Surgical ablation for atrial fibrillation

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This paper reviews the history of surgical procedures developed for eradication of atrial fibrillation (AF) during cardiac surgery for structural heart disease, and in patients with AF without other indication for cardiac surgery. Current evidence indicates that, despite their proven efficacy, the Cox–Maze procedure and its modifications require cardiopulmonary bypass and cannot be easily justified in the case of AF without other indication for cardiac surgery. In patients undergoing cardiac surgery for mitral valve disease, concomitant ablation techniques using modifications of the Maze and alternative energy sources appear to be safe and effective in treating AF, especially in non-rheumatic disease. Minimally invasive epicardial ablation has been recently developed and can be performed on a beating heart through small access incision ports. Various techniques combining pulmonary vein isolation, ganglionated plexi ablation, and left atrial lines have been tried. Initial results are promising but further clinical experience is required to establish ideal lesion sets, appropriate energy sources, and the benefit–risk ratio of such an approach in patients without other indication for cardiac surgery. The role of surgical ablation in the current management of AF is under investigation.

Keywords
Atrial fibrillation • Surgical ablation

Introduction
Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia and a source of considerable morbidity and mortality. The presence of AF accounts for a 50–90% increased risk of overall mortality in the Framingham Heart Study.1 Atrial fibrillation is also associated with significant morbidity, including a four- to five-fold increased risk of stroke,2 a two-fold increased risk of dementia,4,5 and a tripling of risk of heart failure.2 In the Framingham Study, the percentage of strokes attributable to AF increases steeply from 1.5% at 50–59 years of age to 23.5% at 80–89 years of age.3 Atrial fibrillation and its associated morbidity represent a significant socioeconomic burden on the healthcare system consuming between 0.9 and 2.4% of total National Health Service expenditure in the UK, while in the USA total Medicare costs are 8.6–22.6% higher for patients with AF in all age–sex strata.6,7 The Euro Heart Survey on AF has identified inpatient care and interventional procedures as the principal components of the increased economic burden posed by AF.8 Consequently, treatment of patients with AF and, more importantly, primary or secondary prevention of AF, should have a substantial health and socioeconomic impact. Medical AF therapies focused on restoring and maintaining sinus rhythm have had poor results, because antiarrhythmic drugs have minimal long-term efficacy and high rates of adverse events.9,10 Radiofrequency catheter ablation (RCA) is proposed as an effective treatment for recurrent, drug-resistant AF.11 However, single-procedure success rates are 60–80% for patients with paroxysmal AF, with 30–40% of patients requiring a second procedure due to arrhythmia recurrence.12–14 Long-term follow-up data appear even less promising, with arrhythmia-free survival in 29–53% of patients.15–17 For patients with persistent AF, the treatment strategies and the benefit–risk ratio of RCA are even less well established. Extensive and frequently repeated ablation procedures may be necessary in these patients.18 Given the limitations of pharmacotherapy and RCA, surgical ablation of AF using either standard or minimally invasive techniques has gained increased popularity.

Development of open heart surgical techniques for atrial fibrillation ablation
The surgical strategies against AF include three principal targets: (i) isolation of the triggers of AF and interruption of the electrophysiological substrate that sustains the arrhythmia in both the
right and left atria, (ii) reestablishment or maintenance of atrioventricular synchrony ensuring optimal cardiac performance, and (iii) restoration and preservation of atrial mechanical function in order to improve diastolic filling and avoid blood stasis in the atrium. Surgical techniques initially aimed at isolating the abnormal rhythm to a particular area of the atria, thereby limiting the impact upon the ventricles.

**Left atrial isolation**

In 1980, Williams et al. described a procedure called ‘left atrial isolation’. This was achieved by performing a left-sided arteriotomy incision which limited the arrhythmia to the left atrium (LA), leaving the rest of the heart in sinus rhythm. The disadvantage of this procedure was that the risk of systemic thromboembolism from AF was unaffected.

**Corridor technique**

In 1985, Guiraudon et al. put forward the ‘Corridor’ technique in which a portion of the atrial septum (the ‘corridor’) containing the sinoatrial and atrioventricular nodes is isolated intra-operatively and as a result the sinoatrial node would be able to initiate ventricular contraction. This approach failed to achieve sinus rhythm in a significant number of cases. In addition, atrial areas outside the narrow right atrial corridor continued to fibrillate with remaining loss of atrial transport function and persistent risk of thromboembolism.

**Cox–Maze I and II**

In 1991, Cox presented the first of the Maze series of procedures. The concept of these procedures was based on the assumptions that: (i) fractionation of the atrial tissue into smaller segments would not allow multiple re-entrant wavelets to be maintained and (ii) these segments should be linked to each other allowing depolarization of sufficient atrial myocardium without allowing re-entry to occur at the same time. The original Maze I procedure aimed at interrupting all potential atrial circuits in a Maze-like manner. In this procedure, cutting and sewing incisions were strategically made to interrupt the multiple macroreentrant circuits and direct the sinus impulse from the sinus to the atrioventricular node along a specified route. It also allowed most of the atrial myocardium to be activated, resulting in preservation of atrial transport function in most patients. The procedure involved biaxial excisions, incisions encircling each pulmonary vein, extensive incisions starting in the right atrium and extending across the fossa ovalis, incisions from the inferior aspect of the pulmonary veins to the level of the mitral valve annulus, and finally cryoablation at $-60^\circ$C within the coronary sinus. The Maze I procedure had two important disadvantages: significant chronotropic incompetence as a result of the incisions placed near the sinus node, and prolonged interatrial conduction time resulting in atrioventricular dyssynchrony due to incorporation of Bachmann’s bundle during left atrial roof incision. The procedure was modified therefore into the Maze II, wherein incisions around the sinus node were not performed while several alterations were also made to the left atrial incisions.

**Cox–Maze III**

The Maze II procedure was further modified by moving the left atrial roof incisions posteriorly. This constituted the Maze III procedure which overall includes also en-bloc isolation of the pulmonary veins (PVs) and posterior LA along with excision of the left atrial appendage. The Maze III procedure became the gold standard in treating surgically chronic AF since it was associated with a higher incidence of sinus rhythm maintenance, need for fewer pacemaker implantations, and improved long-term atrial transport function. Another important impact of the Maze III procedure was the significant reduction in the rate of cerebrovascular accidents. This positive effect was directly related to the high success rate of the procedure in ablating AF, and to the amputation of the left atrial appendage. Damiano et al. demonstrated long-term results in patients having the Cox–Maze procedure, either as an isolated or combined procedure, with a success rate $>90\%$. Other reports, however, have shown lower success rates, $\sim 70\%$. Reported predictors for failure of the Cox–Maze procedure were duration of AF, increased size of the LA ($>6$ cm), and advanced age. The reported operative mortality rate, ranged from 2 to 3% included patients undergoing concomitant high-risk cardiac surgical procedures. Despite its proven efficacy, the Maze III procedure had not been widely adopted by the surgical community because of its complexity, the involvement of prolonged aortic cross-clamp and cardiopulmonary bypass times, and significant morbidity such as fluid retention, altered atrial function, chronotropic insufficiency due to autonomic denervation, and pacemaker requirements.

**Cox–Maze IV**

To simplify the Cox–Maze operation and make it easier to perform, various groups have replaced the incisions of the traditional cut-and-sew procedure with linear lines of ablation. The new modified procedure, Maze IV, replaces most of the previous incisions with linear ablation lines using newer and easier technologies, such as radiofrequency (RF) energy, cryoenergy, and microwave energy. However, even though this procedure can be performed through a small right thoracotomy, it still requires cardiopulmonary bypass.

**Mini-Maze**

To further simplify AF surgery, Cox also suggested another procedure, the modified Cox–Maze procedure, using three essential lesions necessary to cure most patients of AF. These lesions are (i) an incision encircling the PVs, (ii) left atrial isthmus and companion coronary sinus lesions, and (iii) a right atrial isthmus lesion. The modified Cox–Maze procedure has been shown to be nearly as effective as the full Cox–Maze III. According to Cox’s experience with the Maze procedure, the left atrial isthmus lesion is critical to a successful operation. This lesion, along with conduction through the coronary sinus, has been called the Achilles’ heel of the operation because every failure in Cox’s series was associated with persistent conduction across this isthmus or the coronary sinus.
Radial approach
The radial approach was developed as a development of and an alternative to the Maze procedure, to provide a more physiological atrial activation contraction sequence.38 In contrast to the Maze procedure in which the incisions desynchronize the activation sequence and often cut across the atrial coronary arteries, the incisions produced by the radial approach radiate from the sinus node towards the atrioventricular annular margins and parallel to the coronary arteries. The radial approach was technically easier than the Maze, was equally likely to restore sinus rhythm (90 vs. 92% for the Maze), and was associated with better left atrial transport function after surgery, as assessed with Doppler echocardiography.39 However, the clinical experience with this approach is limited.

Surgery for atrial fibrillation concomitant with other heart operations: clinical experience
Since the Maze procedure is recognized as the most effective way to eliminate AF, combining the Maze procedure during major cardiac surgeries has been adopted in clinical practice. The technical evolution of the Maze procedure resulted in easier and simpler approaches by replacing ‘cut-and-sew’ with ablation lines using various energy sources, and modifying the lesion sets to simpler ones.40,41 The prevalence of AF in patients undergoing cardiac surgery varies and may be up to 50% in patients undergoing mitral valve surgery.24,42–44 Atrial fibrillation onset can be considered a relative indication for mitral valve surgery in those who have significant mitral valve disease.45 However, mitral valve surgery alone does not revert AF back into sinus rhythm.46,47 When the duration of AF preoperatively is longer than 6 months, the risk of remaining in AF is 70–80%.47,48

Since long-standing persistent AF rarely returns to sinus rhythm if left untreated, and several studies indicate that untreated AF will affect late survival, it may be advisable to treat AF at the time of other surgery.49,50 A number of retrospective studies have documented success using a variety of surgical procedures and different technologies for the treatment of AF with concomitant mitral or other cardiac operations. In these series, success rates have varied between 65 and 95% at 6 months.30,51–54 A meta-analysis of nine randomized controlled trials concluded that, when performed in addition to cardiac surgery, the Maze procedure is associated with a significant increase in the odds of freedom from AF at 12 months of follow-up without a significant increase in morbidity or mortality.55 However, although the Maze procedure cures AF in >90% of patients, several studies have shown insufficient sinus-rhythm restoration rates (46–95%) for the Maze procedure in AF associated with rheumatic valve disease.56,57 Decreased freedom from AF is assumed to derive from progressive rheumatic changes to the atrial wall or regeneration of atrial tissue. Rheumatic heart disease produces fibrosis of the atrial muscle, resulting in anatomical remodelling. Increased inflammatory response and degeneration of the atrial myocardium contribute to post-operative AF recurrence.58

In order to reduce the procedural time and extent of surgery, ablating the LA only has emerged as a convincing strategy in the surgical treatment of AF. Additional benefits of LA ablation are that it may reduce post-operative troublesome bradycardias, and is well suited to minimally invasive cardiac surgery.59 Left atrium ablation is typically recommended for patients with recent onset of paroxysmal AF who are undergoing elective surgery with no reason to open the right atrium. The success rates of these procedures range between 74 and 82% at variable follow-up. A meta-analysis of 69 studies of LA and bialtrial ablation showed an AF-free rate superior to bialtrial ablation, whereas survival was comparable for both techniques.59 However, in a recent study, LA ablation resulted in more frequent AF recurrence in chronic AF patients undergoing mitral valve surgery compared with bi-atrial ablation.60

Camm et al.61 addressed the question as to whether cryoablative procedures during concomitant cardiac surgery are effective for the treatment of AF compared with no treatment, catheter-based therapy, or other sources of energy, and identified nine relevant articles. One study showed that cryoablation was significantly more effective than mitral valve surgery alone at a 12-month follow-up (73.3 vs. 42.9%, respectively).62 The use of a concomitant cryoabative procedure was also shown to be superior to subsequent catheter-based cryoablation in restoring sinus rhythm (SR) at a 12-month follow-up (82 and 55.2%, respectively).63 Restoration of SR was significantly decreased in those patients suffering from permanent rather than paroxysmal AF (47 vs. 85%).63 Six of nine studies indicated that cryoablation is most successful in patients suffering from paroxysmal rather than permanent AF. Only one study suggested an increased complication rate from cryoablation; however, no study suggested any negative impact on mortality or morbidity. Thus, cryoablation during concomitant surgery was considered a safe and acceptable intervention for the treatment of AF with an SR restoration rate of 60–82% at 12-month post-surgery.61

Various studies have comparatively evaluated the success rate of other antiarrhythmic surgical procedures in patients undergoing mitral valve replacement against mitral valve replacement alone. Deneke et al.64 assessed the efficacy of sole mitral valve replacement and of additional modified Maze operation using RF ablation in patients with chronic AF. After 12 months, sinus rhythm was reinstituted significantly more often in patients of the combined procedure (80 vs. 27%). The survival rate in the mitral valve replacement plus Maze group at 1 year was found to be 73% with no significant difference with the other group. Doukas et al.65 also studied the long-term restoration of sinus rhythm in patients with chronic AF by sole mitral valve surgery and valve surgery plus left atrial incision and PV isolation. They found that left atrial radiofrequency ablation significantly increased the prevalence of sinus rhythm at 12 months (44.4 vs. 4.5%) without an increase in perioperative morbidity. Gaita et al.66 studied the role of PV isolation alone vs. left atrial linear lesions localized in the posterior region in the treatment of permanent AF in the setting of significant left atrial dilatation and valvular heart disease. They demonstrated that a limited approach involving linear lesions in the posterior region of the LA is extremely effective in restoring and maintaining SR even in the long run. In this patient population, electrical PV
isolation alone is not effective. Regarding paroxysmal AF, Gillinov et al.\textsuperscript{54} assess the effectiveness of three surgical treatments [pulmonary vein isolation (PVI) alone, PVI with left atrial connecting lesions, and a Cox–Maze II or III procedure] in patients undergoing mitral valve surgery. They reported that ablation procedure did not affect prevalence of AF or incidence of ablation failure and thus PV isolation alone may be adequate treatment for patients with paroxysmal AF undergoing mitral valve surgery, particularly when AF is of short duration.

Minimally invasive surgical techniques for atrial fibrillation

The Cox–Maze surgery, although highly effective, was technically challenging and entailed complete open heart surgery by dedicated surgeons in selected populations; thus, it was not widely adopted. Additionally, it is difficult to justify the use of cardiopulmonary bypass and cardioplegic arrest, especially through a sternotomy, for the surgical treatment of AF alone. To bring an effective and reasonable therapy to these patients, recent efforts have been directed towards developing an epicardial approach to ablation that can be performed on a beating heart, preferably through small access incisions or ports. Three minimally invasive surgical technologies have been developed and used for the ablation of lone AF: robotics,\textsuperscript{66} thoracoscopic,\textsuperscript{66,67} and through minithoracotomy.\textsuperscript{68–70} Each has its own advantages and disadvantages but all provide access to the entire atrial epicardium of a beating heart, whereupon lesions can be placed with precision and immediate visual feedback. Pulmonary vein isolation, for example, is easily accomplished in this manner, and LA left atrial appendage excision is possible. The numerous strategies of ablation of minimally invasive procedures involve isolating the PVs either as a box or separately with or without ablation of the ganglionated plexi (GP) and with or without additional ablation lines.

Pulmonary vein isolation

Pulmonary vein isolation by encirclement of the pulmonary veins confines the trigger to the pulmonary veins and, when expertly performed, will cure the majority of patients with paroxysmal AF. The first case reports of a minimally invasive, epicardial PVI ablation performed on a beating heart appeared in 2003 and 2005.\textsuperscript{71,68} The good results of PVI in patients with paroxysmal, persistent, and permanent AF were first reported by Wolf et al.\textsuperscript{69} who applied bilateral video-assisted thoracoscopic off-pump epicardial PVI and removal of the left atrial appendage. This novel approach used a bipolar non-irrigated RF clamp to achieve pulmonary vein isolation while the left atrial appendage was surgically excised. The epicardial approach enabled this procedure to be performed on a beating heart, avoiding the need for cardiopulmonary bypass. In this study, 91% of patients were in sinus rhythm at 3-months’ follow-up. However, a subsequent study by Li et al.,\textsuperscript{72} which followed the ablation protocol of Wolf et al.,\textsuperscript{69} showed that PVI might not be sufficient for persistent AF termination since ectopic foci outside the pulmonary veins and substrate effects play an important role in this setting, although the PVI procedure slows AF and makes supplemental pharmacological cardioversion effective.

Pulmonary vein isolation plus ganglionic ablation

Ganglionated plexi ablation is supported by electrophysiological studies which documented that GP may play a critical role in the initiation and maintenance of AF.\textsuperscript{73,74} These plexi innervate the pulmonary vein myocardial sleeves and the adjacent atrial muscle. Modification of left atrial GP by epicardial or endocardial ablation has been proposed for treatment of paroxysmal AF.\textsuperscript{75–77} The combination of left atrial PV isolation with GP ablation may decrease AF recurrences at least in short-term follow-up.\textsuperscript{75,78–82}

Various studies have evaluated minimally invasive, thoracoscopic surgical ablation procedures which combined epicardial PVI with bipolar RF, GP ablation, and selective excision of the left atrial appendage in patients with AF. Edgerton et al.\textsuperscript{81} reported long-term freedom from atrial tachyarhythmias of 86.3% at 6 months and 80.8% at 12 months in patients with paroxysmal AF, without any operative deaths or major adverse cardiac events. McClelland et al.\textsuperscript{83} reported freedom from AF during 1 year of follow-up in 75% of patients overall, and 87.5% of patients with paroxysmal or persistent AF. Yilmaz et al.\textsuperscript{82} reported a 77% freedom from AF during a mean follow-up of 11.6 months in a patient cohort with paroxysmal (63%), persistent (27%), and permanent (10%) AF. In this study, two patients ultimately underwent a median sternotomy, whereas no cerebrovascular accidents or pacemaker implantation were identified, and none of the patients died. Beyer et al.\textsuperscript{70} reported freedom from AF in 87% of patients (paroxysmal 93%, persistent 96%, and permanent 71%) at 13.6 ± 8.2 months. No mortality was reported, whereas post-operative complications included pacemaker requirement in 5%, phrenic nerve palsy in (3%), haemothorax in (3%), transient ischaemic attack in 1%, and pulmonary embolism in 1% of patients. Han et al.\textsuperscript{84} reported 65% freedom from atrial tachyarhythmias at 12 months in a patient cohort of paroxysmal (73%) and persistent (27%) AF, while recurrences after surgery were usually responsive to catheter ablation and/or antiarrhythmic drugs. The only major complications in this study were one phrenic nerve injury and two pleural effusions while there were no deaths. Ganglionated plexi ablation has been promising in catheter trials and is becoming popular among groups adopting surgical ablation. However, no randomized data exist to clearly define its potential benefit.

Pulmonary vein isolation plus ganglionic ablation plus additional ablation lines

Studies have shown beneficial effects of adding LA ablation lines to PVI, specifically in patients with persistent AF.\textsuperscript{85,86} Krul et al.\textsuperscript{87} applied PVI and GP ablation and created additional left atrial lines in patients with persistent and long-standing persistent AF. Lines consisted of a superior line that connects the ablation lines similar to a mitral isthmus line as commonly used in pulmonary vein myocardial sleeves and the adjacent atrial muscle. Modification of left atrial GP by epicardial or endocardial ablation has been proposed for treatment of paroxysmal AF.\textsuperscript{75–77} These plexi innervate the pulmonary vein myocardial sleeves and the adjacent atrial muscle. Modification of left atrial GP by epicardial or endocardial ablation has been proposed for treatment of paroxysmal AF.\textsuperscript{75–77} The combination of left atrial PV isolation with GP ablation may decrease AF recurrences at least in short-term follow-up.\textsuperscript{75,78–82}
success rate at 1 year was 86% at a patient cohort of paroxysmal (52%), persistent (42%), and long-standing persistent (6%) AF. Three patients had a sternotomy and four had adverse events (haemorrhax, pneumothorax, and pneumonia), while no thromboembolic complications or mortality occurred. Boersma et al.\cite{Boersma2018} reported a 65.6% freedom from left atrial arrhythmia at 1 year in a patient cohort of paroxysmal (76%) and persistent (24%) AF. This prospective randomized clinical trial performed a head-to-head comparison of RCA and minimally invasive surgical ablation in a population of patients with failed prior RCA and/or dilated atria and hypertension, and showed surgical ablation to be superior to RCA (36.5%, \( P = 0.002 \)) in achieving freedom from arrhythmia after a 12-month follow-up. However the procedural surgical ablation adverse event rate (23%) was clearly higher than that of RCA (3.2%), consisted mainly by procedural complications such as pneumothorax, major bleeding, and need for permanent pacing.

**Alternative energy sources**

Cryo-ablation, RF, high-intensity focused ultrasound, laser, and microwave energy devices became such alternatives in an attempt to move towards establishing less invasive modifications of the Maze procedure.\cite{Khargi2010} Khargi et al.\cite{Khargi2010} reviewed the efficacy of alternative energy sources vs. the classic Maze III procedure in the surgical treatment of AF. In this meta-analysis of 16 studies, there were 2279 patients who had undergone surgical ablation with an alternative energy source and 1153 patients who had undergone surgical Maze III. Post-operative sinus rhythm rates with alternative energy sources compared with Maze III were 78.3 vs. 84.9% (\( P = 0.03 \)). As potential explanation for this small but distinct difference was considered the lack of continuous and transmural atrial lesions created by the application of alternative sources of energy, and the higher percentage of patients with paroxysmal AF in the group of Cox–Maze III procedure. The post-operative mortality was substantial but not different for both techniques (4.2 vs. 2.1%, \( P = 0.09 \)), while ~5% of patients underwent a pacemaker implantation. The Cox–Maze IV has significantly shortened operative times while maintaining the efficacy of the traditional cut-and-sew Cox–Maze III.\cite{32,34,35} Although new devices and energy sources have revolutionized surgery for AF, by reducing operations time, their principal limitation is the inability to reliably create transmural lesions on the beating heart. This is owing to the heat-sink effect of circulating blood. The blood pool serves as a ‘heat sink’ when RF and microwave sources are applied to the epicardium and as a ‘cooling-sink’ with cryothermia. Two strategies have been used to overcome this problem. The first is bipolar RF devices capable of creating reliable transmural lesions, both on the arrested and the beating heart. Because of the focused nature of the energy, there is no chance for collateral injury.\cite{91,92} The second strategy uses high-intensity focused ultrasound which excludes the heat sink by precisely focusing energy on the atrial muscle, rapidly heating the tissue, and creating transmural lesions.\cite{91} This advantage can be used to create lesions across the left atrial isthmus from the epicardium without injury to the circumflex coronary artery, which no other energy source can accomplish.\cite{36,91} An alternative to heating the myocardium is cryoablation which obliterates atrial tissue by freezing. An advantage of cryoablation is its presumed ability to relatively preserve tissue architecture and collagen structure.\cite{94} Microwave energy has also been proven as an effective source of energy for use in catheter-based surgical ablation procedures. Electromagnetic radiation induced by microwave energy, transforms electromagnetic into kinetic energy and eventually thermal necrosis of myocardium. The physics of this energy source may allow for deeper and more reliable ablation of atrial tissue than RF energy.\cite{95} A postmortem analysis, however, suggests that the created microwave lesions are highly variable and are often not transmural in nature.\cite{96} There is still lack of adequate clinical data regarding which energy source is best, while the role of energy devices in this field needs further to be clarified. Most of these new technologies also bear their shortcomings. Apart from the uncertainty regarding the transmurality of the lesions, these also include the prolonged ablation time of up to 2 min per lesion, local tissue charring because of high temperatures and collateral cardiac–extracardiac damage caused by undesired spread of the energy.

**Recommended indications for surgical atrial fibrillation ablation**

The indications of surgical ablation remain controversial. No evidence exists for decreased mortality and morbidity or increased quality of life with surgically restored and maintained sinus rhythm in patients with AF. In the only randomized trial that has compared surgical with catheter ablation, surgical was superior to catheter ablation in achieving freedom from left atrial arrhythmias after 12 months of follow-up, albeit at a significantly higher procedural adverse event rate.\cite{89} Thus, institute experience, comorbidities, and patient preference should be taken into consideration for the final decision. The recent (2010) ESC guidelines on AF\cite{85} recommend surgical ablation in:

1. Symptomatic AF patients undergoing cardiac surgery (IIA-A).
2. Asymptomatic AF patients undergoing cardiac surgery in whom the ablation can be performed with minimal risk (IIb-C).
3. Patients with stand-alone AF who have failed catheter ablation and in whom minimally invasive surgical ablation is feasible (IIb-C).

The EHRS/EHRA/ECAS expert consensus statement (2012) on AF recommends surgical ablation in symptomatic AF, paroxysmal or persistent, in patients undergoing surgery for other indications (IIa-C). Stand-alone surgical ablation is recommended for drug-refractory AF (Class 1 or 3 drugs), paroxysmal or persistent, in patients who have failed catheter ablation or prefer a surgical approach (IIb-C). The new 2011 ACC/AHA/HRS guidelines on AF and their updates\cite{11,98,99} do not provide specific recommendations regarding surgical ablation. However, the ACC/AHA 2008 guidelines on adults with congenital heart disease\cite{100} give a IIa-C recommendation for concomitant Maze procedure for atrial tachyarrhythmias in adults with dextro transposition of the great arteries requiring reoperation for any reason, and the 2008 ACC/AHA guidelines on valve disease\cite{101} recommend that Maze...
procedure may be considered at the time of MV repair in patients with a history of AF (IIb-B).

Conclusions

(1) Surgical ablation techniques have been developed and are appealing because of the limited efficacy of conventional catheter ablation to eradicate AF in certain clinical settings.

(2) Surgical treatment of AF by traditional cut-and-sew incisions or ablation lines following the techniques developed by Cox (Maze and modifications) are highly effective but require open heart surgery and cannot be easily justified in the case of stand-alone AF.

(3) In patients undergoing cardiac surgery for mitral valve disease, concomitant ablation techniques using the Maze IV or modifications, various targets, and alternative energy sources appear to be safe and effective in treating AF, especially in non-rheumatic disease.

(4) Minimally invasive epicardial ablation has been recently developed and can be performed on a beating heart through small access incision ports. Various techniques combining pulmonary vein isolation, GP ablation, and left atrial lines have been tried. Initial results are promising, but additional refinements in selection of ablation targets and ablation technology are necessary to facilitate the widespread application of minimally invasive AF ablation. Long-term success of these procedures is also an area not thoroughly studied, as well as identification of groups of individuals that are most likely to benefit from this form of therapy.

(5) Randomized, controlled trials are needed in order to determine the role of surgical techniques in the management of this pandemic disease.

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