terminalis tissue may not demonstrate an epicardial ice ball. The Crista Terminalis can be more than 1 cm thick (Video 1). We add epicardial cryoablation (typically 60 seconds) when needed over the Crista Terminalis and anywhere else we suspect may not be transmural.

The SA lesion set may be limited to the left atrium (LA only), or both left and right atrium (biatrial, or BA, lesion set). There are also three cryoablation lines in the right atrium to complete a biatrial lesion set typically using 2-minute freezes for each (on the thick Crista Terminalis an additional epicardial ablation may be needed). First, cryoablation extends from the atriotomy to the tricuspid annulus, second, from the atriotomy to the inferior vena cava and third to the
superior vena cava (Figure 3B). It’s important to avoid the atrial pacemaker complex which may lead to sinus node dysfunction. The technique has been described in entirety. The results have been equal to other series of mitral valve/maze surgery, but because it is quicker it has been applied far more often than the STS database and other reports. The CryoMaze III was performed in 100% of mitral valve patients since 2013; only 0.7% of the patients needed a new pacemaker, there was no increase in renal dysfunction, late freedom from stroke was 98.3%, and survival returned to that of a normal age and sex matched population. Updating that 2022 publication, since 2018 with a standardized 3 minute box cryoablation, the procedure has a 92% 12 month, 89% 24 month, and 82% 36-month freedom from atrial fibrillation off antiarrhythmics (Follow-up as of January 2024).

There is controversy about using left atrial only ablation vs. biatrial ablation (Figure 1). It’s important to consider the pathophysiology of a patient undergoing concomitant mitral surgery and ablation. Cardioplegia is the most effective antiarrhythmic there is and induces electrical atrial silence. The consequences of mitral disease (pressure and volume overload) are eliminated by successful mitral surgery. In randomized trials even the control groups with long standing persistent AF have a notable success rate of approximately 25% without ablation. Adding the box lesion and other LA lesions decreases the chance of AF recurrence after the cross clamp is removed. Most of our patients therefore undergo only left atrial ablation because contemporary guidelines direct early referral for mitral surgery before the onset of right heart involvement such as tricuspid regurgitation and right atrial enlargement; and most only have paroxysmal AF. LA only ablation is highly effective in such patients. Meta-analyses indicate adding the RA lesion set to create biatrial lesions is associated with the need for a PPM. Several caveats however; pre-op sinus node dysfunction can be present in some patients, surgeons may have inadvertently made incisions or ablations through the atrial pacemaker complex, and in many studies AV node dysfunction is the cause for pacemakers. Maze surgery does not anatomically come near the AV node and surrounding structure and AV node injury is
more likely related to the valve operation (TV, AV, or MV replacement). In general BA ablation will provide a higher late freedom from AF and therefore is warranted in many patients especially those with long standing persistent AF. Finally, in the unusual case that a patient develops AF (or flutter) from a right atrial location after successful MV surgery and LA ablation, then late right side catheter ablation of the cavitricuspid isthmus is straightforward, safe, and should be highly effective. We typically add a biatrial lesion set in certain subgroups of patients such as those with tricuspid regurgitation who undergo tricuspid annuloplasty, a dilated Right Atrium (RA), and a long duration of AF. RA lesions are typically added with tricuspid valve annuloplasty. We routinely perform mitral surgery and Maze surgery via a small 10 cm incision sternotomy, but right thoracotomy approaches using cryoablation have been described with a thoracoscope, or using robotics.

The “cut and sew” Cox-Maze III lesions were reproduced using a combination of bipolar radiofrequency and cryoablation and are referred to as the Cox-Maze IV. Results are also very good and this lesion set was used to obtain Federal Drug Administration labelling for the bipolar RF (radiofrequency) clamps. There are several differences compared to the CryoMaze III we describe. Bipolar RF clamps require epicardial dissection around the pulmonary veins and the dome of the left atrium which adds time. This step is very difficult in reoperations (as discussed below). There are many more applications of the clamp with multiple ablations per application, so it takes significantly more bypass time. Finally, the CM IV requires two disposable devices, bipolar RF and cryoablation, which adds to the cost.

Ablation Options for Closed Left Atrium Operations (CAB; AVR; Aneurysm)

For patients undergoing operations such as CABG and/or AVR that do not include mandatory opening of the LA there are several options (Figure 1). Again, the Left Atrial Appendage should be closed in these patients whenever possible. Which lesion set and technology depends on three main factors: the surgeons experience, patient characteristics including comorbidities
(especially renal function) and age; and on the type of AF. A limited lesion set provides better
success for paroxysmal AF than for long standing persistent AF. An inexperienced surgeon may
be more comfortable with only bilateral pulmonary vein isolation (PVI) using a bipolar RF clamp.
While we would prefer surgeons perform more extensive ablation, bilateral PVI is “better than
nothing”. With a little experience bilateral PVI can be reliably accomplished with about 10-15
minutes of additional cardiopulmonary bypass (CPB) time. It is important to note that effective
transmurality with an RF clamp requires dissection of the epicardial fat pad and 2 successive
ablation applications or “doublets” without unclamping the device. These applications are
typically repeated several times. A new bipolar RF clamp is commercially available and allows a
Box Lesion performed on CPB (Figure 4). When added to a LAA Clip which electrically isolates
the LAA (there should be no gap between the box lesion and LAA clip) then the only LA lesions
from the Cox-Maze III not performed are the mitral annular line and coronary sinus lesion. There
are no significant clinical reports of the effectiveness of this device and lesion set as of this
writing.

Bilateral PVI may be appropriate for patient factors, such as paroxysmal AF in patients with
significant comorbidities that increase surgical risk. For patients with long standing persistent
AF and no significant medical comorbidities it is a viable option to open the LA and perform the
CryoMaze III, as above, depending on the surgeon’s experience. It is also reasonable to open
the RA and perform a complete Biatrial lesion set. The data would indicate this is not performed
often however as concomitant SA is performed in a low percentage of patients who do not need
the LA opened. For instance, a recent STS report indicated that concomitant ablation was
only performed in 33% of patients undergoing surgical aortic valve replacement. The database
information is not detailed enough in this group to give precise reports about how many SA are
PVI only vs. LA only vs. a Biatrial lesion set.

Reoperations
Adhesions, especially patent bypass grafts, alters our approach (Fig 1). A patent Left IMA to LAD changes the safety and wisdom of epicardial S-LAAO. Similarly, epicardial bilateral PVI may be fraught and would add a considerable amount of CPB time. For most patients our preferred approach is to dissect out the right side of the heart and open the left atrium. This allows the surgeon to internally close the LAA, according to the technique recently described.\textsuperscript{19} Cryoablation can then be used to perform the CryoMaze III lesions above (Figure 3A, B). It’s a judgement by the surgeon to decide if RA lesions are added to create a Biatrial ablation. In the situation of a complex reoperation that does not otherwise need the RA opened we rarely do that. The Cox Maze IV using epicardial bipolar RF clamps requires extensive dissection of adhesions and we have avoided using this procedure in reoperations.

Judgement: the role of clinical setting and surgeon experience

The data supporting concomitant closure of the LAA, and performing surgical ablation is solid and demonstrates, not just statistically significant, but major clinically significant benefits for our patients. It’s a clear opportunity to reduce a patient’s long-term risk of stroke and to increase survival. LAAOS III demonstrated the safety of LAA occlusion as well. As a society of surgeons, we should explore why these techniques are used so infrequently.\textsuperscript{16} There are many potential reasons.\textsuperscript{16} Surgeons used to say that the data were not clear that there are clinical benefits. “Judgement reflects decisions based in insufficient data” is attributed to Dr. John Kirklin. The randomized trials, including the CTS Net Trial, were underpowered and not followed long enough to demonstrate an improvement in stroke and survival. They were designed to show an improved return of sinus rhythm, which they uniformly accomplished. Skeptical surgeons who did not want to add the time and risk to add SA said there was not good evidence to “make the EKG look better.” There is copious evidence now supporting stroke and survival benefits and this is well covered in the 2023 STS Guidelines.\textsuperscript{6}
What risks are increased by concomitant ablation, and how can they be managed? The STS database, and single center studies have shown an increase in renal dysfunction, and the database and the Cardiothoracic Surgery Network Trial showed a significant increase in need for a new pacemaker. Understandably, surgeons are risk averse in our current climate of public reporting of 30-day outcomes. When the CryoMaze III was developed we sought to shorten the cross clamp and bypass time as much as possible to reduce the risk of renal dysfunction yet maintain the Maze III lesions to continue with high efficacy. In our study, adding the modified CryoMaze-III procedure increased the average cross clamp time by only 10.5 minutes and the average CPB time by only 13.4 minutes compared to patients without AF who did not have SA and LAAO. There was no increase in renal dysfunction which can be caused by extended CPB time. Due to our referral population of patients with little RA dilation and dysfunction, the LA only lesion set provided high effectiveness. Biatrial lesions were only used in 20%, therefore. With selective use of the RA lesions and avoiding the APC we only used new pacemakers in 0.7% of mitral/CryoMaze III patients including long standing persistent AF patients with biatrial lesions. Therefore adding ablation to mitral surgery can be efficient, effective and safe. But, as with all procedures, surgeons need to use judgement in certain patients with renal dysfunction, conduction system disease, comorbidities, reoperations, and the elderly. Also, the judgement has to be guided by the surgeons’ experience with the technologies and procedures. Surgeon experience is the most important factor influencing judgement. Experienced surgeons can quickly and safely close the LAA and add SA.

In the 30+ years since the first Maze operations there have been a confusing number of lesion sets, technologies, and opinions about which is the “best” approach. Some advocate for a one size fits all approach; a Cox Maze IV procedure or do nothing. Others do little more than bilateral PVI. Hopefully, after the publication of LAAOS III and new guidelines, all surgeons will perform LAA occlusion whenever possible. For new graduates or surgeons who have not had much exposure to surgical ablation and LAA occlusion devices there are surgical videos
(Video 1), hands on courses, seminars, industry, and society courses and proctors available that are good opportunities to learn how to approach the variety of patients we have to manage (Figure 1). LAAO and SA decrease stroke and improve late survival. If a surgeon cannot do the right operation, then referring the patient for treatment by a colleague experienced with AF intervention should be the next step. We hope that this manuscript helps address this educational gap in an important and evolving area of cardiac surgery.


24. McCarthy PM. Simple But Effective Modifications to the Cox Maze Procedure Using Only Cryoablation. Operative Techniques in Thoracic and Cardiovascular Surgery. 2023;


Figure 1. Decision making for concomitant atrial fibrillation treatment.

For patients undergoing mitral surgery it is easy, safe, and effective to add LAAO and LA ablation lesions including a box lesion that also crosses the LAA base, and mitral/coronary sinus lines. These can easily be added in reoperations when using a cryoprobe as little additional epicardial dissection is required for ablation. Right atrial lesions can be added depending on factors such as need for Tricuspid surgery, RA dilation, surgeon experience and patient factors.

When the Left atrium does not need to be opened for the concomitant procedure, then epicardial ablation such as bilateral PVI and the EnCompass™ bipolar RF clamp provide a simple way to create PVI or a box lesion. For surgeons experienced in open LA ablation it is reasonable to perform a CryoMaze III or Cox Maze IV, and we do this routinely. Reoperations make a Cox Maze IV unappealing, and experienced surgeons can consider the risk/benefits of a CryoMaze III. AF, atrial fibrillation; AVR, aortic valve replacement; BA, biatrial; CAB, coronary artery bypass; LA, left atrial; LAA, left atrial appendage; LAAO, left atrial appendage occlusion; LSP, long standing persistent; PAF, paroxysmal atrial fibrillation; PVI, pulmonary vein isolation; RH, right heart.
Figure 2. Left atrial appendage closure.

An epicardial clip is placed to occlude the left atrial appendage. Care is taken to apply the clip at the base of the LAA (keep the stump less than 10mm) but avoid the Circumflex coronary artery which is done with direct vision. We apply the clip when the LA is open as the LAA is decompressed and the clip is easy to apply. (Image used with permission, Atricure, Mason, OH)
Figure 3. The CryoMaze-III lesion set. A. Left atrial lesions are placed inside the LA on the endocardium with a cryoprobe using 2 sets of 3-minute freezes which isolates the pulmonary veins, ablates the left atrial appendage base, and crosses the mitral isthmus. A third line is applied epicardially on the coronary sinus through the oblique sinus (two-minute freeze). B. Right atrial lesions are depicted with dotted white lines to inferior and superior vena cava and avoid the atrial pacemaker complex (APC).
Figure 4. Epicardial Box Lesion: Atrium closed

A commercially available clamp (EnCompass™) is placed through the transverse and oblique sinuses and creates a box lesion encircling the pulmonary veins and posterior LA wall while on cardiopulmonary bypass. (Used with permission, Atricure, Mason, OH)
Video 1. The steps of the CryoMaze III procedure.\textsuperscript{18}
Concomitant Atrial Fibrillation Treatment Decision Making

- **Preop AF Mitral Surgery (LA open)**
  - Minimal Risk PAF or LSP
    - LAA Clip LA Maze or BA Maze
  - Increased Risk or PAF or No RH involvement
    - LAA Clip LA Only Maze

- **Preop AF CAB; AVR; Aneurysm (Non Atriotomy)**
  - Minimum Risk PAF or LSP
    - LAA Clip EnCompass™ or LA Maze or BA Maze
  - High Risk PAF or LSP
    - LAA Clip ± EnCompass™ or PVI
  - Reoperation PAF or LSP
    - Internal LAAO consider LA or BA CryoMaze III