Review Article

Surgical Treatment for Atrial Fibrillation: Where Do We Stand?

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Atrial fibrillation (AF) is a major health problem associated with considerable morbidity, mortality, and consumption of health resourses.[1-4] Although medical AF therapies remain a convenient option, they are plagued by limited long-term efficacy and high rates of adverse events.[5,6] Successful outcomes for radiofrequency catheter ablation (RCA) procedures, particularly in persistent and longstanding AF, appear scarce, with extensive and repeated ablation procedures required for these patients.[7-13] Besides, the association of AF with mitral valvular disease and other cardiac diseases is well known, and very often cardiothoracic surgeons encounter this arrhythmia preoperatively. However, despite adequate correction of valvular disease, AF is expected to persist if it remains untreated.[14-16] Due to the limitations of pharmacotherapy and RCA, surgical ablation of AF has gained increasing popularity, mainly for patients undergoing cardiac surgical procedures for mitral valve disease or congenital deformities. (An in-depth review of this subject has been published elsewhere).[17]

Evolution of open heart surgical procedures for AF treatment

Early attempts at surgical treatment of AF included procedures such as left atrial (LA) isolation[18] and the Corridor procedure.[19] These surgical techniques were able to restore a regular ventricular rhythm, but did not reduce the risk of thromboembolism, because the atria were left to fibrillate.

The concept of the "maze" procedure is to create lines surgically, leading to fractionation of the atrial tissue into smaller segments that would not allow multiple re-entrant wavelets to be maintained. The procedure has evolved over the last 20 years. The initial Maze I and Maze II procedures[20] were modified to the Maze III, which became the gold standard in treating surgically chronic AF since it was associated with a high (>90%) maintenance of sinus rhythm (SR), fewer pacemaker implantations, and a significant reduction in strokes.[21,22] The procedure overall includes *en bloc* isolation of the pulmonary veins (PVs) and posterior LA along with excision of the LA appendage, while the septal incision, contrary to the initial Maze procedures, is located posterior to the orifice of the superior *vena cava* (Figure 1).[23] The overall reported operative mortality (2% to 3%) was derived from patients who had undergone concomitant high-risk cardiac surgical procedures.[24] Despite its remarkable success, the procedure has not been widely adopted by surgeons, due to its complexity, technical difficulty and increased time on car-

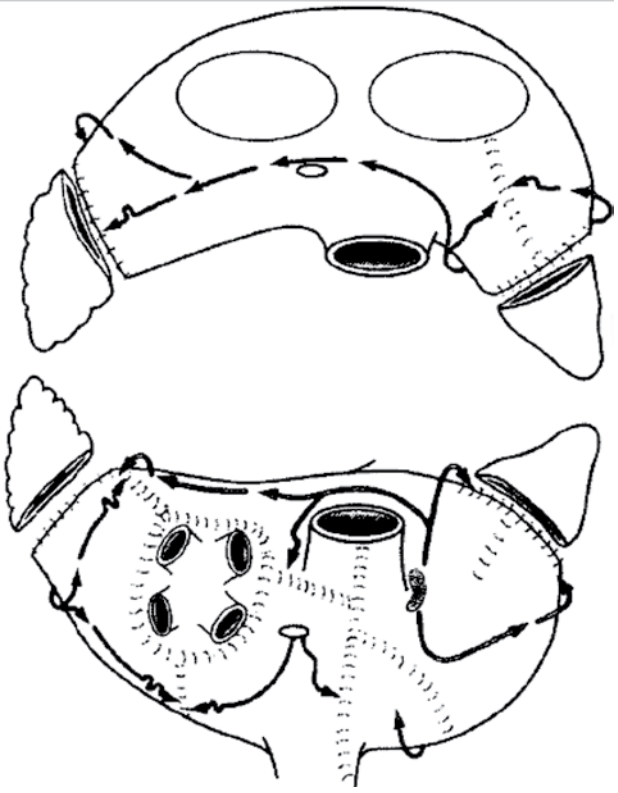

Figure 1. The traditional cut-and-sew Cox-Maze III procedure. (Reprinted with from Shen J et al[21] with permission from Elsevier.)

diopulmonary bypass. To simplify the Cox-Maze operation, the cut-and-sew lesions were replaced with lines of ablation using newer technologies, such as radiofrequency energy (RF), cryothermy energy, and microwave energy (Figure 2).[25-28] These changes reduced the time required to make the lesion set, leading to shorter operative times and less morbidity. Cox has also proposed a modified Cox-Maze procedure that consists of an incision encircling the PVs and a left and right atrial isthmus lesion along with a coronary sinus lesion (Figure 3).[29] The mini-Maze procedure has been shown to be nearly as effective as the full Cox-Maze III.[30] Nevertheless, although modified Maze procedures can be performed through a small right thoracotomy, they still require cardiopulmonary bypass.

Surgery for AF as adjunctive therapy in patients undergoing other cardiac operations

AF is a frequently encountered arrhythmia in patients undergoing various heart operations, while in patients undergoing mitral valve surgery AF may be present in up to 50%.[14-16] However, mitral valve surgery alone does not usually convert AF back into SR, particularly when the duration of AF preoperatively is longer than six months.[16,33]

A success rate between 65% and 95% was reported by a number of retrospective studies using a variety of surgical procedures for the treatment of AF with concomitant mitral or other cardiac operations.[34,35] In a meta-analysis of 9 randomised controlled trials, the Maze procedure, when performed in addition to cardiac surgery, was associated with a markedly increased freedom from AF at 12 months of follow up, without a significant increase in morbidity or mortality.[36] However, the Maze procedure proved to be much less effective (46-95%) when AF was associated with rheumatic valve disease, presumably because of the progressive rheumatic changes and remodelling of atrial tissue.[37,38]

Several studies have evaluated the success rate of the Maze operation using new ablation technologies in patients undergoing mitral valve replacement with chronic AF compared with mitral valve surgery alone. Most of these studies concluded that ablation in addition to valve surgery significantly increased the prevalence of sinus rhythm.[31,39,40] Cryoablation has been found safe and effective, mainly for the treatment of paroxysmal AF, with an SR restoration rate of 60% to 82% at 12-months post-surgery.[41] RF ablation has also reinstituted SR, in both chronic and paroxysmal AF, significantly more often in patients with the combined procedure after 12 months, with similar perioperative morbidity and survival rate in both groups.[31,39,42]

Minimally invasive approach for AF ablation

A minimally invasive approach is considered to be any approach requiring surgical incision other than median sternotomy (i.e. mini-thoracotomy, with either direct vision or thoracoscopy). Current efforts have been directed towards developing an epicardial approach to ablation in order to bring an effective and reasonable therapy to a larger number of patients, including those with standalone AF. This can be performed on a beating heart, preferably through small access incisions or ports. Three minimally invasive surgical technologies have been developed—robotics,[43] thoracoscopic,[43,44] and through mini-thoracotomy[45-47]—while the various strategies involve isolating the PVs either as a box or separately, with or

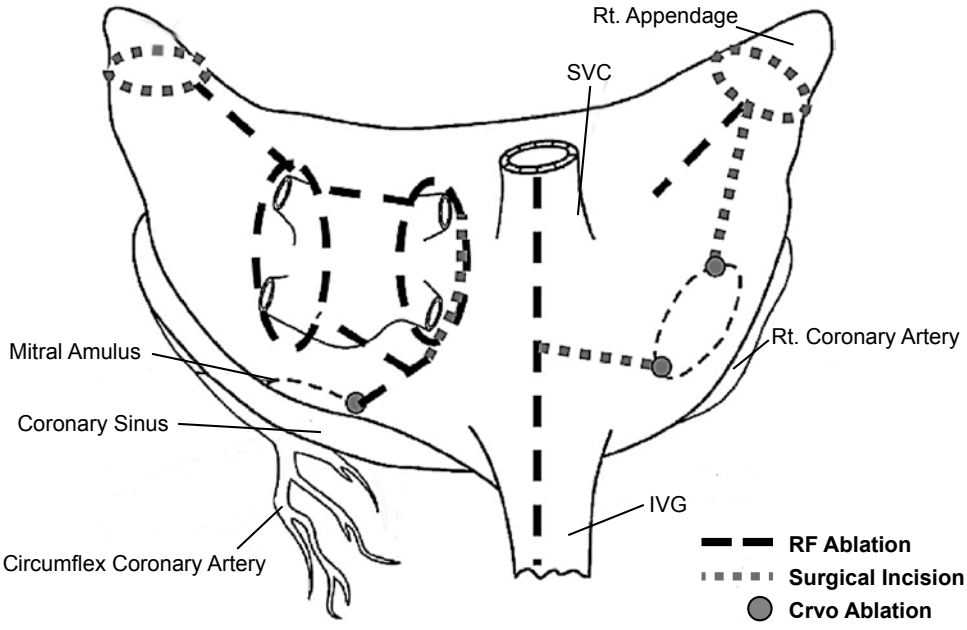

Figure 2. The Cox-Maze IV lesion set. The majority of lesions have been replaced with lines of ablation. IVC – inferior *vena cava*; RF – radiofrequency; SVC – superior *vena cava*. (Reprinted from Shen J et al[21] with permission from Elsevier.)

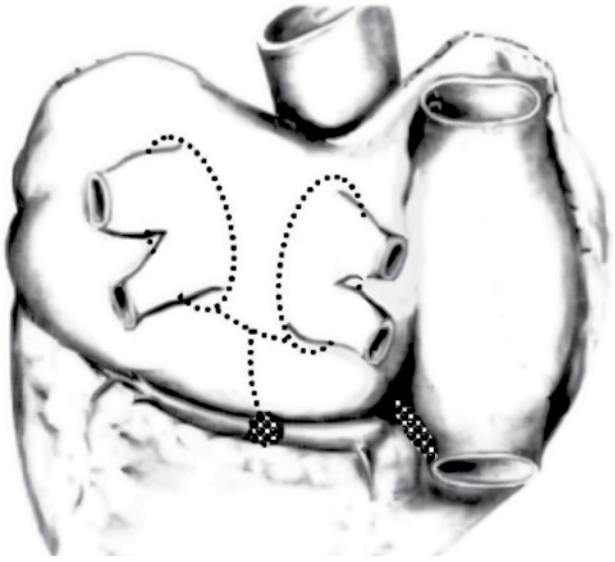

Figure 3. The mini-Maze procedure for atrial fibrillation. (Reprinted from Cox JL et al[29] by permission of Oxford University Press.)

without ablation of the ganglionated plexi (GP) and with or without additional ablation lines.

PVI may be accomplished using a single lesion encircling all PVs, or two lesions encompassing the left and right PVs. The good results of this approach (79.5% to 91% free from AF) refer essentially to patients with paroxysmal AF.[36,42] The complete procedure involves bilateral PVI, using bipolar RF and targeted partial autonomic denervation of the left atrium with selective left atrial appendectomy. A high success rate (85-90%) was reported for patients with paroxysmal AF, without any operative deaths or major adverse cardiac events.[48] The effectiveness, however, for persistent or permanent AF was generally limited, not exceeding a 30% freedom from arrhythmia in some studies at one-year follow up.[49-52]

The beneficial effects of adding LA ablation lines to PVI have been shown mainly in patients with persistent AF.[53] They consist of a superior line that connects the ablation lines encircling the right and left PVs, and an ablation line between the superior line and the left fibrous trigone. The reported procedure success rate at 1 year was 86% in a patient cohort of paroxysmal (52%), persistent (42%), and long-standing persistent (6%) AF.[54] Boersma et al,[55] in a head-to head comparison of RCA and minimally invasive surgical ablation, showed surgical ablation to be superior to RCA (65.6% freedom from left atrial arrhythmia at 1 year vs. 36.5% for RCA), at the expense, however, of an increased adverse event rate for surgical ablation.

New energy sources for surgical ablation of atrial fibrillation

RF, cryoablation, high-intensity focused ultrasound, laser and microwave energy devices became alternatives in an attempt to move towards establishing less

invasive modifications of the Maze procedure. The new ablation technologies require small incisions or ports and can deliver epicardial lesions on the beating heart.[56] Although these new devices have revolutionised surgery for AF by reducing operation time, their principal limitation is the inability to create transmural lesions reliably on the beating heart. RF energy, one of the first energy sources to be used in the operating room for AF, can be delivered by either unipolar or bipolar electrodes. Bipolar RF has the advantage of creating transmural lesions, both on the arrested and the beating heart, without causing collateral injury.[57] Cryoablation appears to have the ability to destroy tissue by freezing instead of heating, preserving tissue architecture and collagen structure;[58] however, there is difficulty in creating lesions in the beating heart because of the cooling sink of the circulating blood volume.[59] Microwave ablation can reliably create transmural endocardial lesions and is less likely to result in char formation compared to RF. However, it is not capable of creating epicardial lesions on the beating heart and may cause collateral injury.[60,61] Laser technology also avoids surface charring; however, it may create collateral damage while data on its ability to create transmural lesions are still lacking.[62] Finally, ultrasound energy is a very promising technology, possessing the ability to create precise lesions without causing collateral injury. It can overcome the heat sink effect of the left atrial blood pool, allowing the creation of transmural lesions when delivered from the epicardial surface.[41,63]

In summary, among the new energy sources, bipolar RF devices and high intensity focused ultrasound appear as the most promising strategies for achieving reliable transmural lesions, on both the arrested and the beating heart, but clinical experience is insufficient. Although a meta-analysis of 16 studies showed postoperative SR rates with alternative energy sources comparable to those of Maze III (78.3% vs. 84.9%),[28] there is still a lack of adequate clinical data regarding the role of novel energy devices and sources in this setting.

Indications for surgical AF ablation

The decision to refer a patient with symptomatic, medically refractory AF for surgery in lieu of catheter ablation remains controversial, as there have been insufficient head-to-head comparisons of the outcomes of catheter and surgical ablation of AF.[55]

The new 2012 HRS/EHRA/ECAS Expert Consensus Statement on catheter and surgical ablation of AF suggests that all patients with symptomatic AF undergoing other cardiac surgery should be considered for AF ablation, provided that the operation is performed by an experienced surgeon. According to this statement,[64] the following are appropriate indications for the surgical ablation of AF:

A) Indications for concomitant surgical ablation of AF

1. Symptomatic AF (paroxysmal, persistent or longstanding persistent) refractory or intolerant to at least one Class 1 or 3 antiarrhythmic medication (IIa-C).
2. Symptomatic AF (paroxysmal, persistent) prior to initiation of antiarrhythmic drug therapy with a Class 1 or 3 antiarrhythmic agent. (IIa-C)
3. Symptomatic longstanding persistent AF prior to initiation of antiarrhythmic drug therapy with a Class 1 or 3 antiarrhythmic agent (IIb-C)

B) Indications for standalone surgical ablation of AF

Standalone AF surgery should be considered for symptomatic AF patients refractory or intolerant to at least one Class 1 or 3 antiarrhythmic medication who prefer a surgical approach or have failed one or more attempts at catheter ablation (IIb-C).

Conclusions

1. In patients undergoing cardiac surgery for mitral valve disease, concomitant ablation techniques using the Maze modifications, various targets, and alternative energy sources appear to be safe and effective in treating AF, especially in non-rheumatic disease.
2. Surgical treatment of AF with the modified Maze techniques is effective, but requires open heart surgery and cannot easily be justified in cases of standalone AF.
3. Minimally invasive epicardial ablation combining PVI, GP ablation, and LA lines have been tried with promising initial results. However, improvement in ablation technology appears essential for the widespread application of minimally invasive AF ablation.

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