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Surgical Treatment of Atrial Fibrillation

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Abstract

Atrial fibrillation (AF) is now commonly treated at the time of valvular heart surgery or coronary artery bypass grafting. Surgical ablation of AF, which is predicated upon the Maze procedure, includes creation of lines of conduction block and excision of the left atrial appendage. A full bi-atrial lesion set is associated with success in 80% to 95% of patients and virtually eliminates the risk of late stroke. A complex but safe operation, the classic cut-and-sew Maze procedure has been applied by relatively few surgeons. However, recent advances in understanding of the pathogenesis of AF and development of new ablation technologies enable surgeons to perform pulmonary vein isolation, create linear left and right atrial lesions, and remove the left atrial appendage rapidly and safely. Lesions are created under direct vision, minimizing the risk of damage to the pulmonary veins and adjacent mediastinal structures. Recently developed instrumentation now enables thoracoscopic and keyhole approaches, facilitating extension of epicardial AF ablation and excision of the left atrial appendage to patients with isolated AF and no other indication for cardiac surgery. In addition, novel devices designed specifically for minimally invasive epicardial exclusion of the left atrial appendage will broaden the range of treatment options for patients with AF, possibly eliminating the need for anticoagulation in selected patients.

Introduction

Background

Atrial fibrillation (AF) is common in patients presenting for management of valvular heart disease or coronary artery disease. Developed by Dr. James Cox, the classic Maze procedure is the predicate operation for ablation of AF; long-term data suggest that the Maze procedure eliminates AF in more than 90% of patients.[1-4] In spite of these unmatched results, the complexity and time associated with the Maze procedure have prevented widespread application by surgeons. Recently, however, there has been increased interest in surgical ablation of AF, fueled by technological advances and demonstration that the pulmonary veins and left atrium are the drivers of AF in most patients.[5] New ablation technologies enable surgeons to perform pulmonary vein isolation, create strategically-placed, linear left and right atrial lesions, and excise the left atrial appendage rapidly and safely.[6-12] Alternate energy sources used to create lines of conduction block and replace surgical incisions of the Maze procedure include radiofrequency, microwave, ultrasound, cryothermy, and laser.[6-12] Applied primarily in patients with valvular heart disease, procedures using these ablation technologies add 15 to 20 minutes to operative time

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and appear to cure AF in 70% to 85% of patients. In addition, recent adaptation of these ablation technologies for thoracoscopic and keyhole approaches now enables minimally invasive surgery in selected patients having stand-alone ablation. In this report, we will 1) Review surgical technique and results of the Maze procedure, 2) Describe new technologies and approaches for surgical AF ablation and, 3) Discuss the development of technology for minimally invasive epicardial ablation and ligation of the left atrial appendage.

The Maze Procedure

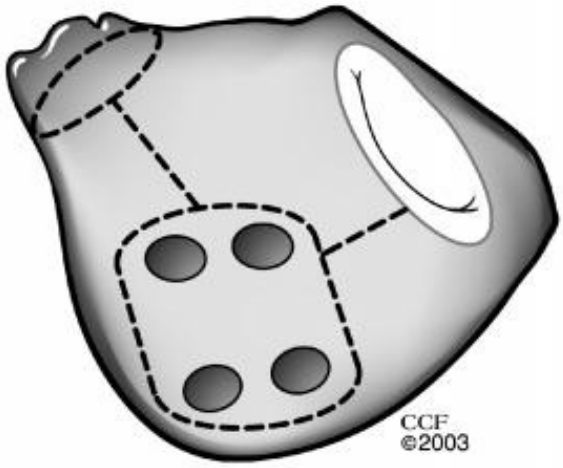
The Cox-Maze III operation, or Maze procedure, is the gold standard for surgical treatment of AF. In fact, it is the most effective curative therapy for AF yet devised, and it sets the standard for new surgical approaches to AF (1-4,13,14). Cox and colleagues designed the procedure based on early experimental and clinical evidence concerning the pathophysiology of AF (1-4). To improve results and simplify the operation, they modified the procedure twice, culminating in the Cox-Maze III.

The Maze procedure includes a complex, bi-atrial lesion set that is applied to all patients having the operation; therefore, it does not include an ablation strategy that is specifically tailored to individual patients[15-19] In the Maze procedure, right and left atrial incisions and cryolesions are constructed to interrupt the multiple, disorganized reentrant circuits that characterize AF (Figure 1). This is termed "cut-and-sew" technique. These lesions direct the sinus impulse from the sinoatrial node to the atrioventricular node along a specified route. Multiple "blind alleys" off this main conduction pathway (the Maze analogy) facilitate coordinated electrical activation of the atrial myocardium. Key components of the Maze procedure include isolation of the pulmonary veins and excision of the left atrial appendage. These features are maintained in most of the newer operations designed to ablate AF.

Although the Maze procedure can be completed minimally invasively through a small chest wall incision, the operation entails cardiopulmonary bypass and cardiac arrest. In experienced centers, the Maze procedure requires 45 to 60 minutes of cardiopulmonary bypass and cardiac arrest.[4,13,14] The operation may be performed alone or in conjunction with other cardiac surgical procedures, such as mitral valve repair or coronary artery bypass grafting.

Cox and colleagues[4] have reported the largest series of patients undergoing the Maze procedure.

Figure 1: Left atrial lesion set of the Cox-Maze III procedure. Schematic illustration of the posterior left atrium. White ovals represent mitral valve, and sets of 4 black ovals represent pulmonary veins. Dashed lines indicate surgical incisions. The pulmonary veins are encircled by a surgical incision, and there is a connecting incision to the mitral valve annulus. The left atrial appendage is excised, and this incision is connected to the pulmonary vein encircling incision.



Among 346 patients, operative mortality was 2%. Reported AF cure rate was 99%, and only 2% required long-term postoperative anti-arrhythmic medication.Of note, results were tabulated by calculating freedom from "symptomatic AF"; long-term rhythm monitoring was not employed. Therefore, these results likely over-state the effectiveness of the cut-and-sew Maze procedure. Successful ablation of AF was unaffected by presence of mitral valve disease, left atrial size, and type of AF (paroxysmal, persistent or permanent). Temporary postoperative AF, attributed to a shortened atrial refractory period, was common and did not diminish long-term results. Fifteen percent of patients required new pacemakers after surgery, and this was generally necessary in patients with underlying sinus node dysfunction. In spite of multiple right and left atrial incisions, right atrial transport function was demonstrated in 98% and left atrial transport in 93%. However, there is some controversy concerning the extent to which atrial mechanical function returns after surgical ablation. Perhaps most importantly, in addition to restoring sinus rhythm the Maze procedure virtually eliminated the risk of stroke or other thromboembolism.[20,21]

Other centers have documented excellent results with the Maze procedure, with restoration of sinus rhythm in 75% to 95% of patients, low risk of late stroke, and very low operative morbidity and mortality.[13,14,21] In recent series, the need for a new pacemaker has decreased to 5% to 10%.[22] These results confirm the safety of the Maze procedure, its efficacy at restoring sinus rhythm, and its prevention of late strokes. In spite of these findings, the Maze procedure has been relatively underutilized. Today, few patients are referred for a surgical Maze procedure for stand-alone AF ablation, and, even in patients requiring cardiac surgery for other reasons, surgeons are reluctant to add a Maze procedure. The perceived surgical complexity and magnitude of the operation account for these practices.

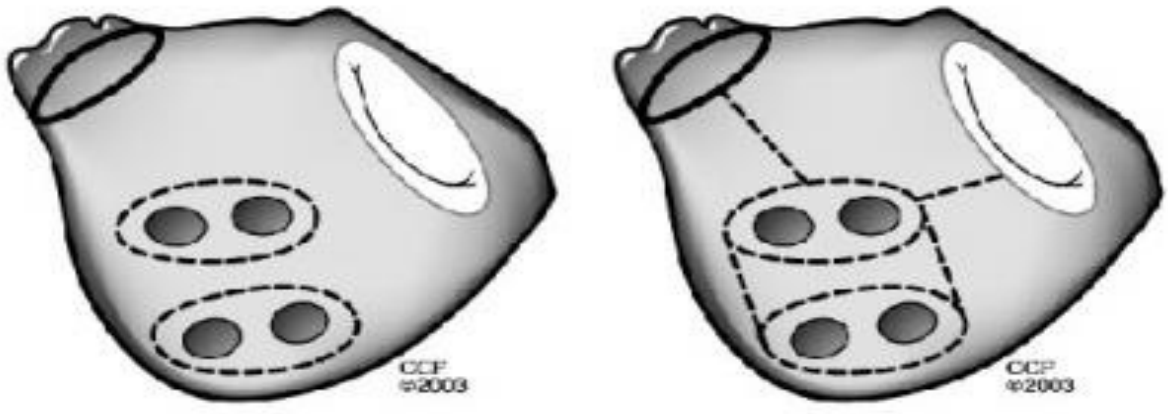
New Approaches for Surgical AF Ablation

The development of new surgical approaches to AF has been predicated upon 2 factors: 1) Recognition that the pulmonary veins and left atrium are critical to the initiation and maintenance of AF and 2) Development of ablation technologies that use alternate energy sources to facilitate rapid and safe creation of lines of conduction block under direct vision.

Lesion Sets

While the Maze procedure was designed to interrupt the multiple macro- reentrant circuits that characterize AF, new approaches are more precisely anatomically focused. There is general agree-

Figure 2: Left atrial lesion set of the Cox-Maze III procedure. Schematic illustration of the posterior left atrium. White ovals represent mitral valve, and sets of 4 black ovals represent pulmonary veins. Dashed lines indicate surgical incisions. The pulmonary veins are encircled by a surgical incision, and there is a connecting incision to the mitral valve annulus. The left atrial appendage is excised, and this incision is connected to the pulmonary vein encircling incision.



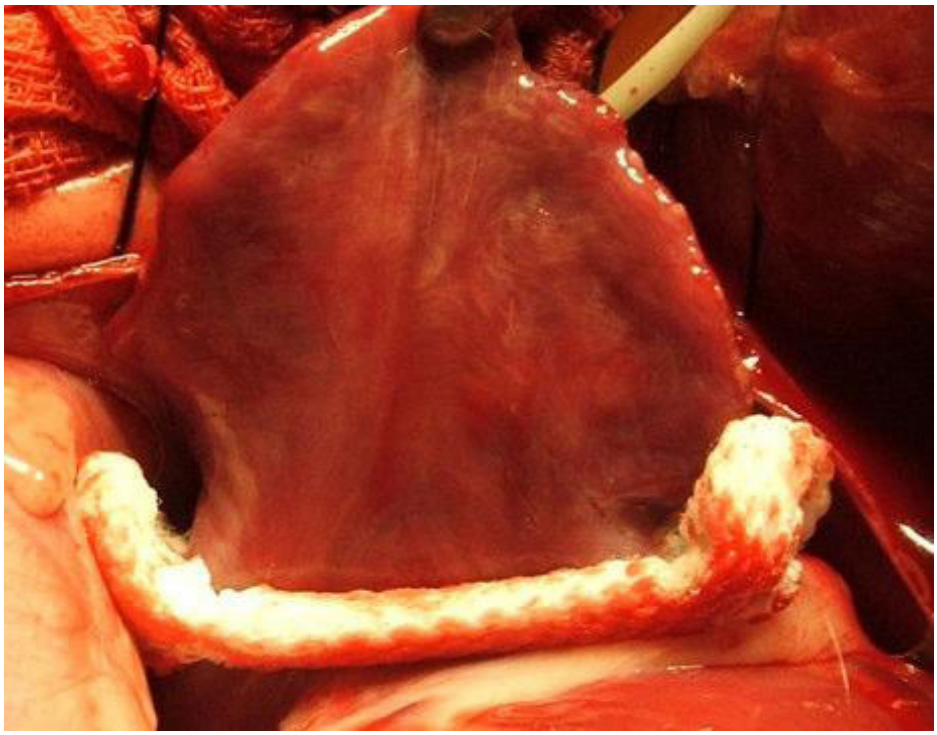
ment that AF requires a substrate and a trigger, and that these substrates and triggers are usually located in the pulmonary veins and left atrium.[23,24] Haissaguerre and colleagues (5) demonstrated that paroxysmal AF originates from ectopic beats in the pulmonary veins in 94% of cases. In addition, autonomic innervation of these regions may contribute to the pathogenesis of AF.[25] Catheter ablation of the posterior left atrium, including the antra surrounding the pulmonary veins, has proven effective at ablating both paroxysmal and permanent AF.[25,26] These data suggest that modification of the left atrial substrate, in combination with pulmonary vein isolation, is an effective therapy for all forms of AF. Surgeons have used alternate energy sources to create a variety of left atrial lesions sets, ranging from wide pulmonary vein isolation with excision of the left atrial appendage to a lesion set that resembles that of the Maze procedure (Figure 2). There is growing consensus that patients with persistent or long-standing persistent AF should receive a lesion set that incorporates more than simple pulmonary vein isolation.[27,28] In such patients, the lesion from the right pulmonary veins to the mitral annulus may be particularly important in prevention of post-procedure left atrial flutter.[29] The addition of right atrial lesions appears to increase freedom from recurrent AF and atrial flutter, but their importance is controversial (30). However, creation of right atrial lesions is simple and safe, and we currently favor their incorporation at the time of surgical ablation.

Ablation Technology

Based upon these advances in understanding of the pathophysiology of AF, a variety of new ablation tools have been developed to facilitate surgical ablation of AF. These probes and catheters rely on alternate energy sources to create long, continuous, linear lesions that block conduction. Energy sources that have been used clinically include radiofrequency, laser, ultrasound, microwave, and cryothermy .[10,11] Radiofrequency, laser, ultrasound and microwave are heat-based energy sources that create lines of conduction block through thermal injury. Each of these modalities can be employed for ablation during concomitant open heart surgery or, alternatively, for standalone, minimally invasive epicardial ablation.

Because the surgeon has the advantages of 1) direct visualization of cardiac structures and 2) catheters that facilitate rapid creation of transmural lesions, there is great interest in ablating AF in patients presenting for other cardiac surgical pro-

Figure 3: Left atrial appendage clip. A cloth-covered, nitinol and titanium clip has been applied to the epicardial aspect of a canine left atrial appendage.



cedures. Completion of left atrial lesion sets requires only 10 to 20 minutes. This amount of time contrasts with the 1 hour required to perform the traditional cut-and-sew Maze procedure. In addition, because incisions are replaced by heat- or cryo-based lesions, the risk of bleeding is virtually eliminated when alternate energy sources are employed.

Although approaches vary somewhat, results are similar with a variety of energy sources. AF is ablated in 70% to 80% of patients having concomitant heart surgery.[10,11] Thus far, most treated patients have had organic heart disease and have received a mitral valve procedure in addition to AF ablation. For them, results with alternate energy sources fall just short of those reported for the classic cut-and-sew Maze procedure.[31,32]

After surgical ablation, perioperative AF is common, occurring in approximately 50% of patients. Although 30% to 40% of patients leave the hospital in AF, many return to sinus rhythm over the ensuing 3 months. Thus, discharge in AF is not an indication of procedure failure.[33] Given the high incidence of perioperative AF, a strategy that includes 3 months of routine postoperative anti-arrhythmic therapy and anticoagulation in all patients is recommended. Because heart rhythm varies in the first 3 months after surgery, we recommend aggressive attempts to restore sinus rhythm during this time frame when patients develop AF or atrial flutter. Heart rhythm generally stabilizes by 3 to 6 months after surgery. Factors that influence procedure success include larger left atrial size, longer duration of AF, and choice of lesion set in permanent AF.[16,34,35]

Future directions: Minimally invasive stand-alone ablation

Open surgical treatment of AF has a long track record of success. The surgeon has the advantage of direct visualization of the left atrium and pulmonary veins, either from the epicardial or endocardial surface of the heart, and this factor, coupled with new ablation technology, enables rapid and safe ablation. Because the surgeon can see cardiac structures, ablation lines can be placed safely on the left atrial cuffs adjacent to the pulmonary vein orifices, thereby avoiding the dreaded complication of pulmonary vein stenosis. Epicardial ablation eliminates the risk of esophageal injury; however, there is uncertainty concerning the ability of unipolar energy sources to create continuous, transmural lesions from the epicardium of the beating heart. With surgical approaches, the left atrial appendage is excised, and this is likely important in decreasing the risk of late stroke. Finally, the simplicity of these techniques makes them generally applicable; all cardiac surgeons can now ablate AF. In current clinical practice, almost all patients with AF who present for cardiac surgery should have both AF ablation and the intended cardiac procedure. Using this experience as a spring-board, surgeons have developed epicardially-based, minimally invasive and thoracoscopic approaches to offer stand-alone AF ablation. While these procedures are currently in early stages of development and application, results are promising. Pulmonary vein isolation and excision of the left atrial appendage can be performed using a minimally invasive "keyhole approach" or thoracoscopically; neither approach requires cardiopulmonary bypass.[36-42] These minimally invasive procedures enable wide, circumferential pulmonary vein isolation, either with a single "box" lesion or separate oval-shaped ablations on the right and left. Connecting lesions across the dome of the left atrium and to the mitral annulus can now be created using specially-designed unipolar energy sources.[42] Procedure times are generally 2 to 4 hours, and median length of hospital stay is 3 days.

Early results, obtained primarily in patients with paroxysmal AF, demonstrate 80% to 90% freedom from AF 6 months after ablation. With continued experience and further advances in instrumentation, procedure time is expected to fall to less than 2 hours, and hospital length of stay to decline to a single day. Application of these minimally invasive, thoracoscopic and keyhole procedures will offer the potential for cure of AF, with improved quality of life and freedom from anticoagulation and anti-arrhythmic medications, to large numbers of patients.

Future directions: the left atrial appendage

Currently there is great interest in development and assessment of endocardial and epicardial procedures for exclusion of the left atrial ap-

pendage.[43,44] It is widely believed that formation and embolism of left atrial appendage thrombi are responsible for the increased risk of stroke in AF patients.[43,44] In AF patients, warfarin inhibits formation of atrial appendage thrombi and reduces cardioembolic strokes, while aspirin prevents smaller, noncardioembolic strokes. Based upon data from the Stroke Prevention in Atrial Fibrillation (SPAF) trials, one-third of AF patients are at high risk for stroke and should be treated with warfarin.[4,45,46] In spite of these observations and recommendations, warfarin is under-prescribed in AF patients. Furthermore, many patients cannot or will not take warfarin. Therefore, interventional therapies that specifically address the left atrial appendage in AF patients are being investigated as potential alternatives to warfarin therapy.

Excision or exclusion of the left atrial appendage is currently performed during surgical ablation of AF and is recommended in ACC/AHA guidelines for patients undergoing mitral valve surgery. However, standard surgical exclusion by suture closure is incomplete in 30% of cases, and stapled closure or excision has been associated with bleeding complications.[47] Thus, there is a need for new surgical approaches to the left atrial appendage. Several devices for epicardial exclusion of the left atrial appendage are under development (Figure 3). Pre-clinical studies suggest that device-based epicardial exclusion of the left atrial appendage is rapid and safe and has the advantage of avoiding placement of a foreign body in the fibrillating atrium.[50] Early clinical results with this epicardially-based left atrial appendage clip are promising. This and other new technologies for minimally invasive epicardial ablation of the left atrial appendage will soon be available for widespread clinical use. Clinical trials are being designed to test the hypothesis that epicardial, device-based exclusion of the left atrial appendage will reduce the risks of stroke and other thromboembolism in patients with AF.Should this hypothesis prove correct, physicians will be able to offer a new strategy for primary or secondary stroke prevention in AF patients.

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