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Atrial Fibrillation Ablation

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Executive Summary

Atrial fibrillation (AF) is the most common sustained arrhythmia in adults and is a rapidly growing epidemic. Catheter ablation for AF is possible because atrial fibrillation is frequently incited by focal triggers, many of which arise from the pulmonary veins. Current ablation techniques seek to eliminate or isolate these triggers from the rest of the atria in order to restore sinus rhythm. The mainstay of ablation remains radio frequency energy, although other energy sources are currently under investigation. Accurate imaging and mapping is important for successful AF ablation. The combination of intracardiac echo, computed tomography (CT), and magnetic resonance (MR) imaging with a three-dimensional electroanatomical mapping system is useful to prepare and perform these procedures. In addition, post-ablation CT or MR imaging can identify pulmonary vein stenosis or atrio-esophageal fistula. The remote catheter navigation technology promises to reduce risk to the patient and radiation exposure to the physician. Significant advances in catheter ablation for AF will lead to safer procedures and better outcomes. More rigorous randomized trials and long-term follow-up are needed to further define the role of catheter ablation in the management of atrial fibrillation.

Introduction

Atrial fibrillation (AF) is the most common sustained arrhythmia in adults. It affects at least two million people in the United States and is a rapidly growing epidemic (1). While heart rate control and anticoagulation is an accepted treatment strategy for many asymptomatic patients, symptomatic patients often require rhythm control. Pharmacologic methods for the control of AF and the maintenance of normal sinus rhythm have an overall poor long term success rate of approximately 50% (2). This has lead to the development of nonpharmacologic interventions to achieve restoration of normal sinus rhythm. Catheter-based ablation for AF has made significant advancements recently in both efficacy and safety. Multiple trials have shown efficacy of catheter ablation for restoring sinus rhythm in patients with AF (Table). This progress has lead to its inclusion as a treatment option for patients with AF in the 2006 update of the ACC/AHA/ESC guidelines for the management of AF (1).

Catheter Ablation for Atrial Fibrillation

Catheter ablation for AF is based on the initial observation that AF is frequently incited by focal triggers, many of which arise from the pulmonary veins (PV) (3). Ablation techniques seek to eliminate or isolate these triggers from the rest of the atria in order to restore sinus rhythm. Currently, many different techniques can be used.

Segmental Ostial Pulmonary Vein Isolation

Initial attempts at AF ablation involved segmental ostial pulmonary vein (SPV) isolation. In this technique, the targets for ablation are the focal triggers of AF in the muscular bands of electrically active atrial-like tissue extending into the pulmonary veins. However, techniques using focal ablation of these sites within the pulmonary veins are associated with frequent recurrence of AF and pulmonary vein stenosis. SPV isolation outside of the pulmonary veins was developed to deal with these PV drivers of AF and reduce the rate of pulmonary vein stenosis (4).

The SPV technique involves electrical and anatomic mapping of the PV ostia. Ablation lesions are placed encircling each PV ostium. Isolation is generally confirmed by the absence or dissociation of local PV potentials around the circumference of the PV or by pacing maneuvers. This is done empirically for all of the PVs or selectively in the PVs where AF triggers can be recorded. Selective PV isolation leads to a significantly higher recurrence rate, presumably because PV AF triggers may not be always firing (5).

Circumferential Pulmonary Vein Ablation

Another technique is that of circumferential pulmonary vein ablation (CPVA). This involves placement of a larger lesion set encircling the PVs in a continuous ablation line. Generally other ablation lines are placed in the left atrium (LA) connecting these ablation lines to the mitral valve (the mitral isthmus line), or con-

Table **Randomized Trials of Atrial Fibrillation Ablation**

Trial	**Study Group**	**Patients**	**Maintenance of Sinus Rhythm**	**Technique**
Pappone et al. **APAP study** (21)	Paroxysmal AF Prior AAD failure	198	86% ablation 22% AAD (p<0.001)	CPVA
Wazni et al. **RF Ablation vs. AAD as First-line Treatment of Symptomatic AF** (22)	Most paroxysmal AF (95%) No prior AAD or AF ablation	70	87% ablation 37 % AAD (p<.001)	PVAI
Oral et al. **CPVA for Chronic AF** (23)	Chronic AF patients	146	74% ablation 58% AAD (p 0.05)	CPVA
Stabile G et al. **Catheter Ablation For The Cure Of Atrial Fibrillation Study** (24)	Paroxysmal AF or persistent AF Intolerant or failed 2 AAD	137	55.9% ablation 8.7% AAD (p<0.001)	CPVA + Cavo-tricuspid line

AF = atrial fibrillation; RF = radio frequency; CPVA = circumferential pulmonary vein ablation; PVAI = pulmonary vein antrum isolation; AAD = antiarrhythmic drug

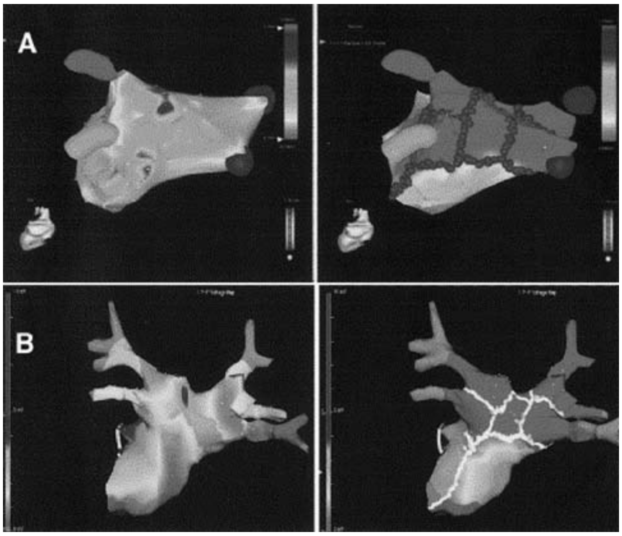

Figure 1 **Circumferential Pulmonary Vein Isolation Lesion Set**
A and B show CartoTM maps pre- (left) and post- (right) CPVA. The dots are the individual ablation lesions. After ablation there is very minimal electrical communication from the pulmonary veins and posterior left atrium to the rest of the left atrium as shown by the red on the post-ablation activation map.

necting the encircling lesions along the roof of the left atrium. These linear lesions are placed in an attempt to reduce the probability of causing macroreentrant left sided atrial flutter (Figure 1). Additionally, a right-sided cavotricuspid isthmus ablation can also be placed to reduce the rate of right sided atrial flutter post-procedure, although this is not always necessary. Complete PV isolation can be confirmed using a multipolar recording catheter, but some centers do not do this routinely. This approach to AF ablation is more anatomically based. It is worth noting that previous strategies involved ablation of a posterior line connecting the sets of ablation lesions around the pulmonary veins, however the report of atrio-esophageal fistula formation as a result of ablation in the posterior wall of the left atrium has led to adoption of the roof line instead (6).

Autonomic ganglionic plexi have also been targeted as ablation targets. Ablation of these plexi can cause vagal denervation of the LA, which combined with CPVA has been reported to achieve higher rates of long term success in ablation of paroxysmal AF (7).

Ablation of Complex Fractionated Atrial Electrograms

The ablation of complex fractionated atrial electrograms (CFAE) has been postulated as an ablation strategy for AF. These CFAEs are sites where the electrograms have a cycle length less than 120 msec, have 2 or more deflections, or have a change in the baseline with continuous low voltage activation. These have been shown to be a marker for areas that drive AF. Targeting these sites has also been added to other ablation approaches to increase the efficacy of AF ablation (4).

A "Tailored" Approach

Recently, a "tailored" approach to ablation of AF was advocated by Oral and colleagues (8). This involves selective ablation of the PVs that appear to be causing AF. Then, CFAEs are mapped and ablated until AF is not inducible. This has led to an acceptable success rate of 80% with less ablation time and minimal reported complications, however 18% of patients need a second procedure to completely isolate the PVs not previously ablated.

Isolation of the Pulmonary Vein Antrum

Pulmonary vein antrum isolation is similar to SPV, but utilizes intracardiac echo (ICE) and a circular mapping catheter (Lasso). The ICE catheter is used to correctly identify the PV antrum, and each PV is electrically isolated by ablating outside the pulmonary vein and in the antrum. Electrical conduction block is confirmed by mapping using the Lasso catheter during and after ablation. This is done to reduce the risk of PV stenosis. The technique is associated with a high success rate of 87% freedom from AF while off medication at 12 months of follow-up (9).

Ablation Technologies

There has been rapid advancement in the technologies used for ablation. While the mainstay of ablation remains radiofrequency energy, other energy sources are currently under investigation. Improvements in ablation technologies will ideally lead to a safer and more efficacious procedure.

Radiofrequency Ablation

An 8 mm tip radiofrequency ablation catheter is frequently used for AF ablations. More recently, open irrigation catheters like Thermo-Cool™ (Biosense Webster), or Cool-Path™ (St. Jude Medical) are increasingly used. These irrigated tip catheters allow delivery of larger lesions at a lower tip temperature than non-irrigated tip radiofrequency catheters (10). In addition, expandable RF catheters like the RF MESH™ catheter (Bard EP) may have the potential to more quickly map and ablate the PVs (11).

Specially formed balloon tip or circular catheters that deliver large lesions around the PVs have been developed. These catheters can deliver large lesions quickly, but may have some limitation in the ability to be utilized in every patient given the significant amount of anatomical variability encountered. An ideal balloon tip or circular catheter would be adaptable to different anatomies.

Cryoablation

Other energy sources have also been developed to deliver effective ablation lesions. Cryoablation uses a supercooled gas to “freeze” the catheter to the endocardial surface. This causes cell injury and apoptosis resulting in ablation lesions. This has been used extensively for surgical ablation with acceptable results. Cryoablation has the advantage of being less thromobogenic. In addition, it is less likely to produce PV stenosis or esophageal injury. The Arctic Front® balloon tip cyroablation catheter with the Freezor MAX ™catheter (CryoCath Technologies) and the CryoCor™ catheter (CryoCor Inc) have been shown in small studies to be safe and successful in the ablation of AF (12-13).

Ultrasound

The use of ultrasound energy for AF ablation has been examined. Natale and colleagues reported the use of the Atrionix™ over-the-wire balloon circumferential ultrasound ablation system in 15 patients (12). They noted a 60% drug-free maintenance of sinus rhythm in short-term follow-up without evidence of PV stenosis. However, long-term results showed only a 30% success rate.

High-intensity focused ultrasound (HIFU) has also been applied to catheter-based systems for ablation. The use of HIFU creates tissue damage by thermal destruction at the site where the ultrasound is focused. This technique has the advantage of being able to deliver heat energy to a deeper, larger area and limit endocardial damage. In addition, HIFU is also not as contact dependant as RF or cyroablation to create ablation lesions (13,14). Long-term clinical data is still lacking for this energy source.

Laser

Laser energy uses light to create discrete ablation lesions. The Endoscopic Ablation System (Cardiofocus) is a balloon catheter that uses arcs of adjustable laser energy with direct endoscopic visualization during the ablation. Neuzil and colleagues reported a 91% success rate in electrical PV isolation and a 75% freedom from AF at 12 months with an acceptable complication rate (15).

Future Techniques

Radiation energy and autologous fibroblasts have also been considered as future methods to place ablation lesions.

Imaging for Atrial Fibrillation Ablation

Intracardiac Echo

Accurate imaging and mapping is important for successful AF ablation. As mentioned, ICE can be used to help the operator visualize the cardiac anatomy in real time. Frequently, the true PV ostia are better visualized with ICE than fluoroscopy. Also, ICE has been reported to help visualize the esophagus during AF ablation, which may be useful in avoiding areas that can pose an increased risk for ablation. In addition, ICE can be used to guide the safety of RF ablation by monitoring for microbubble formation, although this can be difficult when using an open irrigation catheter (16). Finally, ICE images can be used to generate a three-dimensional (3-D) anatomy when they are combined with a 3-D electroanatomical mapping system. They can also be used to facilitate registration of computed tomography (CT) or magnetic resonance (MR) images with a 3-D electroanatomical mapping system (Figure 2) (17).

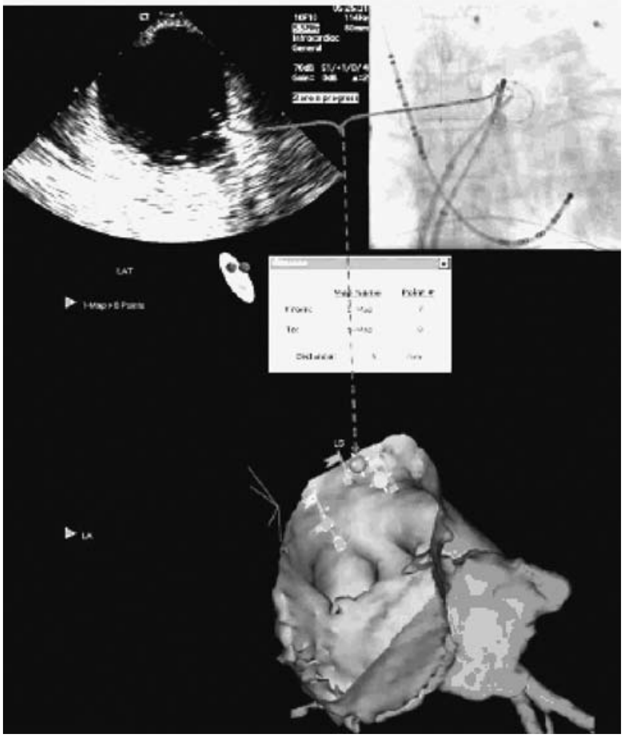

Figure 2 **Intracardiac Echo Guided CT Scan Registration with Electroanatomical Map**
The anatomic landmarks identified by ICE are used to register the position of the catheter with a previous ablation CT scan of the left atrium.

Three-dimensional Electroanatomical Mapping

As alluded to, 3-D electroanatomical mapping systems are useful for AF ablation. The two most commonly used are Carto™ (Biosense-Webster) and Ensite NavX™ (St. Jude Medical). The Carto™ system consists of a steerable catheter with a sensor coil on the tip and a location pad that generates three low-intensity magnetic fields. The Carto™ system tracks the position of the tip of the catheter during electrical mapping and ablation using the sensor and magnetic fields. This data is integrated together with catheter electrogram data to create an electroanatomical map. The Ensite NavX™ systems use three pairs of surface electrodes to generate low-level electrical currents. Standard electrophysiology catheters are used to sense the electrical signals transmitted between three pairs of EnSite NavX™ surface electrode patches. The Ensite NavX™ system integrates the data from the catheters and uses this information to track their movement and construct a three-dimensional map.

Cardiac CT and MR

Cardiac CT and Cardiac MR have been used in many aspects of AF ablation. Cardiac MR offers the advantages of no ionizing radiation and a less nephrotoxic contrast agent. However, cardiac CT is significantly faster and more readily available. Both can produce a detailed picture of the posterior left atrium and the PVs prior to ablation. The PV anatomy can be variable with only 60-70% of patients having the classic 4 separate PV ostia. Anatomic variations include accessory PVs or a common PV ostia (Figure 3). Identification of a persistent left superior vena cava or partial anomalous PV return can help with pre-procedure planning. Imaging data from CT or MR can be merged with the 3-D electroanatomical maps (Carto™ or NavX™) to create a detailed 3-D picture of electrical activation in the atria, enabling 3-D anatomic guidance of catheters to quickly deliver lesions in the correct place. Post-ablation, both CT and MR can identify PV stenosis. Cardiac CT can also be used to identify atrio-esophageal fistula (18).

Rotational Angiography

Rotational angiography was originally developed to provide rapid 3-D images of the neurovasculature in the angiography suite. It has been adapted for use in cardiac procedures. During bolus contrast injection, the C-arm rotates around the patient in a short period-of-time. The resulting images are quickly post-processed and a 3-D fluoroscopy image of the PVs and LA can be obtained before the procedure begins. With oral contrast, the esophagus can also be visualized (Figure 4). These images have been shown to be similar in quality to pre-procedure CT scans in delineating anatomy for AF ablation planning. They offer the advantage of being acquired at the time of ablation, giving a more real-time picture of the anatomy (19).

Magnetic and Robotic Remote Catheter Control Technology for AF Ablation

Remote navigation and ablation technologies can offer multiple advantages in the ablation of AF. Remotely guided catheters can be manipulated in three dimensions. This can allow catheters to be more quickly and precisely maneuvered into difficult-to-reach positions for mapping, and can assist with maintaining better endocardial contact during ablation. Also, the use of remote mapping significantly reduces fluoroscopy exposure to the operator.

The Niobe II™ system (Stereotaxis) is a magnetically guided remote system. It utilizes two permanent

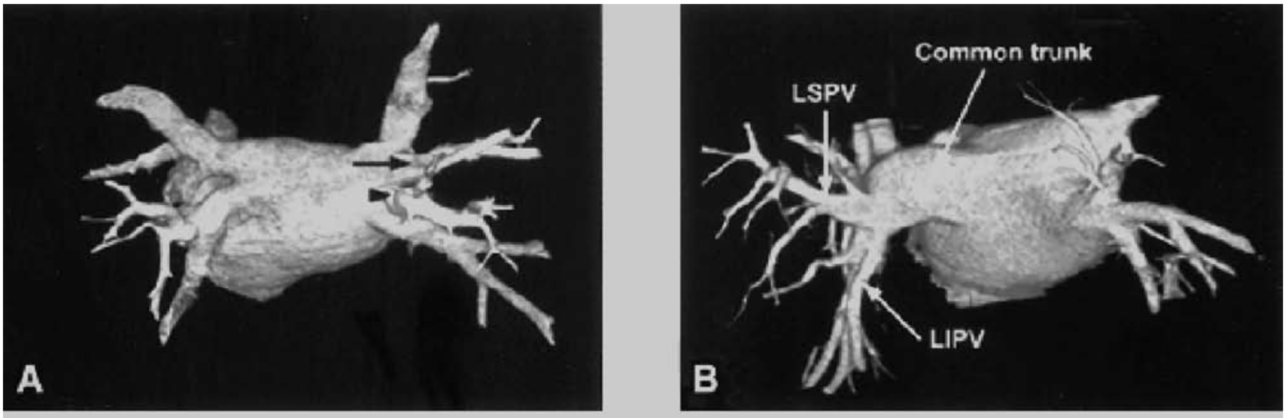

Figure 3 **Variations in Pulmonary Venous Anatomy**
An accessory right pulmonary vein (A) and a common left pulmonary vein trunk (B) on reconstructed 3-D CT scan images.

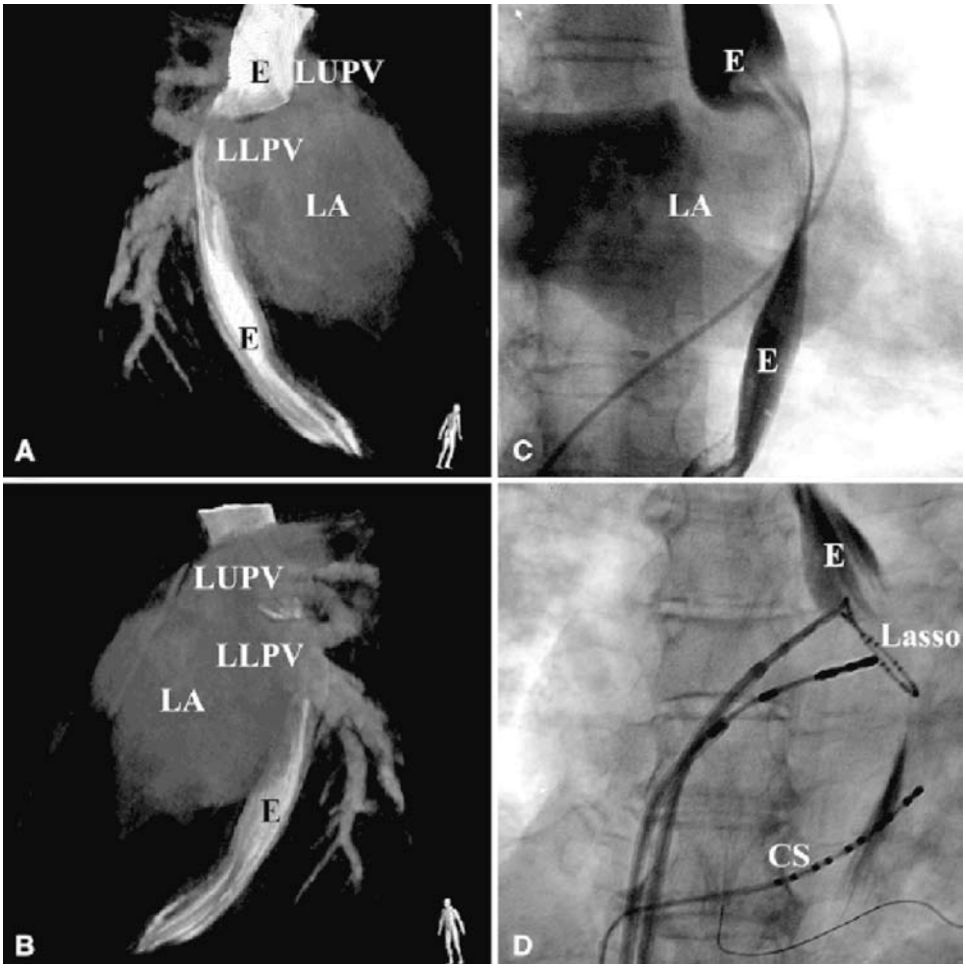

Figure 4 **Rotational Angiography of the Left Atrium, Pulmonary Veins, and Esophagus**
A and B show post-processing images of the left atrium (LA), left upper (LU) and left lower (LL) pulmonary veins (PV), and esophagus after a bolus contrast injection and barium swallow using rotational angiography. C and D are the fluoroscopy images before processing.

magnets that can be pivoted on each side of the table to generate a 0.08 Tesla magnetic field. The catheters are soft, flexible, and can be steered at their tip by the magnetic field. A mechanical device can retract and advance the catheters. The catheters are integrated with the Carto™ electroanatomical map. Mapping and ablation are performed with the catheter using magnetic guidance. Over 300 AF ablations have been done with this system, and the success rates and procedure times with the Niobe II™ are similar to manual approaches after an initial learning curve (20).

The Sensei™ Robotic Catheter System (Hansen Medical) and the Artisan™ Control Catheter (Hansen Medical) have recently been FDA-approved for use in electrophysiology procedures. This system uses robotics to enable the operator to remotely maneuver the control catheter in three dimensions. The catheter consists of outer and inner steerable guides that are mechanically navigated with the robotic catheter system. This system has the advantage of not needing a specialized lab for installation.

Conclusion

Catheter ablation offers an important treatment advancement for patients with atrial fibrillation. Multiple techniques and technologies currently exist, and it is expected that continued evolution of this therapy will lead to safer procedures and better outcomes. While ablation has become a proven treatment for symptomatic AF, rigorous randomized trials with long-term follow-up are needed to improve the selection of patients with atrial fibrillation who will most benefit from catheter-based treatments.

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