

The Modern Surgical Management of Atrial Fibrillation

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Abstract

Atrial fibrillation is the most common arrhythmia disorder. Its incidence is especially high among patients with valvular heart disease. Patients with atrial fibrillation are at a six-fold increased risk of stroke and a two-fold increased risk of mortality. Medical management for rhythm control of patients with atrial fibrillation is suboptimal and no better than simple rate management. However, catheter-based therapies are undergoing intense development. The surgical management of atrial fibrillation has undergone considerable innovation in the last two decades; it is the subject of this review. The “cut-and-sew” Cox-maze III is considered the standard for surgical therapy for atrial fibrillation. More recently, several modifications of the Cox maze lesion set and the development of alternative energy sources to achieve transmural atrial lesions have led to a more simplified maze procedure. This simplified left-sided maze procedure has demonstrated excellent efficacy at intermediate and long-term follow-up. Therefore, the modified maze procedure should be offered to all mitral valve surgery patients and potentially to all cardiac surgery patients with a history of paroxysmal, persistent, or permanent atrial fibrillation.

Key Words: Atrial fibrillation, surgery, maze procedure, cryothermia.

Introduction

ATRIAL FIBRILLATION is the most common arrhythmia disorder, with an estimated prevalence of 2.2 million Americans or 0.4% of the general population, and its prevalence increases with age (1). Patients with atrial fibrillation are at an increased risk for developing left ventricular dysfunction, for stroke and other embolic events caused by atrial thrombi, and for mortality (2, 3). Atrial fibrillation is associated with a 6-fold increased risk of stroke and a nearly two-fold increased risk of mortality (3, 4). Patients with atrial fibrillation following coronary artery bypass graft have a 25% increased risk of mortality (3). Additionally, atrial fibrillation may cause various unpleasant symptoms and adversely impact quality of life.

Comorbid cardiac disease is present in up to 70% of patients with atrial fibrillation. Those cardiac diseases predisposing patients to the development of atrial fibrillation most commonly include hypertension, coronary heart disease, and valvular (particularly mitral) and myocardial diseases (5). Patients with atrial fibrillation as compared with patients in sinus rhythm at the time of mitral valve surgery are at an increased risk of cardiovascular death (6).

For the relief of symptoms, prevention of thrombus and stroke, and the avoidance of left ventricular dysfunction, cardiologists make considerable effort to restore and maintain sinus rhythm in patients with atrial fibrillation. However, as has recently been demonstrated in several large, randomized trials, pharmacologic management of atrial fibrillation is hardly better than simply rate control with appropriate anticoagulation to reduce the risk of thromboembolism (7–9). This situation is largely a consequence of the inadequacies of pharmacologic therapy for the maintenance of sinus rhythm (10).

The prevalence of atrial fibrillation, given the limitations of pharmacological therapy for the maintenance of sinus rhythm (8), has led to the development of alternative, non-pharmacological

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approaches to the management of this disorder, including catheter-based or surgical ablation. This review describes past and contemporary surgical approaches to the management of atrial fibrillation.

Definitions and Pathophysiology

Atrial fibrillation is considered paroxysmal or self-terminating when episodes last less than seven days, usually less than 24 hours (1). It is considered persistent if it fails to terminate and lasts longer than seven days. Persistent atrial fibrillation can be terminated by direct current cardioversion or pharmacologic cardioversion. Atrial fibrillation is considered to be permanent when it is present for more than one year and cardioversion has either not been attempted or has failed.

Atrial fibrillation is believed to arise from enhanced automaticity at one or more rapidly depolarizing foci or result from reentry involving one or more circuits (1). The focal origins of atrial fibrillation, which appear to be more important in patients presenting with paroxysmal atrial fibrillation, have most recently been described by Haissaguerre to occur predominantly in the pulmonary veins (11; Fig. 1). Infrequently, foci may also occur in the right atrium, the superior vena cava, or the coronary sinus (11, 12). The multiple-wavelet hypothesis, first described by Moe (13), proposes a reentrant phenomenon such that fractionation of wave fronts as depolarization propagates through the atria and results in self-perpetuating daughter wavelets. The creation of these wavelets depends on local differences in the refractory period, mass, and conduction velocity within the atria. Such changes evolve in the setting of underlying structural heart disease. The multiple wavelet phenom-

enon appears to be more important in the genesis of persistent atrial fibrillation.

An understanding of the underlying pathogenesis of atrial fibrillation has been critical in advancing surgical approaches for the treatment of this disorder.

Treatment

An ideal treatment for atrial fibrillation would restore normal sinus rhythm, reestablish atrioventricular synchrony, eliminate thromboembolic risk, and restore atrial transport function. Based on the understanding of the underlying mechanism of atrial fibrillation, several procedures have accomplished these goals to varying degrees. However, the results are limited by the inherent complexity and morbidity associated with the specific procedure.

Medical Therapy

Although details of the medical management of atrial fibrillation are beyond the scope of this review, the tenets of medical therapy include rate control of those patients with persistent atrial fibrillation, using beta-blockers, calcium channel blockers or digoxin, and anticoagulation in those patients at risk for systemic embolization (1). If the decision is made for rhythm control, pharmacologic agents such as flecainide, propafenone, sotalol, and amiodarone may be used, depending on the patient's underlying heart disease (1). However, such medications maintain only 30–60% of patients in normal sinus rhythm at 1–2 years follow-up and have a number of side effects (14). Risk of recurrent atrial fibrillation is dependent on the choice of pharmacological agent and several risk factors for recurrence, including the presence of hypertension, atrial fibrillation for longer than one year, enlarged left atrial size, and left ventricular dysfunction (15).

Catheter-Based Therapy

Atrioventricular nodal ablation. Radiofrequency catheter ablation of the atrioventricular (AV) node can be done in patients with permanent atrial fibrillation for whom pharmacologic therapy is unsuccessful. Because ablation of the AV node causes complete heart block, patients first require implantation of a permanent pacemaker. Nodal ablation is acutely successful in 97% of patients, though up to 3–4% of patients have recurrence of AV conduction at follow-up (16). While AV nodal ablation is highly effective for heart rate control, the left atrium remains in fibrillation so that anticoagulation to pre-

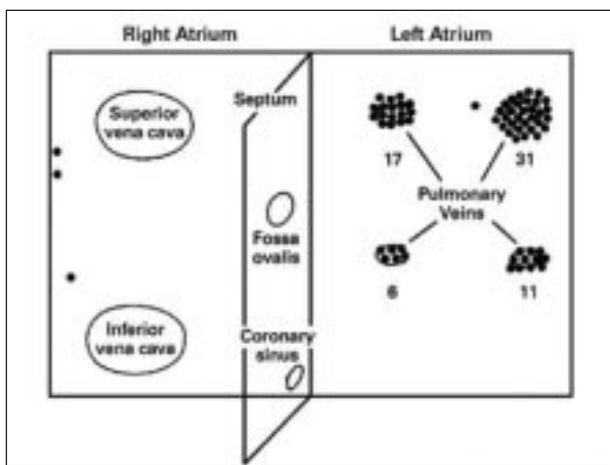


Fig. 1. The source of ectopic foci initiating atrial fibrillation. Reprinted with permission from Haissaguerre, *N Engl J Med* 1998; 339(10):659 (11).

vent systemic embolization, as in patients with chronic atrial fibrillation, remains important.

Pulmonary vein isolation. Based on the surgical experience with atrial fibrillation ablation, a variety of methods of catheter-based radiofrequency ablation are currently being investigated. Current techniques are particularly effective for the treatment of paroxysmal atrial fibrillation (17). Catheter-based ablation has been associated with pulmonary vein stenosis in approximately 5% of patients (18) and on rare occasions has been associated with fatal atriopharyngeal fistulas (19). However, as techniques are refined, there is great potential for catheter-based ablation of atrial fibrillation and restoration of sinus rhythm.

Surgical Therapy

Cox-maze III procedure. The Cox-maze III procedure is considered the standard for surgical treatment of atrial fibrillation. Based on experimental evidence of the pathophysiology of atrial fibrillation, Cox designed the initial procedure, then modified it twice, resulting in the Cox-maze III (20, 21). The Cox-maze III operation involves incision and cryolesions designed to interrupt the macroreentrant “wavelet” circuits that characterize persistent atrial fibrillation (Fig. 2). Multiple full-thickness cuts and sutures within the atrial wall disrupt abnormal reentry pathways (22). Both right and left atrial lesions direct sinus depolarization to the AV node. Several “blind alleys” are constructed along the conduction pathway to allow for depolarization of the atria and to enable atrial transport function (20, 21). Additional lesions surrounding

the pulmonary veins isolate the potential triggers of atrial fibrillation located in the pulmonary veins. Right atrial lesions are designed to prevent atrial flutter. The Cox-maze III lesion set thus includes: a pulmonary vein isolation lesion, a connecting lesion to the mitral annulus and a connecting lesion to the left atrial appendage, a septal lesion, a cryolesion on the coronary sinus, and a right atrial isthmus lesion (23; Fig. 2). Finally, the left atrial appendage is excised to further prevent thrombus formation. The Cox-maze III procedure is often done in conjunction with operative correction of other structural cardiac abnormalities (24).

The Cox-maze III is remarkably effective and has thus been considered the standard for surgical correction of atrial fibrillation, to which every other procedure has been compared. Freedom from atrial fibrillation has been demonstrated in >95% of patients at 5 year follow-up (25) and >90% of patients at 10 year follow-up (26). Restoration of biatrial transport has been demonstrated in >80% of patients (21). The incidence of stroke is markedly reduced (27). Pacemaker implantation is required postoperatively in 5–10% of patients, though a majority of these are for underlying sinus node disease (28).

However, the Cox-maze III has not been widely adopted as a method for treatment of atrial fibrillation. This is primarily due to the operative complexity of the procedure. Even in experienced hands, the Cox-maze III operation requires about 1 hour on cardiopulmonary bypass (29). Additionally, there may be a high rate of reoperation, following the Cox-maze III, due to bleeding (30).

Modified maze procedure. As an alternative to the Cox-maze III, several new approaches to the surgical ablation of atrial fibrillation have been developed, to decrease the complexity of the surgery while maintaining adequate efficacy. These approaches have been designed around either simpler lesion sets, alternative energy sources to the “cut-and-sew” methodology of the Cox-maze, or an epicardial rather than endocardial application of lesions.

Alternative lesion sets. As the focus of the underlying pathophysiology has shifted to the pulmonary veins, novel approaches focusing on isolating the pulmonary veins from the remainder of the left atrium have been developed. From the work of Alfieri, Mohr, and Melo (30–31), it seems that isolating the pulmonary veins is critical to the success of a modified maze procedure. Additionally, a lesion across the left atrial isthmus connecting the lesions encircling the pulmonary veins to the non-conducting tissue of the mitral annulus is crucial to maintenance of sinus rhythm. In a study of 70 patients with persistent or paroxysmal atrial

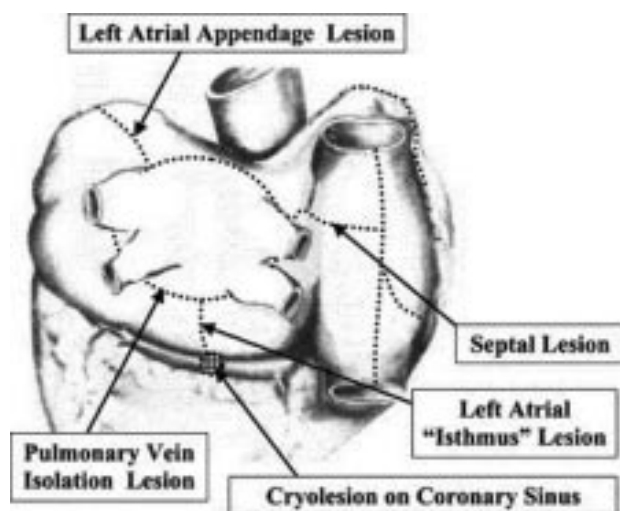


Fig. 2. Lesion set of the Cox-maze III. Reprinted with permission from Cox, *Europace* 2004; 5 Suppl 1:S20 (23).

fibrillation, contiguous lesions surrounding the orifices of the pulmonary veins with a connecting lesion to the mitral annulus resulted in >90% of patients free of atrial fibrillation at 12 months (32). A right atrial isthmus lesion is desirable to prevent postoperative atrial flutter. Finally, as proposed by Cox, a lesion in the coronary sinus is also desirable (23). By eliminating a majority of the lesions and restricting the lesions primarily to the left atrium (34), there is little lost in efficacy, with great reduction in the operative complexity, although there is still controversy about the exact choice of lesion set (29).

Alternative energy sources. While a modification of the lesion set based on a better understanding of the underlying pathophysiology of atrial fibrillation has reduced the operative complexity of the maze procedure, using alternate energy sources such as radiofrequency, cryotherapy, microwave, ultrasound, or laser for creating a lesion rather than the traditional “cut-and-sew” method has been the most important advance in the surgical treatment of atrial fibrillation. Using alternative energy sources, operators hope to create transmural atrial lesions analogous to those created with the Cox-maze III. There are potential advantages and disadvantages to each alternative energy source (Table; 35).

Radiofrequency. The largest study experience of alternative ablation technique has been with the use of unipolar radiofrequency catheter systems. Using radiofrequency energy, the probe is heated to 80°C for 1 minute, with consequent coagulation and destruction of cell and collagen structures (22). Endocardial lesion sets of the left or bilateral atria have proven effective in patients undergoing concomitant cardiac surgery, primarily mitral

valve surgery (34, 36, 37). In general, the radiofrequency ablation using a flexible probe, rigid probe, or pencil-like probe requires an additional 10–20 minutes of operative time (38, 39). Several case series have demonstrated efficacy of 70–80% freedom from atrial fibrillation (40–42). In a study of 200 patients with permanent atrial fibrillation, Sie et al., using a simplified radiofrequency linear ablation, demonstrated 40-month freedom from atrial fibrillation in 73% of patients, although 49% were on antiarrhythmic drugs (40). As with the Cox-maze III, approximately 10% of patients require pacemakers postoperatively (40).

There are, however, dangers specific to radiofrequency ablation of the left atrium. For example, damage to the circumflex coronary artery and catastrophic atrioesophageal fistula formation have been reported, though these complications are exceedingly rare (32, 43, 44). Additionally, radiofrequency ablation is considered thrombogenic, providing the possibility for postoperative left atrial thrombus formation and subsequent embolic complications (45).

Cryotherapy. Unlike radiofrequency ablation, cryoablation generally preserves the integrity of adjacent anatomic structures, due to its preservation of collagen tissue (35). During cryoablation, the probe tip is cooled to –150°C for 1 minute. The freezing and thawing forms intracellular and extracellular ice crystals with resultant irreversible lesions within 2 hours of application (22). Recent molecular-based research suggests that apoptosis may be a mechanism of cell death, particularly in the periphery of the cryogenic lesion (46). By 12 weeks after lesion application, homogeneous, fibrotic, full-thickness lesions of the atrial wall have developed. Additionally, cryoablation is not con-

TABLE
Alternative Energy Sources

	Cryotherapy	Radiofrequency	Microwave	Laser
Clinical Experience	Extensive	Extensive	Minimal	Minimal
Endocardial Disruption	Low	High	High	High
Transmural Lesion	Excellent	Limited, Contact dependent	No	No
Perforation	Low	Low	High	High
Thrombogenicity	Low	High	High	High

Adapted with permission from Lustgarten DL, Keane D, Ruskin J. Cryothermal ablation: mechanism of tissue injury and current experience in the treatment of tachyarrhythmias. *Prog Cardiovasc Dis* 1999; 41(6):481–498 (35).

sidered thrombogenic (35). Several case series have demonstrated similar efficacy of cryoablation and radiofrequency ablation in the management of atrial fibrillation (47–50). Approximately 70–80% of patients remain in sinus rhythm with cryoablation as well. In a study of 95 patients with permanent atrial fibrillation, Manasse et al. demonstrated 81% freedom from atrial fibrillation at 3-year follow-up, with a modified linear cryoablation of the left atrial posterior wall (47). Cryoablation generally requires approximately 10 minutes of operative time (or 20 minutes for biatrial ablation) and currently is done primarily with concomitant cardiac surgery in patients with a history of paroxysmal or persistent atrial fibrillation (50). There have been no reports of collateral coronary or esophageal damage and no reports of thrombus formation.

Microwave. There is considerably less experience with microwave thermal ablation. In this procedure, heat is generated by microwave energy at the probe tip for 20–30 seconds (22). The heating of a microwave probe results in a deep lesion without resultant endocardial char formation, theoretically reducing the risk of thrombus formation (51). Although there is more limited experience, the efficacy seems to be similar to that of radiofrequency or cryotherapy ablation, with no reported complications (52–54).

High-frequency ultrasound and laser are additional energy sources that are under ongoing investigation but have not yet come into common clinical practice (51).

Epicardial versus endocardial lesion application. Epicardial lesion application offers several distinct advantages over the endocardial approach. Epicardial application allows for a beating-heart procedure, minimizing cardiac ischemic time and allowing for a less invasive thoracoscopic approach (Fig. 3; 55). In addition, epicardial application affords better handling of anatomic variation of the pulmonary venous trunks and minimizes the risk of pulmonary vein stenosis. Finally, the reported efficacy is similar to that of endocardial alternative lesion approaches with similar operative time (56, 57). Epicardial lesion application has been performed with both radiofrequency and microwave energy (55, 57, 58). Although there have been no reports of esophageal perforation, left main coronary injury has been reported (59).

Predictors of failure. Several series have studied predictors of success or failure when performing a maze procedure during concomitant cardiac surgery. Preoperative decreased amplitude fibrillatory wave, increased left atrial size, and increased cardiothoracic ratio have been predictive of early recurrence of atrial fibrillation in patients



Fig. 3. Bipolar radiofrequency clamp. Reprinted with permission from AtriCure, Inc., Cincinnati, OH.

undergoing a traditional Cox-maze III procedure (60). The primary predictor of late recurrence in patients undergoing the Cox-maze III is duration of preoperative atrial fibrillation (26). The pathogenesis of the underlying disease was not predictive of Cox maze success (61). However, left atrial size reduction post-operatively was predictive of Cox maze success. Fewer studies have considered predictors of failure of a simplified maze using alternative energy sources. Preoperative increased left atrial size has been predictive of recurrent atrial fibrillation in patients undergoing a simplified radiofrequency maze procedure (36). But these identified factors are probably indicative of more extensive structural heart disease, which leads to the development of wavelet-mediated persistent atrial fibrillation.

Left atrial appendage ligation. The left atrial appendage has been implicated as the primary repository of thrombus in patients with atrial fibrillation, particularly non-valvular atrial fibrillation (62). Several studies have tested the feasibility of left atrial appendage obliteration to reduce the risk of stroke (62, 63). However, no large study evaluating this practice has yet been performed. Additionally, there is a risk of incomplete exclusion of the left atrial appendage, which has been reported in as many as 30–40% of patients on postoperative transesophageal echocardiogram (64). Most recently, there has been interest in the feasibility of percutaneous occlusion of the left atrial appendage (65). At this time, left atrial appendage obliteration continues to be a component of the traditional Cox-maze III procedure. There is variability in the practice of left atrial occlusion in patients undergoing a simplified maze procedure, since the benefit has not clearly been shown.

Postoperative management. There is no consensus regarding the postoperative management of

patients undergoing a surgical maze procedure. In general, if the patient is in atrial fibrillation at the time of surgery, amiodarone is given in the operating room and continued in the early postoperative period. Anticoagulation is started prior to discharge and continued for at least 3 months. Anticoagulation should be stopped only if a Holter monitor shows no episodes of atrial fibrillation. Temporary pacing wires are placed in the operating room for management of postoperative bradycardia. Patients in the early postoperative period may develop a variety of arrhythmias including atrial fibrillation, atrial flutter, or junctional rhythm. Occasionally patients will require a permanent pacemaker, although the indication is primarily for sinus node dysfunction (66).

The Mount Sinai experience. In a recent review of operative outcomes of the modified maze procedure at Mount Sinai Hospital, we obtained follow-up on 73 consecutive patients. Between January 2002 and August 2004, 73 patients underwent a modified left-sided maze procedure in conjunction with mitral valve surgery. A majority of these patients (87%) underwent mitral valve repair. The initial 23 patients underwent unipolar radiofrequency left-sided maze ablation. Although there were no complications associated with the radiofrequency maze ablation, the energy source was changed to cryotherapy because of the reported complications associated with radiofrequency ablation reported in the literature. Subsequently, 50 additional patients underwent a cryotherapy left-sided maze ablation. The lesion set consisted of contiguous endocardial lesions surrounding each group of right and left pulmonary veins with an interconnecting lesion between the pulmonary venous ostial lines and a connecting lesion to the posterior segment of the mitral annulus. There were no additional right-sided lesions.

At an average of 342-day follow-up, there were 5 deaths. Similar to the previously described case series, 69% of patients in our series were in normal sinus rhythm at follow-up. Seven percent (7%) of these patients required cardioversion and 14% required antiarrhythmic therapy to maintain sinus rhythm. Seven percent (7%) of patients required a pacemaker implantation postoperatively. One patient had a stroke postoperatively.

Conclusions

Atrial fibrillation is an increasingly prevalent disease that is a burden to our aging population. Improved understanding of the pathogenesis of atrial fibrillation and the development of new technologies

based on this understanding have led to a renewed interest in the surgical therapy of atrial fibrillation. The much simplified surgical treatment of atrial fibrillation using a modified maze procedure has been safe and effective thus far, and should therefore be offered to all mitral valve surgery patients with a history of paroxysmal, persistent, or permanent atrial fibrillation. Currently it is the standard of care in our institution. With the development of epicardial atrial fibrillation ablation, the thoracoscopic treatment of atrial fibrillation is a very promising, less invasive treatment option for the near future.

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