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# Surgery for Atrial Fibrillation: An Overview

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## 1. Introduction

Atrial Fibrillation (AF) is the commonest cardiac arrhythmia. The Epidemiology of the disease is presented in Figure 1.

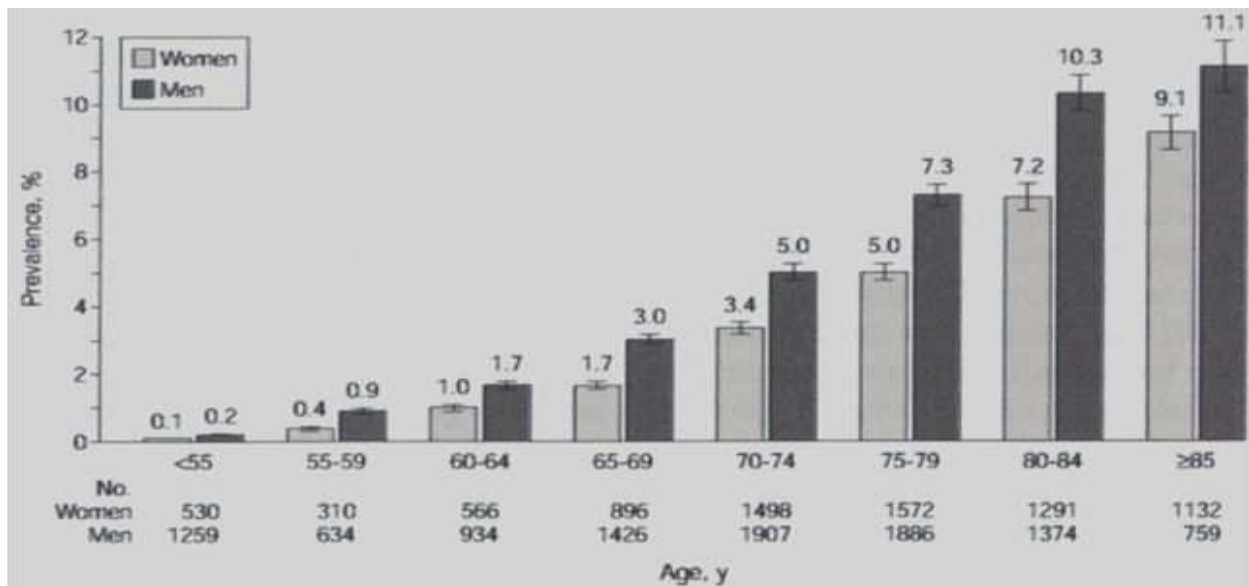
- **Affects 0.4% of general population**
- **2.2 million people in US are in AF**
- **AF accounts for 1/3 of arrhythmia hospitalizations**
- **Predominantly a disease of the elderly**
- **Men more frequently affected than women even after adjustment for all other risk factors**
- **The number of patients with AF is likely to increase 2.5 fold over the next 50 years**

**Figure 1.** Epidemiology of Atrial Fibrillation

AF is usually associated with underlying cardiovascular disorders, however in around 30% of the cases, AF occurs alone.

Atrial Fibrillation occurs when high rate depolarizing waves conduct through different lesion pathways into the atrium leading to asynchronous contraction of atrial wall segments. This will conduct irregularly through the AV node giving irregular ventricular response rate. This asynchronous contraction prevents effective atrial contraction resulting in residual stagnant blood in the chambers leading to thrombus formation which can break off causing CVA. Furthermore, there is a decrease in cardiac output due to loss of atrial kick, which contribute up to 30% of forward cardiac output especially during periods of diastolic dysfunction.

There is an increasing incidence with age and sex as per Figure 2.



**Figure 2.** Prevalence of diagnosed atrial fibrillation stratified by age and sex.

Classification of Atrial Fibrillation as per Figure 3:

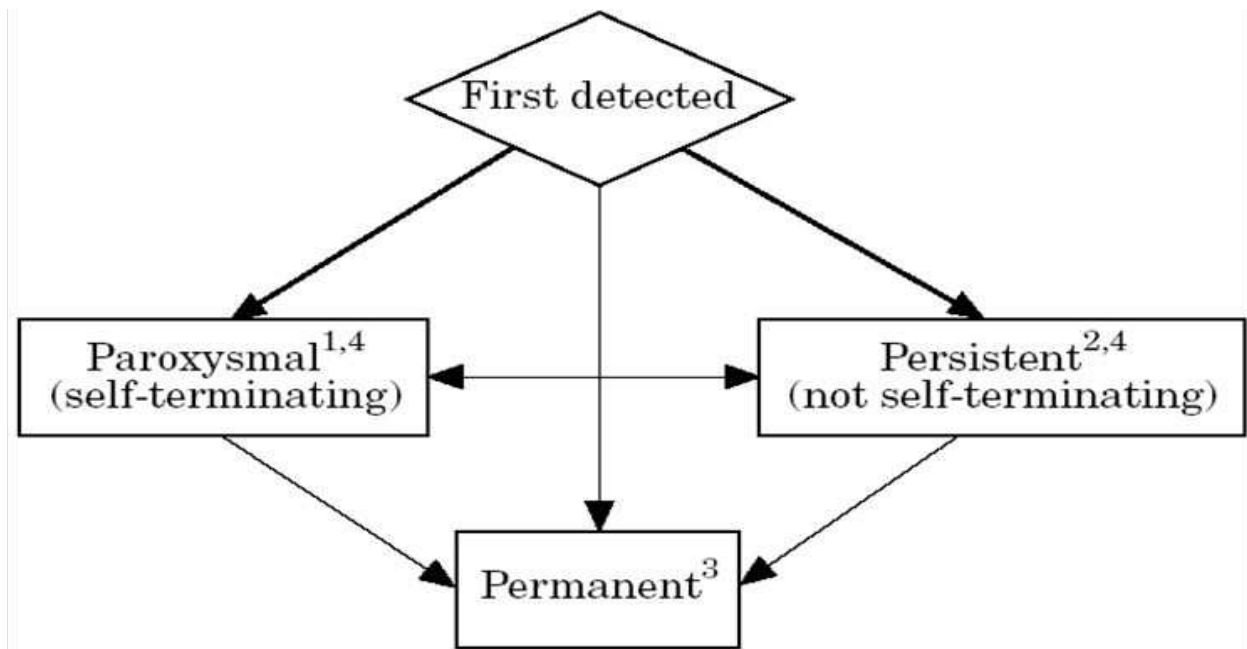
1. Isolated: A Single episode of AF
2. Recurrent: If more than 2 episodes of AF
3. Paroxysmal: Self-limited bouts of AF
4. Persistent: Requires drugs-DC version
5. Permanent: Non-revertable AF

## 2. Significance of AF

AF contributes significantly to cardiovascular morbidity and mortality [1].

AF consists off an independent risk factor for death (RR 1.5 – 1.9). There is a link between AF and Thromboembolism [2] :there is a 5 times increased risk of CVA in patients with AF. The presence of rheumatic valvular disease increases the risk of CVA 17-fold. Ultimately AF is responsible for 15% of all CVAs.

Moreover, conventional medical therapy for AF is unsatisfactory because the failure rate is 50% at 1 year and 85% at 2 years. There is a haemorrhagic risk with the use of warfarin for AF and finally antiarrhythmic agents are not specific for atrial activity.



**Figure 3.** Patterns of atrial fibrillation. (1) episodes that generally last less than or equal to 7 days (most less than 24h; (2) usually more than 7 days; (3) cardioversion failed or not attempted; and (4) either paroxysmal or persistent AF may be recurrent.

### 3. Pathophysiology of AF

1. Historically in 1962, Moe's developed the "multiple wandering wavelet" hypothesis.
2. Allesie in 1995 elucidated on the principles of electrophysiologic changes and electrical remodelling during AF due to:
  - a. Intracellular calcium loading.
  - b. Down-regulated Ca channel activity.
  - c. ↓ Action potential duration.
  - d. Shorter refractory period in left atrial tissue.

The functional requirements for re-entrant arrhythmias are: 1) Tissue substrate to support re-entrant excitation, 2) Area of unidirectional block and 3) Typically areas of slow conduction as depicted in Figure 4.

1. It was finally noted that AF begets AF [3].
2. The importance of primary local generator single re-entry circuits was somehow proved with the concept of surgical interruption of macro-re-entrant circuits with the Cox-Maze procedure.
3. Finally, Haissaguerre in 1998 [4] showed that paroxysmal AF originates from ectopic foci in the pulmonary veins.

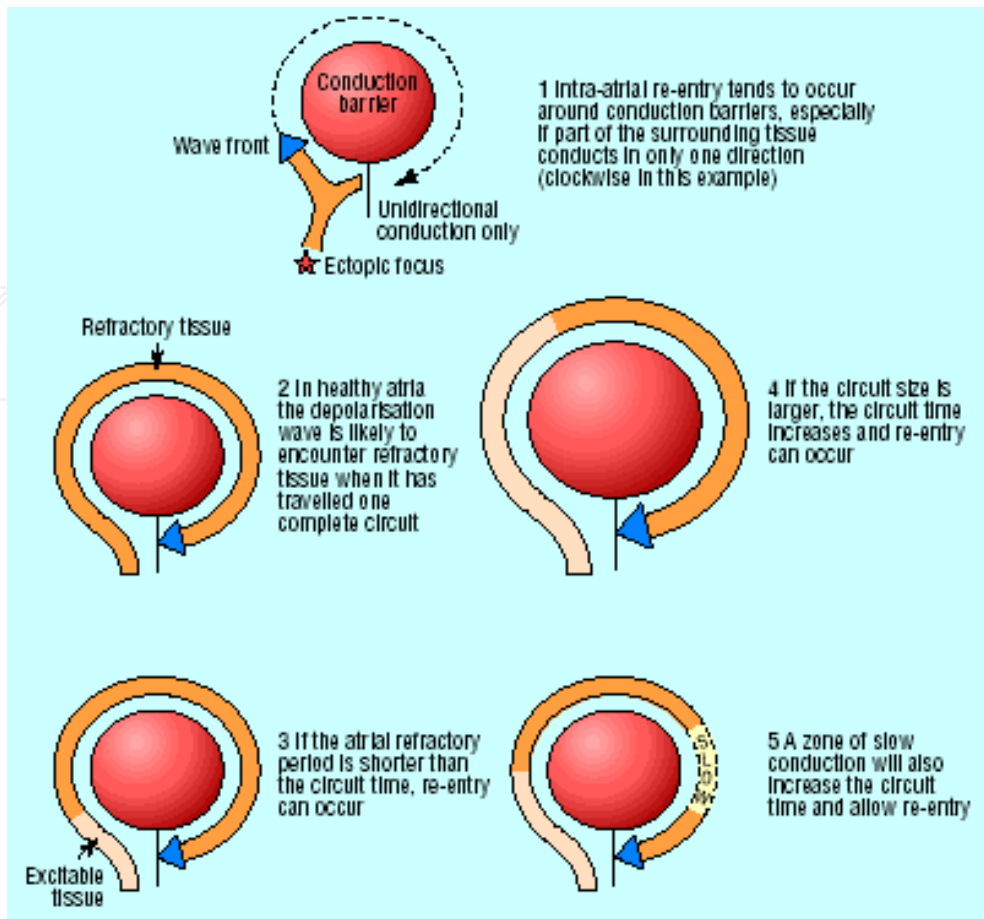


Figure 4. The functional requirements for re-entrant arrhythmias

The minimum diagnostic work-up of an AF patient is presented in Figure 5.

- (1) History and physical examination
  - 1.1 Define the presence and nature of symptoms
  - 1.2 Define the clinical type of atrial fibrillation: paroxysmal, chronic or recent onset
  - 1.3 Define the onset of the first symptomatic attack and/or date of discovery of atrial fibrillation.
  - 1.4 Define the frequency, duration (shortest and longest episodes), precipitating factors and modes of termination (self-terminating versus persistent) of symptomatic episodes.
  - 1.5 Define the presence of an underlying heart disease or other possible identifiable cause (e.g. alcohol consumption, diabetes, hyperthyroidism) which could be cured.
- (2) Electrocardiogram
  - 2.1 Left ventricular hypertrophy
  - 2.2 Duration and morphology of the P waves in sinus rhythm
  - 2.3 Evidence of repolarisation changes, bundle branch block, old myocardial infarction and other abnormality.
- (3) Echocardiogram (M mode and bidimensional)
  - 3.1 Evidence and type of underlying heart disease
  - 3.2 Size of the left atrium
  - 3.3 Left ventricular size and function
  - 3.3 Left ventricular hypertrophy
  - 3.4 Intracavitary thrombus (poor sensitivity).
- (4) Thyroid test function
 

If first discovery of atrial fibrillation, if the ventricular rate is difficult to control or if amiodarone has been used in the past.

Figure 5. The minimum diagnostic work-up of an AF patient

## 4. Surgery for AF

The idea of creating a corridor-link between the sinus node and atrio-ventricular node that could potentially restore regular rhythm became the base of the surgical treatment of AF.

The principles of surgery for AF, takes into account:

- Incisions and creation of lesions in the atria to interrupt macro-re-entrant circuits.
- Creation of blind alleys for atrial electrical activation.
- Appendage excision.

The procedure consists of an open-heart surgical approach, as described by James Cox, namely making linear lesions in the right and left atria to prevent the occurrence of multiple reentering circuits.

Based on mapping studies of animal and human AF, Cox and colleagues [5] developed a surgical procedure (Cox maze procedure) that controls AF in more than 90% of selected patients. In the original procedure atrial appendages are excised and the pulmonary veins are isolated. Appropriately placed atrial incisions not only interrupt the conduction routes of the most common re-entrant circuits, but they also direct the sinus impulse from the surgical ablation node to the atrio-ventricular node along a specified route.

Although encouraging and successful results were obtained, the original surgical technique, the Cox maze I procedure, was modified to become the Cox maze II procedure because of late chrono-tropic problems with the surgical ablation node and intra-atrial conduction delays that resulted in diminished left atrial contraction. However the Cox maze II procedure proved to be technically difficult to perform. As a result, it was modified to become the Cox maze III procedure, which soon became the surgical technique of choice for the treatment of medically resistant AF.

The results of the Cox Maze III (cut and sew) showed that in 346 patients, the operative mortality were less than 2%. The AF was cured in >90-95% of the cases. Left and right atrial function was restored in 93% and 99% of patients correspondingly. 15 % of the patients required pacemakers. Long-term CVA was very low at 0.1% per year [5, 6].

Temporary postoperative AF was frequent, presenting in 38% of patients. This problem was related to a shortened atrial refractory period during the procedure and did not preclude long-term success. Successful ablation treatment of AF was independent of mitral valve disease, type of AF, and left atrial size.

So, although concomitant organic heart disease did not decrease the effectiveness of the Cox maze III procedure in the series of Cox and colleagues, Gillinov et al [7] demonstrated decreased success rate in their study. In most series, concomitant mitral valve surgery with the Cox maze III procedure cured AF in 75% to 82% of patients.

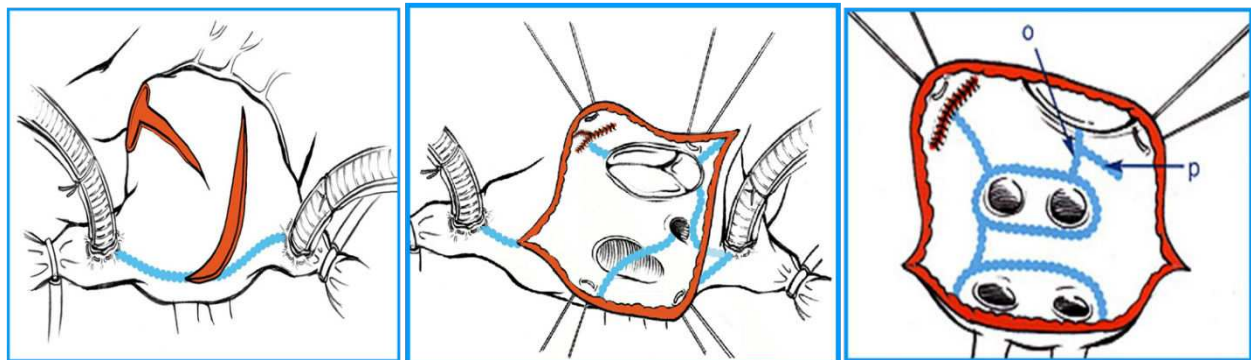
## 5. Beyond the Cox-Maze III

The Cox-Maze III (cut and sew as seen in Figure 6) perceived complexity, is time-consuming and requires CPB and aortic cross clamp. A systematic review by Khargi et al [8] and a comparative study by Chiappini et al [9] concluded that there was not any significant difference in the postoperative SR conversion rates between the classical 'cut and sew' and the alternative sources of energy, which were used to treat atrial fibrillation.

Therefore, during the last decade AF surgery was popularized with simpler operations, by performing only LA maze (Figure 7) and using alternate energy sources for trans-mural lesions to produce lines of conduction block speedily with minor risk of bleeding.

Of note, during LA ablation one performs pulmonary vein isolation, LA appendage resection, possibly LA appendage to left PV lesion and lastly a PV connecting to MV annulus (mitral) lesion.

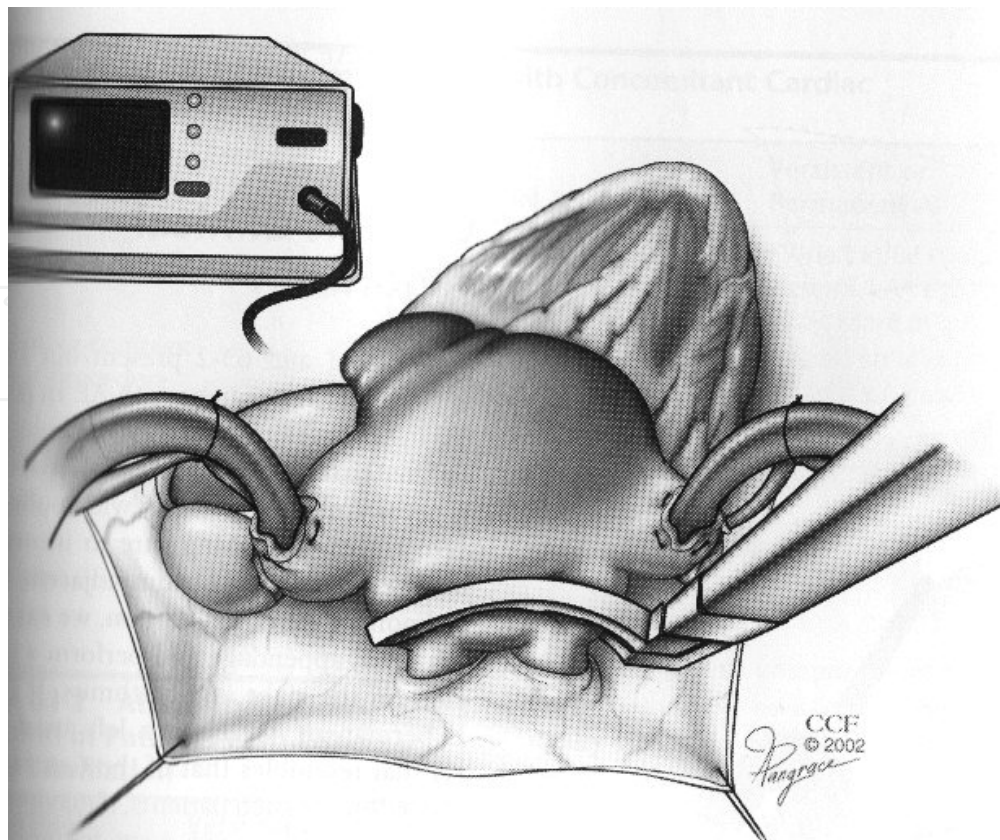
Table 1 shows the results of LA maze using different energy sources and Table 2 shows the characteristics and differences between 3 widely used energy sources.



**Figure 6.** RA and LA Maze (Cox –Maze III)

Author	Year	Number of Patients	Lesion Type	%Sinus Rhythm mid/long-term follow-up
Sie	2004	200	RF	80
Kondo	2003	31	Cryoablation, RF	79.3
Kress	2002	23	RF	86
Wellens	2002	30	RF	65
Guden	2002	23	RF	81
Benussi	2002	132	Epicardial RF	77
Deneke	2002	21	RF	82
Mohr	2002	234	RF	81.1
Knaut	2002	105	Microwave	61
Pasic	2001	48	RF	92

**Table 1.** Left atrial Maze: Results of contemporary publications, using various energy sources.



**Figure 7.** LA maze using alternate energy sources

Radiofrequency	Microwave	Cryotherapy
Current of 350 kHz – 1 MHz.	High frequency electromagnetic radiation causes oscillation of water molecules.	The mechanism of cryogenic tissue injury in the early phase is actually organelle and mitochondrial dysfunction and subsequent edema and cell necrosis upon thawing.
Hyperthermic lesions cause a loss of cellular excitability at 50°C.	The oscillation of the water produces kinetic energy and subsequent heat, a process called dielectric heating. The AFx Microwave device can produce an endocardial ablation by reaching a goal temperature of 50° at 5 mm after 25 seconds. The same device produces an epicardial ablation at 45 seconds using a slightly higher wattage	With the early Frigitronics nitrous oxide based systems, a temperature of –55°C had to be maintained for two minutes, and repeated exposures were sometimes required. Newer, argon-based systems provide cooler temperatures that may permit effective ablations in 45 seconds or less.
The temperature must remain below 100°C to prevent cavitation.		
Radiofrequency energy ablation is very similar to standard electro-cautery. Although there are bipolar and irrigated unipolar RF options, RF is generally unipolar and uses very fast AC current, which avoids depolarizing the heart. The mechanism is resistive of ohmic heating, which involves the concentration of a large amount of energy on a small surface area. The energy disperses to the ground pad, but the area where it is focused is heated, resulting in ablation. It is		



Radiofrequency	Microwave	Cryotherapy
possible to control both temperature and energy. Energy control will permit precise application of, say, 50 watts, but temperature is not controlled. Temperature control allows the device to maintain a precise goal temperature.		
Lesion depths 3-6 mm	Increased depth and volume of heated tissue	Nirous oxide based cryoprobe
Unipolar or Bipolar <ul style="list-style-type: none"> <li>•bipolar concentrates energy between electrodes</li> <li>–easy, quick, narrow lesions</li> <li>•irrigation delays micro bubble formation</li> <li>–accurate lesion monitoring</li> <li>•maximally flexible</li> <li>–handle designed for access and visibility</li> <li>–malleable electrodes for any heart size/shape</li> <li>–jaw head pitch and roll</li> <li>adaptive transmuralit</li> </ul>	Less charring, but less flexible compare with Radiofrequency.	Difficulty with inflexibility of probes
Unipolar: unfocused energy delivery	Risk of damage to surrounding tissues	There is no tissue vaporization or charring
Surface charring may cause thromboembolic complications		The endocardial surface remains smooth
Saline cooled systems improve charring		
Heat is conducted to surrounding tissues (risk of damage, e.g. oesophageal perforation)		
<i>"How do I know I am done"?</i>		
1) Heating of cells creates a shift in intracellular fluid to extra-cellular space		
2) Creates a drop in impedance		
3) Algorithm monitors changes in impedance		

**Table 2.** Various energy sources/ Characteristics and properties

## 6. Recent important advances in AF surgery

The mid- and long-term success rate is in the 80% range. This has prompted various authorities to popularized adding Maze procedures to concomitant cardiac surgery; with the view to potentially treat AF with a simple, short and less invasive procedure. Moreover, minimal access pulmonary vein isolation has been currently implemented for “lone” AFib or as part of a mini-Mitral approach.

Wolf et al [10, 11], reported on 27 patients (22 Males, mean age 57) who underwent Bilateral thoracoscopic PVI and LAA excision for AFib (18 paroxysmal, 4 persistent, 5 permanent AFib). There were no conversions or major complications. There was 91% freedom from AF at 3 months follow-up. The authors concluded that bilateral video-assisted thoracoscopic pulmonary vein isolation with excision of the left atrial appendage is feasible and safe and offers a promising, new, minimally invasive, beating-heart approach for curative surgical treatment of atrial fibrillation.

Jeanmart et al [12] evaluate their practice with the association of the mini-maze procedure, done with the use of the Cardioblade pen, and concomitant minimally invasive mitral valve surgery. They studied 103 patients. 41% had intermittent and 59% permanent AFib. At mean follow up of 17 months, 70% of the patients studied were in Sinus Rhythm and 2% were pacemaker dependent. The authors concluded that the use of unipolar radiofrequency ablation to perform a mini-maze during minimally invasive mitral valve surgery is a safe procedure and is associated with good early results.

## 7. Postoperative AFib

Post-operative AFib is different to conventional AF (micro- versus macro-re-entrant circuits). Moreover the local refractory periods may be shorter and re-entrant circuits can be smaller. Post-operative AFib is common after open-heart surgery (30-50%) and it must be treated with anti-arrhythmics and anticoagulation, if it persists more than 48 hours. Warfarin should be continued on all patients for at least 3 months and lastly in patients who remain in AFib for 6 weeks, cardio-version is essential.

If AF with concomitant cardiac surgery	“Lone” AF (for younger patients with limiting symptoms, Contraindication to anticoagulation, Thromboembolic stroke while on anti-coagulation )
Paroxysmal or persistent AF: PVI and LAA excision	Paroxysmal or persistent AF: minimally invasive PVI and LAA excision
Permanent AF: left Maze (PVI, LA connecting lesions and LAA excision) and Right side Maze	Permanent AF: left Maze or Cox-Maze III

**Table 3.** Strategies for the surgical treatment of AF

## 8. Conclusions

Regardless of the method used, the goals remain the same. The lesions should, ideally, be transmural; when minimally invasive procedures are implemented, the lesions should proceed from the epicardium of the beating heart, which changes the physics of many of the lesions. The method must also allow for tissues of variable thickness and characteristics, as a patient with rheumatic atrial pathology will have a much more difficult atrium to ablate than a coronary bypass patient.

A natural question arises as to which lesion pattern surgeons should be using. There probably isn't a simple answer to this question, because:

- a. Data on lesion set efficacy is influenced by patient variables such as left atrial diameter, duration of preoperative atrial fibrillation, coexisting pathology etc.
- b. Comparing the efficacy of one lesion pattern to another in clinical trials will require too many patients in each treatment arm to achieve statistical power.
- c. Not all lesion patterns can be effectively or safely delivered with all energy sources.

Table 3, represents our policy of implementing strategies for the surgical treatment of AF. By enlarge; the right atrium has a longer effective refractory period than the left atrium and in general sustains only longer reentry circuits, the most common being the counterclockwise circuit of typical atrial flutter. Atrial flutter can be ablated, by a trans-mural lesion connecting the tricuspid annulus to the IVC; additional lesions connecting a lateral right atriotomy to the IVC or coronary sinus to the IVC is occasionally necessary to ablate an atypical right atrial flutter.

In summary, in patients with persistent or permanent AF who present for cardiac surgery, the addition of surgical AF ablation led to a significantly higher rate of sinus rhythm in RCT and non-RCT studies compared with cardiac surgery alone, and this effect remains robust over the longer term (1-5 years). Although non-RCT studies suggest the possibility of reduced risk of stroke and death, this remains to be proven in prospective RCTs with adequate power and follow-up [13, 14].

## 9. The future

Further refinements in energy sources, lesion sets, minimally invasive techniques will be developed. Routine preoperative EP screening and better understanding of selection criteria will improve success rates. That may be achieved with close collaboration with EP cardiologists.

The up till now results are encouraging therefore minimally invasive PVI may be routinely considered in all cardiac surgical departments. Lastly, Left atrial maze should become standard treatment of persistent/permanent "lone" AF in selected patients, especially where EP techniques fail.

## Author details

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