Advances in Cardiothoracic Surgery
Chapter 5

Principles for Surgical Management of Atrial Fibrillation

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First Published January 30, 2016

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Abstract

Atrial Fibrillation (AF) is a worsening global pandemic affecting over 33.5 million people worldwide. It has significant healthcare and financial implication. Medical management has not been able to provide all the required solutions. Surgery for AF has evolved as an additive armamentarium to address the residual problems. This manuscript reviews the evolution of AF surgery and the use of alternative energy sources. The goal of treating AF is to achieve sinus rhythm or rate control, adequate cardiac output and prevention of thromboembolic event. Continuing pharmacologic agents to maintain or achieve this goal after surgery should not be regarded as a marker of failure of surgery. There is need for further research to address the pathology and treatment of AF.
Introduction

Atrial fibrillation (AF) is the commonest arrhythmia and constitute a significant morbidity and economic burden. It is a global healthcare problem with evidence suggesting an increased incidence and prevalence worldwide [1]. A world-wide population based study in 2010 estimated there were 33.5 million individuals with AF and 5 million new cases yearly [2].

In the United Kingdom 1.28% of the total population have AF, an incidence of 0.3%. The prevalence doubles with each advancing decade of age from 0.5% at age 50-59 years to 9% at age 80-90 years [3]. In Europe there were approximately 8.8 million adults with AF in the year 2010 and this will more than double in 2060 [3].

In the USA in 1.12% of the total population had AF in the year 2005 and the prevalence is expected to more than double in 2050 [4].

A recent epidemiologic study in China showed a 20-fold increase in the prevalence of AF and 13-fold increase in AF related stroke over an 11 years period, with a lifetime risk of 1 in 5 Chinese adult [5].

The financial cost of AF to the United Kingdom National Health Service (NHS) in 1995 was £244 to £531 million representing 0.6-1.2% of overall health care expenditure in the UK. This amount doubled in the year 2000 [3].

In the USA the estimated direct and indirect economic cost of all-cause stroke was US$ 34.3 billion in 2008 and AF related stroke accounted for 20% of this amount [3].

The treatment of atrial fibrillation is in the first instance pharmacologic aimed, at restoration of normal sinus rhythm and/or heart rate control with prevention of thromboembolic event [6].

Not all cases of atrial fibrillation are amenable to pharmacologic modulation alone. Recent understanding of the mechanism of initiation and maintenance of AF has given rise to further intervention modalities for the management of AF. These modalities include surgical ablation, which involve disruption of the pathways involved in the initiation and maintenance of AF.

Surgery for atrial fibrillation was started by William and colleagues in 1980 and has evolved over the years to involve different lesion sets and the use of various energy sources. The gold standard for the treatment of atrial fibrillation is Cox Maze with a conversion rate of 98-99%. This is the standard by which other treatments are rated.

Our objectives is to outline the electro-physiologic basis of the various lesion sets, efficacy of the various energy sources, indications for surgery and overview of the various surgical techniques and their outcome.

Materials and Methods

An extensive English literature search using the MEDLINE database between 1960 and 2010 was performed. Keywords used for the search includes atrial fibrillation, surgical ablation, cox maze procedure, cardiac
surgery, surgery, denervation, radiofrequency, microwave, ultrasound, laser and cryothermy. Additional studies were identified from references cited in identified studies and review articles.

**Results and Discussion**

**Definition and Classification of Atrial Fibrillation**

AF is a supraventricular tachyarrhythmia characterised by uncoordinated atrial activation with consequent deterioration of atrial mechanical function. On the electrocardiogram (ECG) AF is characterised by replacement of consistent P-waves by rapid oscillations or fibrillatory waves that vary in amplitude, shape and timing, associated with an irregular frequent rapid ventricular response when atrioventricular (AV) conduction is intact [7].

There are many conflicting and vague definitions to characterise the different clinical patterns of AF, this has made comparison of studies and assessment of treatment difficult [7].

A clinically useful classification of AF must carry therapeutic implications. Therefore the joint American College of Cardiology/American Heart Association/European Society of Cardiology Task Force has described a clear nomenclature on the classification of AF. According to this guidelines classification starts with the first diagnosed episode of AF.

When a patient has had 2 or more episodes, AF is defined as recurrent. If the arrhythmia terminates spontaneously, recurrent AF is said to be paroxysmal; when sustained for more than 7 days, AF is designated persistent. Termination with pharmacological therapy or direct-current cardioversion does not change the designation. First-detected AF may be either paroxysmal or persistent AF. The category of persistent AF also includes cases of long-standing AF (e.g., greater than 1 year), usually leading to permanent AF, in which cardioversion has failed or has not been attempted.

**Pathophysiology of Atrial Fibrillation**

**Pathology of AF**

The most frequent patho-anatomical features of AF is atrial fibrosis and loss of atrial myocardium. Histological examination of atrial tissue of patients with AF showed patchy fibrosis juxtaposed with normal atrial fibres, this may account for non-homogeneity of conduction. Histology of left atrial tissue in patients following mitral valve surgery showed mild to moderate fibrosis in patients with sinus rhythm or early onset AF as against severe fibrosis and substantial loss of myocardium in patients with long-standing AF [9]. In experimental studies of heart failure, atrial dilatation and interstitial fibrosis facilitated sustained AF [9]. Similar changes occur with ageing. Several RAAS pathway are activated in experimental and human AF and ACE inhibition and angiotensin II receptor blocked has the potential to prevent AF by reducing fibrosis [11].
Electrophysiology of AF

The onset and maintenance of a tachyarrhythmia requires a trigger and an anatomical substrate. Two mechanisms namely automaticity and multiple re-entrant circuit have been put forward to explain the electrophysiology of AF. These mechanisms may coexist and are not mutually exclusive.

Automatic Focus Theory

A focal source for AF could be identified in humans and ablation of this source could extinguish AF. Pulmonary veins (PV) are the most frequent source of this rapid atrial impulse, other foci have been identified in the superior vena cava, ligament of Marshall, left posterior free wall, crista terminalis and coronary sinus. In histological studies, cardiac muscle with preserved electrical properties have been shown to extend into the PV [12,13]. Atrial tissue on the PV of patients with AF have shortened refractory period than in control patients and in other parts of the atrium. This heterogeneity of conduction may promote re-entry and form a substrate for sustained AF [14].

Multiple Wavelet Hypotheses

Moe and colleagues proposed that fractionation of wave fronts propagating through the atria results in self-perpetuating daughter wavelets. In this model the number of wavelets at any time depends on the refractory period, mass and conduction velocity in various parts of the atria. A large atrial mass with a short refractory period and delayed conduction increases the number of wavelets, favouring sustained AF. The resulting increase in wavelets density promotes the onset and maintenance of AF [15].

Indications for AF Surgery

Lone AF

The main indication for surgical treatment of AF is intolerance of the arrhythmia in a patient who has failed medical therapy. Patients with lone AF should receive a trial of medical therapy prior to surgery. A significant number of patients with AF are referred to surgery due to significant side effects or intolerance of anti-arrhythmic drugs.

The development of tachycardia induced cardiomyopathy (TIC) in patients with AF is another important indication for surgery. TIC is a condition of atrial or ventricular dysfunction resulting directly from increased heart rate in a patient with otherwise structurally normal heart. TIC can lead to heart failure if left untreated. It is important to identify this entity as it is reversible by surgical restoration of sinus rhythm [16,17].

Contraindication to long term anticoagulation such as patients who have developed intracranial bleeding while on warfarin is an important indication for surgery [17,18].

In addition patients with chronic AF who have suffered cerebrovascular accident despite adequate anticoagulation should be considered for surgery.
**Concomitant AF**

All patients with AF who undergo elective cardiac surgery (coronary artery bypass grafts, valve replacement or repair) should strongly be considered for concomitant Cox-maze procedure. Recent studies have shown that adding a maze procedure can reduce the risk of cardiac and stroke related deaths in these patients [19,20]. The only contraindication to maze procedure is in high risk patients who tolerate their AF well and have not had problem with anticoagulation.

**Surgical Options for AF Treatment**

The surgical treatment of AF is aimed at altering the geometry and anatomy needed to support AF.

**Left Atrial Isolation**

In 1980 William and colleague developed the left atrial isolation procedure which was successful in confining AF to the left atrium and restoring sinus rhythm in the rest of the heart. This procedure was important because it restored a normal ventricular rhythm without requiring a permanent pacemaker. Electrical isolation of the left atrium also unexpectedly restored normal cardiac hemodynamic. This occurred because the right atrium and right ventricle contract in synchrony following the procedure, providing a normal right sided cardiac output that was delivered to the left side of the heart. Although the left atrium is isolated, the left ventricle immediately adapted to the normal right sided cardiac output and delivered a normal forward cardiac output. By confining AF to the left atrium this procedure restored regular heartbeat and normal cardiac output but did not eliminate the risk of thromboembolism as the left Atrium was still in AF [21].

**The Corridor Procedure**

In 1985 Guirandon and co-workers introduced the corridor procedure for the treatment of AF. This was an operation that isolated a strip of atrial septum harbouring both the SA node and AV node, thereby allowing the SA node to drive the ventricles [22]. The procedure corrected the irregular heartbeat associated with AF, but the atria either remain in AF or developed their own asynchronous intrinsic rhythm because they were isolated from the septal “corridor”. This procedure isolates the atria from their respective ventricle precluding possibility of AV synchrony. The corridor procedure was abandoned because it neither address the hemodynamic compromise nor the thromboembolism associated with AF [23].

**The Atrial Transection Procedure**

The above procedures aim to confine AF to the atria and prevent its propagation to the ventricles they were not targeted to cure AF.

In 1985 Cox’s group described for the first time a series of experiments that attempted to cure AF in a canine model. After a number of experiments it was found that a single long incision across both atria and down the septum cured AF. This atrial transaction procedure prevented
the induction and maintenance of AF or atrial flutter in every canine receiving the procedure. Unfortunately this procedure was not curative in its clinical application [24].

Extensive experimental investigation at Washington University under James Cox led to the introduction of the maze procedure in 1987.

**Cox Maze Procedure**

The Cox maze procedure was designed to interrupt all or any micro-re-entrant circuits that might potentially develop in the atria, thereby precluding the ability of the atria to fibrillate or flutter.

The Maze procedure was the first surgical procedure to successfully restore AV synchrony and regular heartbeat, thus significantly decreasing the risk of thromboembolism and stroke [25]. The cox-maze procedure involves surgical incisions across both right and left atrial. The incisions were placed so that the SA node could direct sinus impulse throughout both atria. It also allows all the atrial myocardium to be activated, resulting in preservation of atrial transport function in most patients [26].

The original technique, the maze I procedure was introduced in 1991, only to be soon modified to become maze II procedure because of late chronotropic incompetence and high incidence of pacemaker implantations. The maze II proved to be extremely technically difficult to perform and was modified to become the maze III procedure, also known as the cox-maze III procedure.

The Cox maze is the gold standard for the surgical treatment of AF, long term follow-up of patients who had the procedure showed a reproducible 97% AF free [27].

**Pulmonary Vein Isolation**

There are newer procedures developed for surgical treatment of AF. This involves isolation of the pulmonary veins (PV) either as a box or singly with a connecting lesion. Most surgeons also advocate creating a lesion to the mitral annulus from the PV isolation and amputation of the left atrial appendage.

**Left Atrial Volume Reduction**

Left atrial diameter is a predictor of recurrent AF after the maze procedure. Concomitant left atrial volume reduction with maze procedure enhances restoration and maintenance of sinus rhythm with improvement of cardiac output [28,29].

**Energy Sources for Maze Lesions**

The Cut-and-sew Cox Maze procedure is replaced by ablation procedures that use alternative energy sources. Radiofrequency (RF), microwave, ultrasound, laser and cryothermy are used to produce lesion sets speedily with minor risk of bleeding [30-36]. These ablation technology must meet certain important criteria which include achievement of bidirectional block, safety, adaptable to minimal invasive approach and requires less time to perform.
The mechanism of action and shortcomings of the various energy sources in use today are shown in table 1 and table 2 [37]. Energy sources that produce thermal lesion could cause injury to surrounding structures, especially the oesophagus.

**Table 1: Mechanism of action in Different Energy sources [37].**

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Mechanism of action</th>
<th>Tissue Destruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiofrequency</td>
<td>Radiofrequency current between two electrodes</td>
<td>Thermal</td>
</tr>
<tr>
<td>Microwave</td>
<td>Electromagnetic waves at 2.45GHz dielectric ionic movement</td>
<td>Thermal</td>
</tr>
<tr>
<td>Cryothermy</td>
<td>Nitrous oxide, argon</td>
<td>Freezing and Thawing</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>Mechanical pressure waves at high frequency</td>
<td>Thermal</td>
</tr>
<tr>
<td>Laser</td>
<td>Photon absorption and heat conduction</td>
<td>Thermal</td>
</tr>
</tbody>
</table>

**Table 2: Limitation of Different energy sources [37].**

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Trans-mural Efficacy</th>
<th>Clinical Experience</th>
<th>Endocardial/Epicardial Use</th>
<th>EndocardialThrombogenicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiofrequency</td>
<td>+/+</td>
<td>++++</td>
<td>+/+</td>
<td>++</td>
</tr>
<tr>
<td>Microwave</td>
<td>+/+</td>
<td>+</td>
<td>+/+</td>
<td>++</td>
</tr>
<tr>
<td>Cryothermy</td>
<td>++</td>
<td>+++</td>
<td>+/−</td>
<td>+</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>++++</td>
<td>+</td>
<td>−/+</td>
<td>++</td>
</tr>
<tr>
<td>Laser</td>
<td>+</td>
<td>+</td>
<td>−/+</td>
<td>++</td>
</tr>
</tbody>
</table>

Radiofrequency (RF) energy uses alternating current of 350kHz to 1 MHz to heat tissue. Trans-mural line of conduction block (3 to 6mm depth lesion) is produced by heating tissue for approximately 1 minute at 70C -80C with maximal power output of 150W. RF can be applied by either unipolar or bipolar electrode and the electrode can be either dry or irrigated. The probes may be applied on either endocardial or epicardial surface of the heart. Irrigation with saline cools the tissue and drives the focus of energy deeper, which allows creation of deeper lesions. With unipolar RF systems there is possibility of damage to adjacent structures (i.e., oesophagus, coronary arteries and cerebrovascular accident). The bipolar irrigated system confounds this disadvantages creating precise and controlled trans-mural lesions in less than ten seconds, and is effective on the beating heart [38-40].

Microwave energy creates electromagnetic radiation that induces oscillation of dipoles such as water molecules in tissue, transforming electromagnetic energy into kinetic energy and heat. Recent post-mortem histology study showed that microwave induced lesions were not trans-mural and the extent of myocardial damage were highly variable [41]. Microwave has a benefit over unipolar RF ablation because the volume and depth of heated tissue are bigger resulting in higher possibility of trans-mural lesions, however electro-physiologic evaluation during microwave ablation is necessary to optimise the result [42]. It does not char the endocardial surface and is also considered as an ablation tool during minimally invasive cardiac surgery [35]. Coronary artery stenosis has been reported with microwave ablation however no reports of oesophageal injury [43].
Cryothermy

Cryo-ablation is well documented in arrhythmia ablation surgery and as an element of the Cox Maze III procedure [43]. Nitrous oxide and argon are the two common cryo-thermal energy sources in use. A one atmosphere of pressure nitrous oxide is capable of cooling tissues to -89.5°C while argon has a minimum temperature of -185.7°C. Nitrous oxide base atrial ablation at -60°C creates a transmural lesion that can be visually verified [38]. Cells within the frozen tissue are irreversibly damaged, the fibrous skeleton of the heart is preserved making cryo-ablation one of the safest of the technologies available. Because of the heat sinks provided by circulating endocardial blood epicardial cryo-ablation on beating heart has not been transmural. Although argon based cryo-ablation for 2 minutes at -160°C has demonstrated capacity to develop isolation of thin tissues (PV and RAA) on a beating heart in an animal model with associated coronary artery intimal hyperplasia and oesophageal injury [45]. The disadvantages of cryo-ablation include potential damage to coronary artery, thromboembolism and the relatively long time require to create lesions (1-3 minutes) and lack of effect on beating heart.

High Intensity Focused Ultrasound (HIFU)

Ultrasound involves the propagation of sound waves at a frequency of 2 to 20MHz. Surgical ablation of AF using ultrasound is one of the newest modalities being clinically tested. Ultrasound effectively ablates tissue via mechanical hyperthermia. A transducer with a piezoelectric crystal vibrates at a fixed frequency when electrical energy is applied to it to emit ultrasound waves. The resulting waves travel through the tissue causing compression, refraction and particle motion. This translates into kinetic energy and ultimately thermal coagulative tissue necrosis. High intensity focused ultrasound (HIFU) produces high concentration of energy in a focused area and can rapidly create transmural epicardial lesions through epicardial fat in less than 2 seconds. Ultrasound energy sources seem to be particularly advantageous. They create a non-invasive, non-contact, focal ablation in three dimensional volume sparing the surrounding tissues. It also rapidly raises the temperature of the target tissue to above 80°C, effectively killing the cells [46]. HIFU creates a very well defined highly focused targeted thermal lesion without harming intervening tissues with very limited collateral injury [47]. HIFU is much less affected by heat sinks, it can be collimated through fluid media, and is ideal for application with a balloon delivery system [48-50]. In a multicentre study by Ninet and colleagues, HIFU was clinically evaluated. 103 patients with AF underwent beating heart PV isolation with concomitant cardiac procedures. At 6 months follow-up the freedom from AF was 85% [51].

Complications of AF Surgery

The risk of AF surgery include death (1% when performed as an isolated procedure), permanent pacing (especially with right sided lesions), recurrent mechanical hyperthermia. A transducer with a piezoelectric crystal vibrates at a fixed frequency when electrical energy is applied to it to emit ultrasound waves. The resulting waves travel through the tissue causing compression, refraction and particle motion. This translates into kinetic energy and ultimately thermal coagulative tissue necrosis. High intensity focused ultrasound (HIFU) produces high concentration of energy in a focused area and can rapidly create transmural epicardial lesions through epicardial fat in less than 2 seconds. Ultrasound energy sources seem to be particularly advantageous. They create a non-invasive, non-contact, focal ablation in three dimensional volume sparing the surrounding tissues. It also rapidly raises the temperature of the target tissue to above 80°C, effectively killing the cells [46]. HIFU creates a very well defined highly focused targeted thermal lesion without harming intervening tissues with very limited collateral injury [47]. HIFU is much less affected by heat sinks, it can be collimated through fluid media, and is ideal for application with a balloon delivery system [48-50]. In a multicentre study by Ninet and colleagues, HIFU was clinically evaluated. 103 patients with AF underwent beating heart PV isolation with concomitant cardiac procedures. At 6 months follow-up the freedom from AF was 85% [51].
bleeding requiring reoperation, impaired atrial transport function, delayed atrial arrhythmia (especially atrial flutter), pulmonary vein stenosis and atrio-esophageal fistula. There is also the associated risk of median sternotomy and cardiopulmonary bypass.

**Discussion**

Traditionally the management of atrial fibrillation has been pharmacological. The non-pharmacological techniques for the management of AF evolved as an addendum to address the short comings of the traditional treatment modality. The fundamental objectives of the management of AF are relief of symptomatology by restoration of sinus rhythm/rate control, haemodynamic stability and prevention of thromboembolism. It is important to emphasise that these objectives still remain the focus of every treatment modality. The combination of a pharmacologic and non-pharmacologic modalities to achieve this goal should not be view as a failure of the non-pharmacologic technique, as long as there are no associated adverse consequences [52]. We suggest that the term ‘surgical management of atrial fibrillation’ does not preclude the use of pharmacological agents. The term should imply the involvement of a cardiac surgeon in the management of AF and not exclusion of pharmacological agents. The goal of surgical management of AF only becomes exclusion of pharmacological agents when their use are of no benefit or constitute significant harm.

Pharmacologic agents could be used prophylactically preoperatively or in the postoperative period to enhance the restoration and maintenance of sinus rhythm and haemodynamic stability and this should not be viewed as failure of surgical treatment where no harm is done [53].

The goal standard for the surgical management of AF still remains the Cox maze III. In an eight and half years follow up of a series of 178 patient following operation Cox and colleagues found 93% of all patient were arrhythmia free without anti arrhythmic medication. Of the remaining patients with arrhythmia recurrence all were converted to sinus rhythm with medical therapy. Ninety eight percent had documented right atrial function and 94% left atrial function. And of all patients who were documented to have normal sinus node preoperatively only one required a permanent pacemaker [54]. In a case control study Feinberg and colleagues demonstrated 83% right atrial and 61% left atrial function following the Cox maze procedure [55]. In a recent long term follow-up study of patients following mechanical mitral valve replacement surgery and concomitant Cox maze III for rheumatic valve disease and permanent AF, Wu and colleagues showed actuarial freedom from AF of 83.7% at 5 years and 79.1% at ten years, with significant reduction in left atrial size, however all patients were anti-coagulated [56]. This could suggest the progressive nature of the pathological process causing AF despite surgical intervention [10]. We hypothesise that the initiating stimulus causing AF (most probably the cause of interstitial fibrosis and atrial myocardioyte depletion) needs to be removed. It is interesting to note
that ACE inhibition and angiotensin II receptor blocked 
have been shown to inhibit this fibrotic process [11,57,58].
The short comings of this ‘Cut and sew’ Cox maze 
technique is the length of time required, increased risk of 
bleeding, technical complexity and occasional poor left 
atrial transport function.

Contemporary developments in AF surgery are largel 
ly aimed at addressing these shortcomings. Meta-analysis 
of clinical outcome of the maze procedure by Kong and 
Reston showed there are few RCT with several short com 
ings which include heterogeneity, small sample size and 
selection bias, result of some of these are shown in tables 
1-3 [52,59].

To address the left atrial transport function of the 
Cox Maze III, the radial approach was developed by Ni 
tta and colleagues, this consist of atrial incision radiating 
from the Sino-atrial node to the atroventricular annular 
margins, this allows amore physiologic atrial activation 
sequence and also preserve the atrial coronary blood sup 
ply [60].The radial approach equally prevented sustained 
AF and provides a more synchronous activation sequence 
and better atrial transport function representing a more 
physiologic alternative to the Cox mazelll [61].

Giant Left atrium(GLA) defined as LA diameter great 
er than 65mm is often associated with mitral regurgitation 
and AF. GLA can cause pressure on the main bronchus,

lung and left ventricle with corresponding cardio-respir 
atory embarrassment and risk of sudden death. Its exist 
ence merits careful evaluation and surgical intervention 
when needed. Partial resection of the inferior and or super 
ior left atrial wall is the commonest surgical technique 
[62].

Table 3: Randomised Control Trials comparing Results of 
concomitant Maze and AAD alone at 12months.

<table>
<thead>
<tr>
<th>Author/year</th>
<th>Mean age</th>
<th>Number</th>
<th>Type of AF</th>
<th>Randomisation</th>
<th>Success</th>
<th>Complications</th>
<th>Duration of AF (Months)</th>
<th>LA diameter(mm)</th>
</tr>
</thead>
</table>
| Vasconcel 
los et al 2004 [76] | 49.4±10  50.8±9.7 | 29 | Permanent/ 
Persistent | 15Maze 14 AAD | 80% 56% | 23±19 33±28 | 55.5±5 55.9±5 |
| Blomstrom-
Lundkvist et al 2007 [77] | 69.5±7.9  65.7±8.8 | 71 | Permanent/ 
Persistent | 36Maze 35AAD | 61% 43% | 26±33 33±54 | 61±11 58±7 |
| Delima et al 2004 [78] | 50±15.3  50±15.4 | 20 | Permanent/ 
Persistent | 10Maze 10 AAD | 60% 30% | 14±9.6 16±13.24 | 60±16 62±12 |
| Schuette et al 2003 [79] | 64.6±10  70.2±7.6 | 43 | Permanent/ 
Persistent | 24 Maze 19 AAD | 63% 47% | 5.8±2.4 9.2±9.2 | 54.9±11 54.4±17 |
| Wang et al 2005 [80] | 70 | 33 RFA 37 AAD | 67% 33% |
| Oral et al 2006 [81] | 57±9 | 146 | Permanent | 77 CPVA 69 amino+DC+ 
CV+CPVA | 74% 4±5 4±5 | 45±6 45±5 |
| Stabile et al 2006 [82] | 137 | 69 RA isthmus+LA 
ablation +AAD 69 AAD | 56% 9% |
| Papavasi et al 2006 | 198 | 99 CPVA 99 AAD | 66% 22% |
lone AF and up to 91% of treated patients were free of AF at follow-up [63]. Wudel and Edgerton also reproduce similar results with the same technique in different centres [64,65]. Sirak and colleagues recently developed the five-box thoracoscopic Maze procedure which compartmentalises virtually all arrhythmogenic anatomy etiologic in atrial fibrillation, enabling simple verification by demonstrating bidirectional block, its efficacy approximates Cox Maze benchmark [66].

Onorati and colleagues have demonstrated that ganglion plexus ablation significantly improves hospital and follow-up results of the Maze procedure during mitral valve surgery [67].

Ad and colleagues have demonstrated that postoperative furosemide infusion reduces the excessive fluid retention and subsequent pulmonary complication commonly associated with the maze procedure [68].

Recently Venalli and colleagues have described a right mini-thoracotomy for the left Maze using High intensity focused ultrasound(HIFU) on a beating heart to achieve epicardial box lesions of the pulmonary veins and mitral isthmus, using trans-oesophageal echocardiography (TEE) guide positioning of the ablation devise on the mitral isthmus. This technique has less operative risk, high cure rate and rapid patient recovery [69].

Recently Stulak and colleagues introduced the concept of prophylactic maze for patient at high risk of developing late AF following mitral or tricuspid valve surgery.

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>LA Volume 1</th>
<th>Permanent/P</th>
<th>33 RFA</th>
<th>85%</th>
<th>62±10.5</th>
<th>66.6±9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akpinar et al 2003</td>
<td>53±10</td>
<td>67</td>
<td>33 RFA</td>
<td>34</td>
<td>85%</td>
<td>9%</td>
</tr>
<tr>
<td>Deneke et al 2002</td>
<td>64.7</td>
<td>64±9</td>
<td>15 maze</td>
<td>10</td>
<td>3.6</td>
<td>59.8±5</td>
</tr>
<tr>
<td>Guang et al 2002</td>
<td>62.9±8.6</td>
<td>40.6±9.3</td>
<td>61AAD</td>
<td>96</td>
<td>117(59.4)</td>
<td></td>
</tr>
</tbody>
</table>

Left atrial volume (LA) reduction concomitant with the Maze procedure has been reported to facilitate sinus rhythm recovery even in patients with refractory AF, this is associated with significant improvement in LA systolic ejection fraction [29].

The use of the new energy sources for the lesion sets in amaze and advancement in minimally invasive surgical technique, has revolutionised the procedure, Wolf and colleagues have evolved the (mini-Maze Wolf technique) this minimally invasive technique consist of Pulmonary vein isolation, left atrial appendage excision and directed partial cardiac denervation and EP mapping via bilateral video assisted thoracoscopic surgery(VATS). This closed chest technique uses bipolar non-irrigated radiofrequency ablation to achieve the trans- mural lesion sets of the Cox Maze procedure on a beating heart. It is indicated for...
These were patients in sinus rhythm requiring mitral and or tricuspid valve surgery but had high risk to develop postoperative AF. The identified independent risk factors for developing late AF following mitral valve surgery include advance age, left atrial size >55mm, greater than mild tricuspid regurgitation and diabetes. Late on set AF is associated with decreased late survival and prophylactic maze may be warranted [70].

Recently Ad and colleagues have demonstrated that a post-discharge follow-up protocol designed not only to capture patients rhythm status but also coordinate their clinical management when required significantly improves outcome following surgical ablation [6,71].

In the last 3 decades significant advancements have been made towards understanding the pathophysiology and management of atrial fibrillation with very encouraging results. But none of the management modalities so far seems to reverse or halt the histopathological process that underlays the mechanism for the development of AF. The available data from follow-up studies seem to show varied levels of increased recurrence of AF over time following treatment [27,56,72-74]. This suggests that interstitial fibrosis and atrial myocardioocyte depletion still progresses despite the existing interventions. We argue that none of the existing treatment modalities is curative of AF as they do not reverse or halt the progressive interstitial fibrosis and atrial myocardiocyte depletion which provides a significant component of the substrate which initiates and or maintain AF. This observation is supported by the fact that there is a positive correlation between the degree of refractoriness of AF to treatment and atrial interstitial fibrosis [9].

Studies have shown that ACE inhibitors seem to halt the interstitial fibrosis and reduce the arrhythmogenicity of the atria. It is likely that a potential cure for AF would lay in further understanding and modulation of the effects of the angiotensin-aldosterone pathway on the atria [11,57,58]. It is likely that the addition of an ACE inhibitor in management of AF will be beneficial in the long term.

We suggest that the measurement of the outcome of AF treatment as the presence or absence of antiarrhythmic drugs should be discouraged where there is no hazard associated with their use. We submit that the goal of the management of AF is alleviation of symptoms, haemodynamic stability and prevention of thromboembolic events regardless of the use of tolerable pharmacologic agents [75]. The use of tolerable pharmacologic agents to consolidate or supplement results of surgical ablation should be encouraged and not considered a failure of treatment.

**Conclusion**

AF is an increasing global problem with significant economic and healthcare burden. Pharmacological treatment has not provided all the answers. The introduction of surgery for AF has significantly expanded the treatment armamentarium. Continuation of pharmacotherapy after surgery to achieve therapeutic goals should not be regarded as failure of surgical treatment. There is need for further research in the pathology and treatment of AF.
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