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Surgical ablation of atrial fibrillation

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ABSTRACT

Surgical ablation of atrial fibrillation (AF) is currently performed in many major hospitals throughout the world. This paper reviews the development of surgical procedures for AF ablation. It is hoped that the paper can provide a foundation for those involved with ablation of AF to improve patient care. AF is triggered by a rapidly firing focus and could be treated with a localized ablation procedure. A large body of literature has confirmed the safety and efficacy of surgical ablation of AF. New ablation technologies have simplified the surgical treatment of AF and expanded the indications. Generally, more extensive lesion sets have had better long-term outcomes. Despite the tremendous progress that has been made in the development of surgical ablation of AF, many questions remain unanswered. It is anticipated that well designed clinical trials will continue to provide solid evidence to help formulate practice guidelines in the future.

1. Definitions and mechanisms of atrial fibrillation

Atrial fibrillation (AF) is a common supraventricular arrhythmia characterized by chaotic contraction of the atrium. Any arrhythmia that has the electrocardiogram (ECG) characteristics of AF and lasts for a 12-lead ECG recorded, or at least 30 s on a rhythm strip, should be considered an AF episode [1,2].

For years, considerable progress has been made in defining the mechanisms of initiation and perpetuation of AF [3–5]. With the recognition that, in a subset of patients, AF was triggered by a rapidly firing focus and could be treated with a localized ablation procedure, the arrhythmia community refocused its attention on the pulmonary veins (PVs) and the posterior wall of the left atrium (LA), as well as the autonomic innervation in that region. It also reinforced the concept that the development of AF requires a trigger and an anatomic or functional substrate capable of both initiation and perpetuation of AF. Some authors [6–8] have proposed that, in the presence of an appropriate heterogeneous AF substrate, a focal trigger can result in sustained high frequency reentrant AF rotors. The waves that emerge from the rotors undergo spatially distributed fragmentation and give rise to fibrillatory conduction. Sustained high rates in the atrium and/or the presence of heart disease are associated with structural remodeling of the atria and alter the substrate even further and help to perpetuate AF [9–11].

2. Classification of atrial fibrillation

Although there are several classification systems for AF, the classification system that was developed by the ACC/AHA/ESC 2006 Guidelines for the Management of Patients with Atrial Fibrillation and the ESC 2010 Guidelines for the Management of Atrial Fibrillation [2,12,13] is recommended here.

A patient who presents with AF for the first time is considered to have first diagnosed AF, irrespective of the duration of the arrhythmia. Paroxysmal AF is defined as recurrent AF (≧ two episodes) that terminates spontaneously within seven days. Persistent AF is defined as recurrent AF that is sustained for more than seven days. Patients with continuous AF who undergo cardioversion within seven days should be classified as having paroxysmal AF if the cardioversion is performed within 48 h of AF onset, and persistent AF if the cardioversion is performed more than 48 h after AF onset. Longstanding persistent AF is defined as continuous AF with duration of greater than one year. A fourth category of AF is “permanent AF”. The term represents a joint decision by the patient and a physician to cease further attempts to restore and/or maintain sinus rhythm at a particular point in time. It

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represents a therapeutic attitude on the part of a patient and his/her physician rather than any inherent pathophysiological attribute of the AF. If after reevaluation, a rhythm control strategy is recommended, the AF should then be redesignated as paroxysmal, persistent, or longstanding persistent AF. Silent AF is defined as asymptomatic AF diagnosed by an opportune ECG or rhythm strip. A particular patient may have AF episodes that fall into one or more of these categories. It is recommended that patients be categorized by their most frequent pattern of AF during the six months prior to performance of an ablation procedure.

3. Surgical ablation of atrial fibrillation

Although antiarrhythmic agents can be used for rhythm or rate control, the medications are not universally effective, and chronic requirement for medication and anticoagulation may also adversely affect quality of life (QOL). A large body of literature, including multiple prospective randomized clinical trials, has confirmed the safety and efficacy of surgical ablation of AF [14]. In general, surgical ablation procedures for AF can be grouped into three different groups: a full Cox-maze procedure, pulmonary vein isolation (PVI) alone, and PVI combined with left atrial lesion sets.

3.1. Cox-maze procedure

The Cox-maze procedure was first introduced for the surgical treatment of AF in 1987 by Dr. James Cox [15], with the intention of eliminating AF by using incision scars to block the abnormal electrical circuits. This procedure was designed to interrupt all macroreentrant circuits that might potentially develop in the atria. Fortuitously, the operation also isolated all of the PVs and the posterior LA. The Cox-maze procedure successfully restored both atrioventricular synchrony and sinus rhythm as well as decreased the incidence of late stroke [16]. This effect was attributed to both AF control and amputation of the LA appendage. The procedure involved creating multiple strategically placed incisions across both the right and left atria, which enabled the sinus node to direct the propagation of the sinus impulse throughout both atria. It also allowed most of the atrial myocardium to be activated, resulting in the preservation of atrial transport function in most patients [17]. A series of systematic improvements have subsequently been made, culminating in the 1992 Cox-maze III procedure, which is now considered to be the “gold standard” for effective surgical treatment of AF [18–20].

3.2. New surgical ablation technology

Despite its efficacy, the Cox-maze procedure did not gain widespread application. Few cardiac surgeons were willing to add the operation to coronary revascularization or valve procedures due to its complexity, technical difficulty, and risks. In an attempt to simplify the operation and make it more accessible to the average surgeon, groups around the world replaced the incisions of the traditional cut-and-sew Cox-maze procedure with linear lines of ablation. These ablation lines are created using a variety of energy sources including radiofrequency (RF) energy, cryoablation, microwave, and high intensity focused ultrasound (HIFU) [21,22]. The various technologies can be organized into two major groups: those that use a unipolar energy source and those that use a bipolar clamp.

The unipolar energy sources (cryoablation, unipolar RF energy, HIFU) radiate either heat or cold from a single source. The unipolar devices do not reliably provide the surgeon with an indication of when the ablation results in a transmural lesion. Since most of these ablation devices were released clinically without dose–response studies, their use has led to occasional collateral cardiac and extracardiac damage [23,24]. Moreover, these energy sources have a fixed depth of penetration, which may make their use in pathologically thickened atria or from the epicardial surface on the beating heart problematic [25–28].

Bipolar RF ablation has been able to overcome some of these shortcomings [29–31]. Since energy is delivered between two closely approximated electrodes embedded in the jaw of a clamp device, the energy is focused and results in discrete lesions. The energy is confined to within the jaws of the clamp, reducing the possibility of collateral cardiac or extracardiac damage. The weakness of these devices is that they can only ablate tissue that can be clamped within the jaws of the device. This has limited the potential lesion sets, particularly in the beating heart. These devices have been incapable of fully ablating the right and LA isthmus and have required adjunctive unipolar ablation to perform a complete Cox-maze III lesion set [32].

In spite of some deficiencies, the development of these new ablation technologies has benefited the surgical treatment of AF by making a technically difficult and time-consuming operation easier for general cardiac surgeons to perform. Replicating the full Cox-maze lesion set with linear lines of ablation has been shown to be both feasible and clinically effective. A number of groups have reported excellent results with ablation-assisted Cox-maze procedures [33–35].

3.3. Surgical atrial fibrillation ablation concomitant to other cardiac surgery

At present, more than 50% of the patients undergoing open-heart surgery who have AF are offered concomitant AF surgery [36]. Prior AF might place patients undergoing cardiac surgery at risk for early and late mortality. Moreover, patients who have AF before cardiac surgery have been shown to be generally older, have worse ventricular function, and other comorbidities [37–39]. AF may not be a specific marker for high-risk patients, but it may be an independent risk factor for increased long term morbidity and mortality. Therefore, AF surgery may improve survival or reduce late adverse cardiac events.

There have been several prospective randomized clinical trials of surgical AF ablation performed in conjunction with other cardiac surgical procedures [40–43]. A variety of left atrial lesion sets and ablation tools were used in these trials including RF, microwave, and cryoablation. In one study [41], 97 patients referred for mitral valve surgery with six months or more of continuous AF were randomized to receive mitral valve surgery and left atrial RF ablation (RFA) or mitral valve surgery alone. At 12-month follow-up, sinus rhythm was present in 44% of RFA patients and 4.5% of controls ($p < 0.001$). Restoration of sinus rhythm in the RFA group was accompanied by greater improvement in mean shuttle-walk distance compared with controls ($p = 0.003$). Patients randomized to receive RFA had similar rates of post operative complications and deaths as control patients.

More recent studies have documented success using a variety of different technologies, most commonly bipolar RF ablation, for the treatment of AF with concomitant mitral or other cardiac operations [44–47]. Success rates of these studies have varied between 65% and 95% at six months. There has been great variation in the results between different centers. This can be attributed to many factors, including surgeon experience, lesion sets, and the use of different ablation technologies. The type of lesion set has had the biggest impact on late results. Generally, more extensive lesion sets have had better long-term outcomes. The Cox-maze procedure and lesion sets created with alternative energy sources had a similar low prevalence of late post operative AF. A large meta-analysis of retrospective studies has also demonstrated significantly better late results with biatrial lesion sets when compared to LA lesion sets alone [48].

The primary advantage of adding a full Cox-maze procedure to concomitant surgery, aside from the resumption of sinus rhythm, is a reduction in the risk of stroke. For patients with a classic maze operation, the risk of stroke at 10 years has been less than 1% in large published series