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Review Article

Surgical Treatment of Atrial Fibrillation: A Review

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Atrial fibrillation is the most commonly sustained arrhythmia in man. While it affects millions of patients worldwide, its incidence will markedly increase with an aging population. Primary goals of AF therapy are to (1) reduce embolic complications, particularly stroke, (2) alleviate symptoms, and (3) prevent long-term heart remodelling. These have been proven to be a challenge as there are major limitations in our knowledge of the pathological and electrophysiological mechanisms underlying AF. Although advances continue to be made in the medical management of this condition, pharmacotherapy is often unsuccessful. Because of the high recurrence rate of AF despite antiarrhythmic drug therapy for maintenance of sinus rhythm and the adverse effects of these drugs, there has been growing interest in nonpharmacological strategies. Surgery for treatment of AF has been around for some time. The Cox-Maze procedure is the gold standard for the surgical treatment of atrial fibrillation and has more than 90% success in eliminating atrial fibrillation. Although the cut and sew maze is very effective, it has been superseded by newer operations that rely on alternate energy sources to create lines of conduction block. In addition, the evolution of improved ablation technology and instrumentation has facilitated the development of minimally invasive approaches. In this paper, the rationale for surgical ablation for atrial fibrillation and the different surgical techniques that were developed will be explored. In addition, it will detail the new approaches to surgical ablation of atrial fibrillation that employ alternate energy sources.

1. Introduction

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice. The overall prevalence of AF in the population ranges between 1 and 2%. The relationship between AF and age is strong. The prevalence doubles with each decade of age, reaching almost 9% at the age of 80–89 years [1, 2]. This can be an underestimate of the real number as it overlooks the undetected asymptomatic AF cases and paroxysmal AF.

Although atrial fibrillation can be considered an innocuous arrhythmia, it is associated with serious morbidity and mortality [3]. First, it increases the risk of thromboembolism and stroke, as a result of blood stasis in the left atrium. It has been estimated that AF results in three- to five-fold increase in stroke risk [4]. Second, the irregularly irregular heart beat leads to symptoms palpitations, shortness of breath, anxiety, and reduced exercise tolerance in the patient. Third, atrial fibrillation leads to a number of cardiac and hemodynamic changes including a reduced myocardial systolic function and tachycardia-induced cardiomyopathy [5, 6].

In addition to the clinical morbidity and mortality of AF, it imposes a huge burden on the economy. Stewart and colleagues looked at the cost that AF imposes on health and social services in the UK in 1995 [7]. AF accounted for 0.62% of the UK National Health Service (NHS) expenditure, which is equivalent to £244 million. Hospitalization and drug prescriptions accounted for 50% and 20% of this expenditure respectively. The expenditure is expected to rise as the incidence of AF continues to rise due to the increase of the number of people over the age of 80 years. Thus, AF is an extremely expensive public health problem.

Given the great impact of atrial fibrillation on health resources and patients' welfare, several pharmacological and surgical therapies have been developed over the years. The purpose of this review is to review the rationale for surgical ablation of atrial fibrillation and describe the different approaches and procedures used in the ablation of atrial fibrillation in cardiac surgery patients.

2. Rationale for Surgical Ablation

AF is present in up to 50% of patients undergoing mitral valve surgery and in 1% to 6% of patients presenting for coronary artery bypass grafting (CABG) or aortic valve surgery [8–11]. Atrial fibrillation is strongly associated with mitral valve dysfunction, hence most studies focus on patients who have mitral valve dysfunction. In those patients, atrial fibrillation is a marker of advanced cardiovascular disease and is associated with a more severe left ventricular dysfunction and a greater left atrial enlargement [11–13].

AF onset can be considered a relative indication for mitral valve surgery in those who have mitral valve dysfunction [9]. However, mitral valve surgery alone does not revert AF back into sinus rhythm [14, 15]. In most instances mitral valve surgery alone does not cure AF. When the duration of AF preoperatively is longer than six months, the risk of remaining in AF is 70–80%. In contrast, when the duration of preoperative AF is less than three months, particularly if it is paroxysmal, there is an 80% cure rate after mitral valve surgery [12, 14, 16]. Therefore, ablation should be added to the mitral valve procedure in any patient with AF greater than six months duration or in any patient with AF that is not paroxysmal.

3. Pathophysiology of Atrial Fibrillation

There is general agreement that AF requires a trigger for its initiation and a substrate for its maintenance. Triggers include atrial ectopic foci, changes in atrial wall tension, and alteration in autonomic tone [17–19]. The substrate is an atrial abnormality, frequently inflammation or fibrosis, and it causes electrical dysfunction that favours development of AF.

These substrates and triggers have been localized anatomically to the pulmonary veins and the left atrium [20]. The mechanism underlying the pulmonary vein ectopy is still under investigation. After triggers propagate into the atrial myocardium, fibrillation is maintained by continuation of these trigger beats with breakdown of conduction or by intra-atrial reentrant processes.

Our understanding of AF initiation and maintenance stems from previous experimentally founded theories that address the genesis of AF. One theory considers AF to be a manifestation of one or more reentry circuits (multiple-wavelet theory) or reentrant rotors involving the atrial surface [21]. The second theory postulates AF to be the result of fibrillatory conduction throughout the atria originating from a rapid discharge from one or several foci (focal theory) [22]. Both mechanisms are relevant to the clinical spectrum of AF.

The clinical classification of AF is helpful in management. Chronic AF can be classified into three subtypes: paroxysmal, persistent, and permanent [23]. Paroxysmal AF is defined as episodes that start and stop by themselves, generally lasting less than 24 hours but sometimes lasting up to 7 days. Persistent AF is defined as episodes lasting more than 7 days or that require termination, either pharmacologically or electrically. Permanent AF is defined as longstanding continuous episodes, where repeated attempts to terminate have either failed or not tried.

Cardiac remodelling (electrical, contractile, and structural) is another important part of the pathophysiology of AF. It plays a role in determining whether AF is persistent or permanent. There has been an explosion of research into atrial remodelling during AF and the converse process of "reverse remodeling" [24, 25].

4. Surgical Treatment Options

The development of new surgical approaches to AF has been predicated upon two factors: understanding that the pulmonary veins and left atrium are critical to the initiation and maintenance of AF and development of ablation tools that use alternate energy sources to facilitate rapid and safe creation of lines of conduction block under direct vision.

Surgical therapy ranges from simple procedures such as removal or plication of the left atrial appendage to reduce the risk of thromboembolic complications [26–28] to a variety of procedures aimed at preventing the recurrence of AF.

4.1. Historical Background before the Cox Maze

4.1.1. Left Atrial Isolation. In 1980, Williams and colleagues developed the left atrial isolation procedure by using animal models [29]. This procedure isolated the left atrium electrically from the remainder of the heart without disrupting normal conduction. This was successful in isolating AF to the left atrium and restoring the remainder of the heart to sinus rhythm.

The left atrial isolation has been applied clinically by Graffigna and associates [30] to a hundred patients with chronic AF and mitral valve disease. They showed that sinus rhythm has been restored in 72% of those patients, with a mean follow up of 14.6 months. However, the obvious shortcoming of this approach is continued fibrillation of the left atrium and its uncertain impact on the risk of thromboembolism.

4.2. The Corridor Procedure. In 1985, Guiraudon and coworkers [31] introduced the corridor procedure for AF, creating an isolated strip of muscle which links the sinoatrial and AV nodes (Figure 1), thus driving ventricle rate via the AV node-His bundle complex. 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 persistent loss of atrial transport function and persistent risk of thromboembolism.

4.3. The Cox Maze. All the above-mentioned procedures fall short of the ideal, which is the cure of the arrhythmia and resolution of its principle adverse consequences (thromboembolism). The Cox-Maze III operation or the Maze procedure is the gold standard for surgical treatment of AF. In fact,

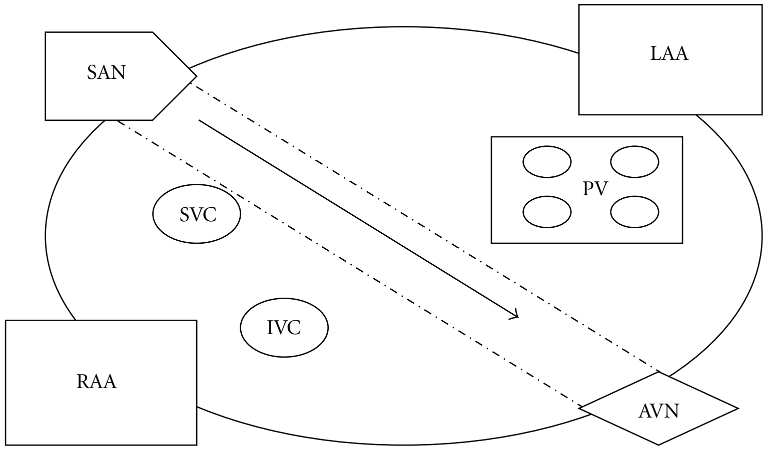

Figure 1: The Corridor Procedure designed by Guiraudon in 1985. Arrow show the direction of flow of electrical current. (SN: SA node, PV: pulmonary veins, AVN: atriventricular node, SVC: superior vena cava, IVC: inferior vena cava, LAA: left atrial appendage, and RAA: right atrial appendage).

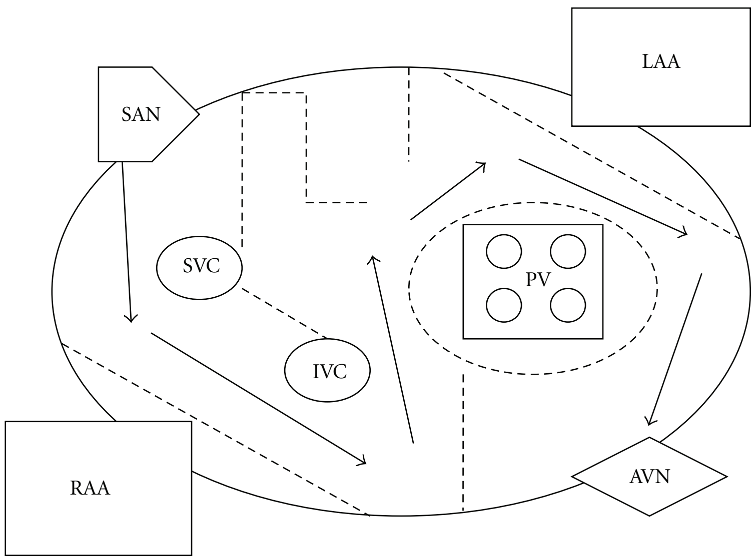

Figure 2: The Cox-Maze III lesion pattern described by James Cox in 1991 with cut and sew technique. Arrows show the direction of electrical current flow from the SA node to the atrioventricular node. (SN: SA node, PV: pulmonary veins, AVN: atriventricular node, SVC: superior vena cava, IVC: inferior vena cava, LAA: left atrial appendage, and RAA: right atrial appendage).

it is the most effective curative therapy for AF yet devised [32–34].

In 1991, Jimmy Cox described the Maze procedure for the surgical cardioversion of AF. Cox et al. designed the procedure based on experimental and clinical evidence concerning the pathophysiology of AF. To improve results and simplify the operation, they modified the procedure twice, culminating in the Cox-Maze III. In the Maze procedure, incisions are made strategically to interrupt the multiple macroreentrant circuits and direct the sinus impulse from the sinoatrial node to the atrioventricular node along a specified route (Figure 2). The Maze procedure includes encircling and isolating the pulmonary veins and excising the left and right atrial appendages. Although the Maze procedure may be performed with minimal invasiveness through a small chest wall incision, the operation requires cardiopulmonary bypass and cardiac arrest. In experienced hands, the Maze procedure requires 45 to 60 minutes of cardiopulmonary bypass and cardiac arrest. The operation may be performed alone or in conjunction with other cardiac surgical procedures, such as mitral valve surgery or coronary bypass grafting.

Cox et al. [35] have reported the largest series of patients undergoing the Maze III procedure. Among 118 patients, operative mortality was 2%. AF was cured in 93% of patients at 8.5 years of followup, and only 2% of patients required long-term postoperative antiarrhythmic medication.

The postoperative success was unaffected by presence of mitral valve disease, left atrial size, and type of AF (paroxysmal, persistent, or permanent). However, the atrial fibrillatory wave and left atrial diameter were independent predictors of sinus rhythm restoration after the maze procedure in patients with chronic atrial fibrillation and organic heart disease [36].

Temporary postoperative AF and atrial arrhythmias were common, occurring in 38% of patients. This problem was attributed to a shortened atrial refractory period; most importantly, postoperative AF was temporary and did not diminish long-term results. Fifteen percent (15%) of patients required new pacemakers postoperatively. This was a result of the underlying sinus node dysfunction rather than the Maze procedure itself. In spite of multiple right and left atrial incisions, the right atrial transport function was demonstrated in 98% of patients, and the left atrial transport function was demonstrated in 93% of patients. Furthermore, the Maze procedure virtually eliminated the risk of stroke or other thromboembolism [37]. Other medical centres reproduced these excellent results that confirm the safety of the Maze procedure and its efficacy at restoring sinus rhythm leading to the virtual elimination of late strokes. In spite of these excellent results, the Maze procedure has been relatively underused, and even in patients requiring cardiac surgery for other reasons. The perceived surgical complexity and magnitude of the operation can account for these trends.

4.4. New Approaches for Surgical AF Ablation. In an attempt to decrease the ischemic time and the on-pump time, the Cox-Maze III has evolved to a procedure that uses the latest ablation technology instead of the traditional "cut and sew" method to achieve the designated areas of conduction block. The main techniques use thermal energy to create the desired electrical barriers. These include microwave, bipolar radiofrequency, laser, and cryotherapy. The new techniques appear to be less time consuming and less technically demanding.

Microwave energy has been used to create transmural lesions on the arrested heart, but transmurality is inconsistently achieved. In a prospective randomized trial, Schuetz and colleagues [38] used a combination of microwave ablation and atrial size reduction to restore sinus rhythm in 80% of patients presenting with permanent atrial fibrillation. In another study, microwave and unipolar radiofrequency produced equivalent results (80% freedom from AF at 1 year) when used to create the Cox-Maze III lesion set [39].

The most extensive experience has been with dry unipolar radiofrequency devices. Analysing 16 studies that employed this method for ablation, Khargi and colleagues [40] found that AF has been eliminated in an average of 78% of patients with permanent AF. The success rate ranged from 42 to 92%.

Stulak et al. [41] analysed data from 56 patients who underwent the bipolar radiofrequency (RF) ablation lesions to both atria using the Cox-Maze III incision map. Results from this study showed that the use of RF ablation was associated with significantly less freedom from AF both at hospital discharge and after 15 months of followup. They were 5 times more likely to be in AF on followup. However, the use of RF while performing concomitant surgery may simplify the procedure, but with a lower chance of treating AF.

4.5. Minimally Invasive Procedures. The surgical treatment of atrial fibrillation has evolved further with time and has become technically simpler and faster with the advent of new ablative technologies. Complete endoscopic ablation with microwave energy has been performed with good success and few complications. Pruitt and colleagues [42] studied fifty patients with atrial fibrillation (33 paroxysmal and 17 permanent) who underwent thoracoscopic or robotic-assisted off-pump epicardial microwave ablation. Those investigations reported no perioperative death, a mean length of stay of 4 days, and a 79.5% (35 of 44 patients) success rate overall, with much better cure rates in paroxysmal disease (93.5%) than in permanent disease (69.2%). In 5 patients (10.0%) microwave ablation and subsequent electrophysiology intervention failed and a Cox-Maze III operation was performed to achieve cure or sinus rhythm.

In another study, Beyer and colleagues [43] performed a multicenter study of 100 patients with atrial fibrillation (39 paroxysmal, 29 persistent, and 32 permanent) who underwent bilateral minithoracoscopic, video-assisted, pulmonary vein ablations using bipolar radiofrequency, ganglionic mapping and ablation, and LAA resection. The mean operative time was 253 minutes, and the mean length of stay was 6.5 days. Results showed that there was an 86% overall success rate (93% paroxysmal, 96% persistent, and 71% permanent), 62% discontinuation of antiarrhythmic drugs, and 65% discontinuation of anticoagulation. However, there was a 13% rate of complication (pacemaker implantation, phrenic nerve injury, postoperative hemothorax, and transient ischemic attack) over a mean follow-up time of 13.6 months.

There are many promising innovations using minimal-access procedures for standalone and concomitant AF. It is prudent to say that within a few years, surgeons will be performing a number of surgical ablations with minimal complexity and maximum effectiveness, using port-accessed, video-assisted, and robot-assisted surgical techniques and specialized navigation instruments.

5. Conclusion

There are three epidemics of cardiovascular disease in the 21st century: atrial fibrillation, congestive heart failure, and the metabolic syndrome. AF is common in patients presenting for cardiac surgery. If it is left untreated, it increases morbidity and mortality. Therefore, one should consider surgery for AF in those patients.

One of the most significant obstacles facing the widespread adoption of surgical approaches is the lack of large controlled studies and trials that evaluate the different techniques and methods for surgical ablation of AF. In addition, further understanding of the fundamental electrophysiological mechanism of AF will aid in finding new approaches and a cure for this arrhythmia. AF must be targeted quickly because the longer the patient is in AF, the harder it becomes for him/her to revert back to sinus rhythm, "AF begets AF."

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