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Atrial Fibrillation Ablation by the Epicardial Approach

Anil K. Gehi[1], Andy C. Kiser[2], J. Paul Mounsey[1]

[1]Division of Cardiology, Department of Medicine, University of North Carolina at Chapel Hill. [2]Division of Cardiothoracic Surgery, Department of Surgery, University of North Carolina at Chapel Hill.

Abstract

Catheter ablation is an effective treatment for atrial fibrillation (AF). However, over long-term follow-up, it is becoming clear that AF often recurs and repeat ablation is required. With the goal of improving efficacy, particularly in those patients with risk factors for poor outcomes using a standard endocardial ablation technique, surgical epicardial ablation has emerged as an alternative methodology. Since its advent in the 1980s, surgical ablation techniques have continued to evolve. New ablation tools make a minimally invasive surgical approach possible. And most recently, we have seen the development of a hybrid (epicardial and endocardial) approach to AF ablation, which can draw upon the advantages of both options.

Introduction

Atrial fibrillation (AF) is the most common clinical arrhythmia and associated with significant morbidity and mortality. The incidence of AF continues to rise, likely attributable to the aging of the patient population and the rising prevalence of chronic cardiac disease. As the overall prevalence of AF rises, it continues to be a great burden on the healthcare system.

Since its advent in the late 1990s, radiofrequency (RF) endocardial catheter ablation has emerged as a tool for the management of symptomatic AF. The improved efficacy of endocardial catheter ablation over antiarrhythmic drug therapy has been established in several randomized controlled trials. However, longer-term data have proved to be less encouraging.[1, 2] When followed over several years, it is clear that recurrence of AF after endocardial catheter ablation is relentless, often warranting repeat ablation procedures.

With the goal of improving efficacy, particularly in those patients with risk factors for poor outcomes using a standard endocardial ablation technique, surgical epicardial ablation has emerged as an alternative technique. In this article, we review the development of epicardial approaches to AF ablation, beginning with open heart techniques developed in the 1980s and culminating in hybrid (combined endocardial and epicardial ablation) techniques.

Epicardial surgical ablation can be performed concomitantly with other cardiothoracic surgical procedures or as a stand-alone operation. Stand-alone epicardial AF ablation can be an open chest or minimally invasive procedure. Epicardial AF ablation can be combined electively with an endocardial catheter ablation done either at the time of epicardial surgery, or delayed days or weeks after an initial epicardial procedure. A general problem with the assessment of success rates of catheter and surgical based procedures for AF is lack of standardization in how outcomes were measured. The Heart Rhythm Society guidelines recommend no more than 30 seconds of AF be the criteria a successful procedure. But in many studies only symptomatic recurrences proven by ECG were counted as failures, and in many others only 24 or 48 hour Holter monitors were required. The closest to a gold standard currently available is an implantable looping event recorder, but few large studies have employed this technology.

Open Heart Surgical Techniques For AF

Surgical techniques for rhythm control of AF emerged in the 1980s. The "Corridor" procedure was described by Guiraudon et al in 1985.[3] With this surgery, a portion of atrium including the sinoatrial and atrioventricular node were isolated from the remaining atrium. Unfortunately, success rates were low and the atria outside of the corridor continued to fibrillate, minimizing atrial transport function and leaving patients with a continued risk for thromboembolism.

James Cox developed the Maze procedure in the late 1980s.[4] By dividing the atria into smaller segments with a cut-and-sew technique, fewer re-entrant circuits could be maintained. Incisions encircled

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Andy Kiser is a paid speaker and consultant for Estech. Paul Mounsey is a paid speaker and consultant for Estech and nContact.

Corresponding Author:
Anil K. Gehi, MD
Assistant Professor
Cardiac Electrophysiology
Division of Cardiology
CB 7075, 160 Dental Circle
6025 Burnett-Womack Bldg
Chapel Hill, NC 27599-7075

the pulmonary veins with connecting lesions to the mitral annulus and the left atrial appendage. Initial surgeries were associated with significant sinus node dysfunction. However, modifications to the lesion set culminated in the Cox-Maze III operation.[5] Modifications included eliminating incisions around the sinus node, moving the left atrial roof incision more posteriorly, and excising the left atrial appendage. The Cox-Maze III surgery became the gold standard for surgical treatment of AF with long-term success rates of >90% as assessed by symptom guidance alone.[6] However, the surgery never gained popularity given its complexity and significant morbidity.

Modifications to the Cox-Maze III were made to simplify the surgery while maintaining its efficacy. The Cox-Maze IV developed by Damiano and others replaces cut-and-sew lines with ablation using technologies such as radiofrequency, cryothermy, or microwave energy ablation.[7] Khargi et al compared the efficacy of alternative energy sources (cyroablation, radiofrequency, high-intensity focused ultrasound, laser, microwave) to cut-and-sew techniques.[8] Post-operative freedom from AF using an alternative energy source is comparable to the cut-and-sew technique but reduces cross clamp times.The Cox-Maze IV can be performed through a mini-thoracotomy but still requires cardiopulmonary bypass, largely due to an inability to created consistently transmural lesions on a beating heart. Because contiguous and transmural lesions are difficult to create on the beating epicardial surface, numerous epicardial patterns have been described in the literature, each incorporating different lesions and different ablation energy sources.

AF Surgery with Concomitant Heart Surgery

Simplifications to the Maze procedure with alternative energy sources make it easier to combine the Maze procedure with concomitant cardiac surgery. The prevalence of AF, particularly in those with mitral valve surgery, is estimated to be 40-60%. Moreover, AF in patients with valve disease is associated with decreased survival. With direct access to the left atrium, concomitant heart surgery represents a prime opportunity for surgical ablation, yet only 62% of patients undergoing mitral valve surgery undergo concomitant AF surgery.[10]

Several studies have demonstrated a significant increase in AF free survival in those undergoing concomitant Maze surgery. Kong et al performed a meta-analysis of 9 randomized controlled trials comparing the efficacy of surgical maze concomitantly with cardiac surgery versus pharmacologic therapy for treatment of AF. When compiling a total of 472 patients, surgical maze increased the odds of freedom from AF at 12 months after cardiac surgery over 5-fold (OR 5.22). There was no corresponding increased in hospital stay, peri-operative complications, or mortality.[11]

Success rates are lower in those with structural heart disease like rheumatic or ischemic heart disease and in those with persistent AF. Typically left atrial ablation alone is recommended in those with paroxysmal AF, whereas biatrial ablation may be preferred in those with persistent AF and those with enlarged right atria.[12,13]

Several approaches for AF surgery when performed with concomitant cardiac surgery have been studied. The majority of studies have utilized cryoablation although radiofrequency ablation and cut-and-sew procedures have been utilized as well. At a minimum, lesion sets consist of pulmonary vein isolation with some including ancillary linear ablation between the pulmonary veins to isolate the posterior left atrium. Generally, studies have been small but consistently outcomes are adequate with pulmonary vein isolation alone in those with paroxysmal AF but additional linear ablation is beneficial in those with persistent AF.

Camm et al compiled data evaluating the utility of cryoablation specifically with concomitant cardiac surgery compared with no treatment, catheter based therapy, or other sources of energy in maintaining sinus rhythm in those with AF. From 291 studies,[9] were identified which provided the best evidence although high quality data was lacking. The authors conclude that because complication rates are low and success rates at 12-months are reasonable (60-82%), the practice of AF surgery with concomitant heart surgery is an acceptable approach.[14]

Standalone Minimally Invasive Surgery for AF

Although the Cox-Maze surgery is highly effective, its complexity and associated morbidity have limited its adoption as a widespread standalone treatment for AF. More recently, alternative minimally invasive techniques have been developed for surgical treatment of AF in those not requiring concomitant cardiac surgery.

Epicardial off-pump pulmonary vein isolation can be performed either through a thoracoscopic or mini-thoracotomy approach. Initial results with bilateral video-assisted thoracoscopic epicardial PVI using a bipolar non-irrigated RF clamp (Atricure, Inc, Cincinnati, OH) were promising with 91% free of AF at follow-up.[15] Management of stroke risk by way of left atrial appendage (LAA) removal is an added benefit.

As the role of ganglionated plexi (GP) in the initiation and maintenance of AF has become apparent, ganglionated plexi ablation has emerged as a potential ancillary strategy for surgical AF ablation. Several studies have evaluated the benefit of standalone epicardial pulmonary vein isolation with ganglionated plexi ablation on the maintenance of sinus rhythm. Edgerton et al reported outcomes in 52 patients with symptomatic paroxysmal AF.[16] Patients underwent bilateral minithoracotomies with GPs identified by vagal response to high-frequency stimulation. Bipolar radiofrequency clamp pulmonary vein antral isolation with GP ablation was performed. LAA was excised or stapled in 88%. Patients were followed with 24-hour Holter or 2 week monitoring at 6 and 12 months. Average hospital length of stay was 5 days. Three patients required post-operative pacemaker implantation. At 12-months follow-up, 80% of patients were in sinus rhythm.

However, the majority of patients in these initial studies had paroxysmal AF. Follow-up studies demonstrated that pulmonary vein isolation alone is insufficient for the treatment of persistent AF. Additionally, the particular role of ganglionated plexi ablation is unclear as no randomized studies have specifically evaluated its benefit.

Because endocardial catheter ablation can be highly effective for paroxysmal AF and is a much less invasive procedure, standalone epicardial ablation for paroxysmal AF has never gained widespread acceptance.

In those with persistent AF, adding linear ablation to pulmonary vein isolation appears to be beneficial. Edgerton et al developed a beating-heart approach replicating the lesions of the Cox maze procedure using minimally invasive techniques known as the "Dallas" lesion set (Figure 1).[17] In 30 patients (10 persistent, 20 long-standing persistent), Edgerton et al described the use of bilateral PV antral isolation using a bipolar RF clamp (Atricure, inc) with GP ablation.

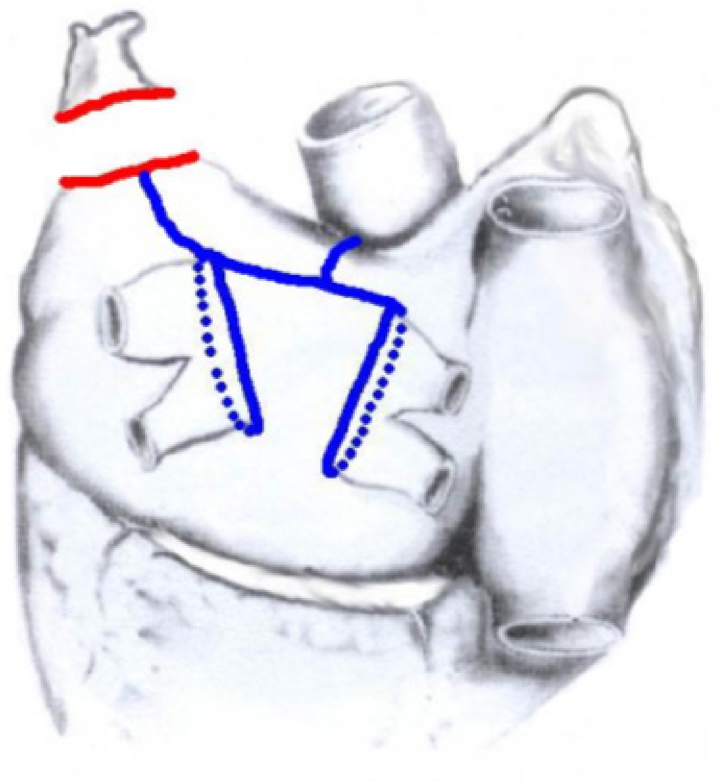

Figure 1: The “Dallas” epicardial lesion set. Blue lines indicate epicardial ablation lesions (Atricure). Red lines indicate surgical lines.

Subsequent linear ablation included a left atrial roof line, a line between the roof and the left fibrous trigone (anterior trigone line), and a line to the base of the resected left atrial appendage. Conduction block across the roof and anterior trigone lines was verified by pacing techniques. Patients were followed for 6 months with ECG and 14-21 day auto-triggered monitors. Pacemaker implantation was required in 3 (10%) patients. At 6 months, overall success rate was 58% off anti arrhythmic drugs and 80% with or without antiarrhythmic drugs as assessed by long-term (14-21 day) event monitoring.

A larger study of 89 patients with paroxysmal (35%), persistent (24%), or long-standing persistent (42%) AF undergoing the “Dallas” epicardial lesion set was reported by Weimar et al.[18] Mean hospital length of stay was 8 days. One patient required conversion to extracorporeal circulation. Freedom from AF and antiarrhythmic drug therapy was 71%, 82%, and 90% at 6, 12, and 24 months, respectively with no difference in those with paroxysmal or persistent AF. However, 5% of patients required subsequent catheter ablation for recurrent AF or atrial flutter.

Nasso et al described the use of an alternative surgical technique for pulmonary vein isolation through a right minithoractomy in 104 patients (Figure 2).[19] A linear vacuum-assisted unipolar RF ablation catheter (Estech, San Ramon, CA) was looped around the pulmonary veins by way of the transverse and oblique pericardial sinuses using a magnet tipped introducer. Patients were followed with 24-hour Holter monitoring. Periprocedural complications including 1 case of intraoperative LA rupture requiring sternotomy for repair, 1 case of hemorrhagic stroke 4 days post-op, and 1 transient ischemic attack in the early post-operative period. At an average 17 months follow-up, 89% were free of AF (96% with paroxysmal AF and 80% with persistent AF).

Finally, Boersma et al compared the efficacy and safety of catheter ablation and minimally invasive surgical ablation in 124 patients with drug-refractory AF, left atrial dilatation (> 4cm), and hypertension in the FAST study.[20] AF was paroxysmal (67%), persistent (33%), or long-standing persistent (8%). The surgical ablation consisted of the “Dallas” lesion set as described by Edgerton. Catheter ablation consisted of wide-area linear antrum ablation with PV isolation guided by circular mapping catheter. Additional lines were made at the discretion of the operator. Patients were followed with ECG and 7-day Holter monitoring at 6 and 12 months. Median length of stay was 5.5 days vs 2 days for surgical or catheter ablation, respectively. In the surgical group, complications included 1 patient requiring convertion to median sternotomy, 1 patient requiring pacemaker implantation, 6 patients with pneumothorax, 1 with hemothorax, 1 with stroke, 1 tamponade, and 1 rib fracture. In the catheter group, complications included 1 transient ischemic attack and 4 groin hematomas. However, at 12 months, freedom from AF > 30 sec in the absence of antiarrhythmic drugs was 66% in the surgical group vs 37% in the catheter group (p=.0022).

Hybrid Surgery for AF

Hybrid (combined endocardial and epicardial ablation) is an intriguing option, which can take advantage of the strengths of surgical and catheter-based ablation. Fundamentally, catheter based ablation has the advantage of mapping techniques for ensuring bidirectional electrical isolation of pulmonary veins or other linear ablation. In addition, certain areas of the atria (e.g mitral isthmus, cavotricuspid isthmus) are more accessible from an endocardial approach. Catheter ablation techniques also offer the opportunity for detailed mapping of atypical flutters or atrial tachycardia. However, point-by-point ablation can be cumbersome and may not be durable. Surgical ablation offers an anatomic approach with direct visual guidance but no electrophysiologic guidance. There are significant

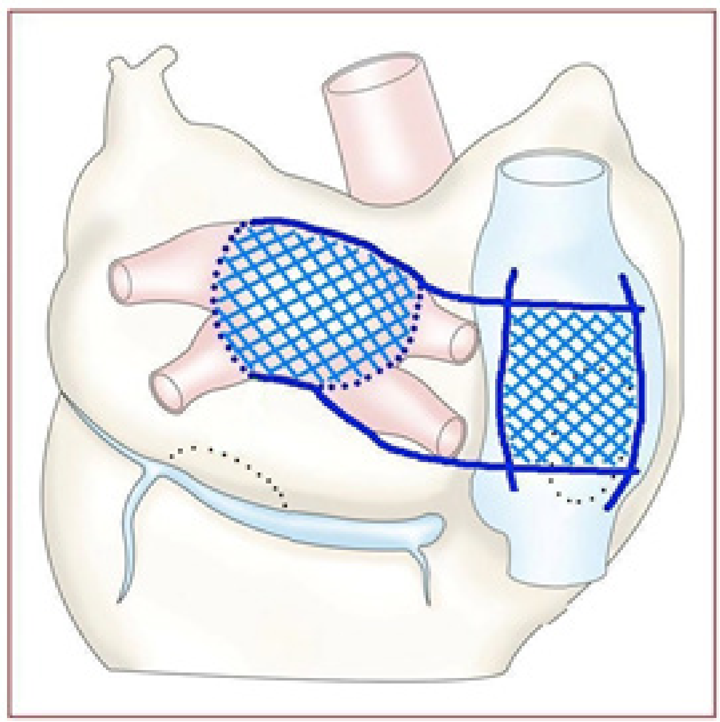

Figure 2: Epicardial lesion set. Blue lines indicate epicardial ablation lesions (Estech). Hashed area indicates isolated myocardium.

challenges to a hybrid ablation procedure including multidisciplinary team availability, requirement of a hybrid laboratory, sequence of the procedure, and anticoagulation strategy. However, the potential benefits of a hybrid approach can outweigh these challenges, particularly in patients whose outcomes may be more limited with a traditional catheter-based procedure.

Mahapatra et al reported their experience with a hybrid epicardial and endocardial ablation in 15 patients with persistent or long-standing persistent AF who had failed at least one attempt at endocardial ablation and antiarrhythmic drug therapy.[21] Patients were excluded if they had another indication for cardiac surgery or a prior history of cardiac surgery. Bilateral thoracoscopic off-pump epicardial ablation (Atricure, Westchester, OH) was performed using the Dallas Lesion set (pulmonary vein isolation, SVC isolation, roof and mitral line, elimination of ganglia response, ligament of Marschall ablation, and left atrial appendage exclusion). Patients were cardioverted and PV and SVC isolation was confirmed by an electrophysiologist in the operating room. Endocardial ablation was performed an average of 4 days later. During endocardial ablation, SVC isolation was confirmed, a cavotricuspid isthmus line was created, and PV isolation and block across the roof and mitral line were confirmed. Finally, high dose isoproterenol was used for induction. Any atrial flutter induced was mapped and ablated. If AF was induced, additional complex fractionated atrial electrogram ablation was performed. All patients were treated with amiodarone or dofetilide for 3 months post-procedure. Routine 7-day or 24-hour continuous monitoring was performed. Outcomes were compared to a matched catheter ablation alone control group. Overall, hospital length of stay in the hybrid group was longer but otherwise there were no acute complications in either group aside from a tamponade in the catheter-alone group. At 20 months of follow-up, more patients in the hybrid group were free of atrial arrhythmias off antiarrhythmic drugs (87% vs 53%, p=.04).

LaMeir et al reported their experience comparing a hybrid epicardial and endocardial ablation in 35 patients with epicardial only ablation in 28 patients (45-50% paroxysmal, 18-23% persistent, 31-32% long-standing persistent).[22] Bilateral thoracoscopic epicardial ablation (Atricure, Westchester, OH) included pulmonary vein isolation, roof and inferior LA ablation targeting a posterior "box", and GP ablation. Entrance and exit block across the PV and posterior box lines were checked. In the hybrid group of patients, PV isolation and block across the lines were checked endocardially. Induction of AF was performed during endocardial ablation with rapid pacing and/or isoproterenol infusion. In the case of persistent AF, a mitral line was created. Additional SVC isolation was added in those with persistent or long-standing persistent AF. And cavotricuspid isthmus ablation was performed in those with a history of typical right atrial flutter or if it became apparent during the procedure. Finally, left atrial appendage exclusion was performed in those with an LAA tachycardia or those with $CHADS_2$ score >= 1. Patients were followed with 7-day continuous monitoring at 3, 6, and 12 months post-procedure. There were no complications including mortality, stroke, or reoperation for bleeding in the two groups. Median length of hospital stay was 3-4 days. At 1-year follow-up, success rates free of atrial arrhythmia > 30 seconds off antiarrhythmic drug therapy were higher in those undergoing hybrid ablation compared to epicardial alone (91% vs 82%, p=.07), particularly in those with persistent or long-standing persistent AF.

Pison et al reported their experience in 26 patients undergoing hybrid thoracoscopic and transvenous ablation for AF in patients who had either failed prior catheter ablation, had an enlarged left atrial volume (>= 29 ml/m2), or had persistent or long-standing persistent AF.[23] Similar to the studies of Mahapatra and LaMeir, the pulmonary veins were isolated at the antra using a bipolar RF clamp (Atricure, Westchester, OH). Isolation was confirmed endocardially. In those with persistent AF, a roof line and posterior LA line (box lesion), SVC isolation, and intercaval lines were created. An epicardial and endocardial mitral line was created. A cavotricuspid isthmus line was made in those with a prior history of atrial flutter or flutter during the procedure. Finally, the left atrial appendage was excluded in a subset. Patients underwent 7-day continuous monitors at 3, 6, 9, and 12 months post-procedure and antiarrhythmics were discontinued at 6 months. Ten of 26 patients had persistent AF, 1 had long-standing persistent AF, and the remainder had paroxysmal AF. Mean hospital length of stay was 7 days. There were no major complications. At 1-year follow-up, success rate (no atrial arrhythmia > 30 seconds without antiarrhythmic drugs) was 93% in those with paroxysmal AF and 90% in those with persistent AF with 2 patients requiring redo catheter ablation after the hybrid procedure.

Zembala et al reported their outcomes in Poland using a hybrid ablation technique in 27 patients with persistent (5) or long-standing persistent[22] AF and a left atrium less than 6 cm diameter. 24 The epicardial portion of the procedure was performed by way of subxyphoid pericardioscopic access through the diaphragm. An irrigated, unipolar, vacuum-assisted RF linear ablation catheter was utilized through a pericardioscopic access cannula (nContact Surgical, Morrisville, NC). The epicardial lesion set included a posterior box (roof and low posterior LA lines), antral PV ablation, and connecting lesions to the coronary sinus. Endocardial ablation was performed 15-20 days later. The endocardial lesion set included completion of antral PV isolation, mitral isthmus ablation, and cavotricuspid isthmus ablation. Patients were maintained on antiarrhythmic drug therapy

Table 1: Summary of hybrid (combined endocardial and epicardial) ablation studies for treatment of atrial fibrillation.

Author	N (hybrid)	AF type (hybrid)	Epicardial Ablation Tool	Control Group	Complication Rate	Success Rate
Mahapatra et al17	15	Pers (60%), LSP (40%)	Atricure	Endocardial alone	0%	87% (hybrid), 53% (endocardial)
LaMeir et al18	35	Parox (46%), Pers (23%), LSP (31%)	Atricure	Epicardial alone	0%	91% (hybrid), 82% (epicardial)
Pison et al19	26	Parox (58%), Pers (38%), LSP (4%)	Atricure	None	0%	92%
Zembala et al20	27	Pers (19%), LSP (81%)	nContact	None	11%	80%
Gehi et al21	101	Parox (16%), Pers (47%), LSP (37%)	nContact	None	6%	73%
Gersak et al22	73	Pers (30%), LSP (70%)	nContact	None	8%	73%
Civillo et al23	104	Parox (27%), Pers (30%), LSP (43%)	nContact	None	5%	73%

N = number of patients; Parox = paroxysmal AF; Pers = persistent AF; LSP = long-standing persistent AF for 3 months post-ablation. Twenty-four hour Holter monitoring was performed at 6 and 12 month postoperatively. Complications included one patient with tamponade, a second patient requiring sternotomy due to bleeding from an inferior vena cava laceration, and a third patient who died 27 days after discharge of unclear cause. At 6 months post-procedure 72% of patients were in sinus rhythm, 67% without antiarrhythmic drug therapy. At 1-year post-procedure 80% of patients were in sinus rhythm and off antiarrythmic drug therapy.

Gehi et al reported their experience in a cohort of 101 patients undergoing simultaneous hybrid epicardial-endocardial ablation also using a pericardioscopic technique. [25] The majority of patients had persistent (47%) or long-standing persistent (37%) AF. Patients with paroxysmal AF had failed at least 1 attempt at endocardial ablation alone. Epicardial ablation was performed through a subxyphoid pericardioscopic technique using an irrigated, unipolar RF linear ablation device (nContact Surgical). The epicardial lesion set included antral PV ablation, posterior LA box ablation, and connecting lesions to the coronary sinus. The posterior LA was mapped during the epicardial portion of ablation to ensure electrical silence. Immediately following epicardial ablation, endocardial ablation was performed to complete antral PV isolation and mitral isthmus ablation. Additional complex fractional atrial electrogram ablation, superior vena cava ablation, and cavotricuspid isthmus ablation was left to the discretion of the elecrophysiologist. (Figure 3) Any atrial flutter or atrial tachycardia was mapped and ablated. Patients were followed by 3, 6, and 12-month 24-hour Holter monitoring or implantable looping monitor (Reveal, Medtronic, Minneapolis, MN). Complications included 2 patients with tamponade, 2 patients with bleeding (1 requiring surgical intervention), and 2 deaths (1 atrialesophageal fistula and 1 sudden, unexplained with unrevealing autopsy). Repeat endocardial ablation was performed in 6% of patients. Including repeat ablation, 12-month arrhythmia free survival was 73% without concomitant antiarrhythmic drug therapy.

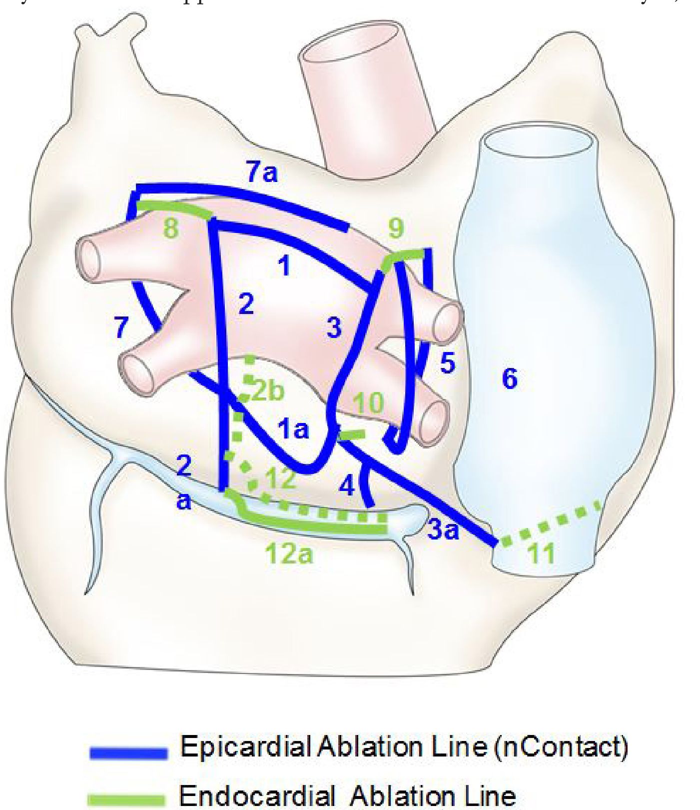

Figure 3: Hybrid pericardioscopic lesion set (adapted From Gehi et al21)

Epicardial and endocardial ablation lines performed by the surgeon (blue) and by the electrophysiologist (green). 1=Cephalad Posterior Left Atrium; 1a=Caudal Posterior Left Atrium; 2=Left Posterior Left Atrium; 2a=Left Inferior Pulmonary Vein to Coronary Sinus; 2b=Left Inferior Pulmonary Vein to Mitral Annulus; 3=Right Posterior Left Atrium; 3a=Right Inferior Pulmonary Vein to Inferior Vena Cava; 4=Right Inferior Pulmonary Vein to Right Atrium; 5=Right Anterior Pulmonary Veins; 6=Waterston's Groove and Right Atrium; 7=Left Anterior Pulmonary Veins; 7a=Left Atrial Roof; 8=Connection ablation at Left Superior Pulmonary Vein; 9=Connection ablation at Right Superior Pulmonary Vein; 10= Connection ablation at Right Inferior Pulmonary Vein; 11=Cavo-Tricuspid Isthmus; 12=Left Atrial Cononary Sinus; 12a=Internal Coronary Sinus

Gersak et al compiled the experience of 4 European centers performing the combined epicardial and endocardial ablation via the pericardioscopic approach in 73 consecutive patients. [26] All patients had persistent or long-standing persistent AF with an average AF duration of >4 years. Using a similar lesion set to that of Gehi et al, epicardial ablation included antral PV ablation and posterior LA box ablation. Immediately following epicardial ablation, endocardial ablation included confirming isolation of the PVs and the posterior atria. Patients were followed with regular 24-hour Holter monitoring or an implantable loop recorder. Adverse events included 1 stroke, 1 tamponade, 2 with bleeding requiring transfusion, and 2 with bleeding requiring conversion to sternotomy. Over 1-year follow-up, 4% require repeat endocardial ablation and arrhythmia free survival was 73%.

Civello et al reported their single-center experience in 104 patients (27% paroxysmal, 30% persistent, 43% long-standing persistent) undergoing hybrid ablation using a transdiaphragmatic approach (nContact).[27] Patients were followed with 72-hour Holter at 6 and 12 months post-procedure. Complications included 1 cerebrovascular accident, 1 pericardial effusion, 2 pleural effusions, and 1 pulmonary vein stenosis requiring stenting. Repeat procedures were performed in 5% of patients. At 12 months post-procedure, 73% were in sinus rhythm without antiarrhythmic drug therapy and 89% with or without antiarrhythmic drug therapy.

Advantages / Disadvantages of Epicardial Ablation for AF

There are several potential advantages and disadvantages to epicardial ablation techniques for AF. Epicardial ablation offers the opportunity for direct visualization of the atrium and ablation lesions. Even though endocardial ablation technological advances may improve the likelihood of robust antral isolation (e.g. balloon ablation), linear epicardial ablation, particularly in the atrial body, may be more consistent and result in long-standing, transmural, high quality lesions. Ablation from the direction of epicardium to the endocardium allows one to avoid injury to the esophagus when performing ablation on the posterior LA, a potentially critical region for the maintenance of AF. The left atrial appendage can be managed to mitigate stroke risk if necessary. However, approaches using a standalone minimally invasive epicardial approach have their limitations. There are significant anatomic considerations. Beating heart epicardial ablation does not consistently create lesions that extend to the mitral or tricuspid annulus, leaving an opportunity for iatrogenic circuits causing recurrent AF or flutter. Detailed mapping of ablation lines including antral PVI lines and other left or right atrial lines can be challenging in the operating room but are critical to improving success rates. Surgical risk with epicardial ablation is sufficiently higher than endocardial ablation approaches, with the potential for catastrophic complications.

Hybrid (epicardial and endocardial) ablation, either in a simultaneous or staged manner offers significant improvements to a standalone epicardial approach. Following epicardial with endocardial ablation offers the opportunity to verify epicardial lesions and approach territories that are inaccessible epicardially. Similar to performing endocardial ablation, there are often gaps in epicardial ablation lines no matter the tool used to create these (e.g. Atricure, nContact, Estech). Endocardial mapping following epicardial ablation allows for gaps in epicardial ablation lines to be identified and completed. Endocardial "touch up" of epicardial ablation lines is typically easier and likely more durable after epicardial ablation than after endocardial ablation. Thus, hybrid ablation offers the potential for more robust linear ablation and a lower likelihood of iatrogenic flutter. In addition, the electrophysiologist is ready to map and ablate arrhythmias encountered during ablation including atrial flutter or atrial tachycardia. Additional complex fractionated electrogram ablation is possible with endocardial ablation. As demonstrated in the studies outlined above, a hybrid approach has demonstrated improved efficacy compared with either an endocardial alone or epicardial alone approach. However, no study to date has compared a hybrid approach with multiple endocardial ablations with a randomized controlled design. It is likely that multiple, staged endocardial ablations will also improve outcomes. This is highlighted by the fact that staged endocardial ablation reveals a high likelihood of pulmonary vein reconnection.[28] The only study approaching this comparison is the study of Mahapatra et al comparing redo endocardial ablation with simultaneous hybrid ablation in those who had failed prior endocardial ablation.[21] As discussed previously, those undergoing hybrid ablation had better outcomes. In addition, no cost effectiveness study has yet been performed to justify the significant additive cost of the hybrid procedure.

There are, however, several factors which must be considered when building a hybrid ablation program. The approach for epicardial ablation needs to be decided upon and mastered. Several tools have been developed (Atricure, nContact, Estech), each with their advantages and disadvantages. There may be surgical approaches that must be individualized to the patient based on prior surgeries or other anatomic considerations. Ultimately the comfort level and skill of the cardiac surgeon is the most important factor in choosing an epicardial ablation tool. Hybrid AF ablation changes the working relationship between the electrophysiologist, the cardiac surgeon, and the patient. A multidisciplinary approach benefits all those involved but can be a significant change to the current working environment. Performing hybrid ablation requires significant changes to the system of patient care. Considerations include: the location for the ablation procedure (hybrid surgical suite or staged operating room then EP laboratory), personnel involved during the epicardial and endocardial portions of the procedure (single dedicated team or multiple teams), anesthesia care (dedicated cardiac anesthesia or not), and post-operative care team (cardiac surgery team, electrophysiology team, or a combination). The potential for complications, particularly during the epicardial portion of the procedure, must be considered and a clear plan must be in place to intervene quickly. In addition, communication and planning is critical to pre-operative, peri-operative, and post-operative care. This includes issues regarding antiarrhythmic drug use, anticoagulant use, and management of any post-operative arrhythmia.

Conclusions:

Epicardial AF ablation has come a long way since the initial techniques developed by James Cox. Although the development of epicardial and endocardial ablation techniques had largely occurred in parallel, we are seeing a merging of approaches that offers the potential for significant synergistic benefits. Given the potential risk of epicardial ablation, currently its role is best suited to those in whom endocardial ablation alone may have more limited benefit. This includes those with persistent or long-standing persistent AF, those with significant structural cardiac disease, or those with prior failed attempts at endocardial ablation. But in these populations, hybrid ablation in particular offers distinct advantages, which make it an exciting and promising approach.

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