

The Who, What, Why, and How-To Guide for Circumferential Pulmonary Vein Ablation

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Introduction

Circumferential pulmonary vein (PV) ablation for patients with atrial fibrillation (AF) is an effective treatment that is becoming more widely accepted and practiced.^{1,2} A significant learning curve exists, however, and periprocedural and postprocedural management is important to maximize success rates and reduce complications. Until recently this procedure was considered a purely anatomic approach without clear electrophysiologic endpoints, operator dependent, and nonreproducible. This article describes the methodologic approach to this ablation procedure. We report our extensive experience based on approximately 4,000 patients with either paroxysmal or chronic AF, many of whom have structural heart disease (Fig. 1).

Inclusion and exclusion criteria are listed in Table 1.

Preprocedure

One month before the procedure, all patients undergo transthoracic echocardiography (TTE), 24-hour ECG monitoring, and daily transtelephonic recordings by random or symptom-triggered recordings. Three or more consecutive international normalized ratio (INR) values between 2.5 and 3.5 should be documented in patients with chronic AF before the procedure. Antiarrhythmic drugs (except amiodarone) and digoxin are discontinued for more than five half-lives before the ablation procedure. All patients are admitted the day before the procedure. Laboratory tests, history and physical examination, quality-of-life questionnaire, ECG, and transesophageal echocardiography (TEE) are performed in all patients upon hospital admission.

Periprocedural Anticoagulation

Three days before the procedure, patients taking anticoagulants (usually those with persistent or chronic AF) stop oral anticoagulant therapy. The night before the procedure, heparin infusion is started to achieve an activated clotting time (ACT) ranging from 200 to 250 seconds. Heparin infusion is stopped 2 hours before the ablation pro-

cedure to safely obtain vascular access and perform the transseptal puncture. After transseptal puncture, heparin is restarted as an initial bolus (5,000 U), followed by infusion or additional boluses to maintain an ACT between 250 and 300 seconds or between 300 and 350 seconds if evidence of smoke and/or decreased velocity is noted at TEE.

Analgesia

Because ablation in the left atrium (LA; particularly around the left inferior PV and posterior wall) can be uncomfortable or painful, we use a weight-adjusted infusion of intravenous remifentanyl 0.025–0.05 $\mu\text{g}/\text{kg}/\text{min}$.

Ablation Procedure

Three catheters are used: a standard bipolar or quadripolar catheter in the right ventricular apex to provide backup pacing; a quadripolar catheter in the coronary sinus (CS) to allow pacing of the LA; and the ablation catheter, which is passed into the LA following transseptal puncture with a standard Mullins sheath. A pigtail catheter is temporarily positioned above the aortic valve, acting as a landmark at the time of transseptal puncture. The pigtail catheter is then removed, but arterial vascular access is maintained throughout the procedure for continuous arterial pressure monitoring. Power, impedance, and electrical activity are monitored continuously during navigation and ablation. We use 8-mm-tip catheters to prevent thrombus formation, particularly given our higher power (100 W) and temperature settings (65°C). Impedance may increase suddenly if thrombus forms on the catheter tip. In our experience, a much more useful indicator is a 40% to 50% reduction in the power delivered to reach target temperature. If thrombus formation is suspected, catheter withdrawal from the LA without advancing the transseptal sheath may be necessary to preserve transseptal access. This avoids stripping any thrombus present on the catheter tip as the catheter is withdrawn into the sheath, which can result in systemic embolization. We normally start by acquiring the location of all four major PVs and the mitral annulus as anatomic landmarks for the CARTO (Biosense-Webster, CA, USA) navigation and create the map by entering each PV in turn. To acquire PVs we use three criteria based on (1) fluoroscopy, (2) impedance, and (3) electrical activity. Entry into the vein is clearly identified as the catheter leaves the cardiac shadow on fluoroscopy, the impedance usually rises above 140 to 150 Ω , and electrical activity disappears. Due to the orientation

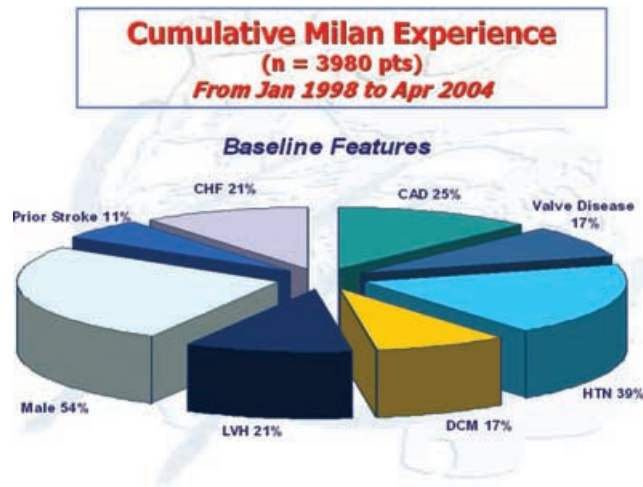


Figure 1. Breakdown of patient characteristics treated in Milan, Italy, between 1998 and 2004. CAD = coronary artery disease; CHF = congestive heart failure; DCM = dilated cardiomyopathy; HTN = hypertension; LVH = left ventricular hypertrophy.

of some veins and the limitations of catheter shape, it can be difficult to enter deep into some veins, but the impedance still rises when the catheter is in the mouth of the vein. To better differentiate between PVs and LA, we use voltage criteria (fractionation of local bipolar electrogram) and impedance (rise $>4 \Omega$ above mean LA impedance) to define PV ostium. Clearly, the anatomic appearance on CARTO acts as added confirmation of catheter entry into the PV ostium, and an 8 mm-tip deflectable catheter (Navi-Star, Cordis-Webster, CA, USA) is used for mapping and ablation.

Mapping Process

The mapping and ablation procedures are performed by using the CS atrial signal if the patient is in sinus rhythm (SR) or the right ventricular signal if the patient is in AF, as the synchronization trigger for CARTO. If spontaneous ventricular rates during AF are too low, we usually pace the right ventricle at higher rates to increase the CARTO system

TABLE 1
Patient Selection

Inclusion Criteria	
At least one monthly episode of persistent symptomatic AF	
At least one weekly episode of paroxysmal AF	
Permanent AF	
At least one failed trial of antiarrhythmic drugs	
More than one antiarrhythmic drug to control symptoms	
Exclusion Criteria	
New York Heart Association functional class IV	
Age >80 years	
Contraindications to anticoagulation	
Presence of cardiac thrombus	
Left atrial diameter ≥ 65 mm	
Life expectancy <1 year	
Thyroid dysfunction	
Recent Updates	
Patients with mitral and/or aortic metallic prosthetic valves are not excluded	
Previous repair of atrial septal defects is not an absolute contraindication	

AF = atrial fibrillation.

sampling rates. If the patient is in SR we map during continuous CS pacing to increase the refresh rate (Fig. 2). The chamber geometry is reconstructed in real time by interpolation of the acquired points. Usually, 100 points are required to create adequate maps of LA and PVs and up to 200 points for accurate mapping of left atrial tachycardia (AT). Local activation times can be used to create activation maps, which are extremely important when attempting to map and ablate focal or macroreentrant atrial tachycardias. Intracardiac echocardiography is used only for investigational purposes.

Radiofrequency Ablation

Once the main PVs and LA have been adequately reconstructed, radiofrequency (RF) energy is delivered to the atrial endocardium with RF generator settings of 55° to 65°C and a power limit of 100 W. This is reduced in the posterior wall to 50 W and 55°C to reduce risk of injury to the surrounding structures. The gray location map is used for the ablation procedure as it avoids presentation of unnecessary information to the operator (Fig. 2, panel 2). RF energy is applied continuously on the planned circumferential lines, as the catheter is gradually dragged along the line. Continuous catheter movement, often in a to-and-fro fashion over a point, helps keep catheter tip temperature down due to passive cooling. Successful lesion creation at each point is considered to have taken place when the local bipolar voltage has decreased by 90% or to <0.05 mV. On average, a total of 10 to 15 seconds of RF is required. If the catheter position deviates significantly from the planned line or falls into a PV (usually associated with a sudden rise in impedance $>4 \Omega$), RF application is immediately terminated until the catheter is returned to a suitable location. Circumferential ablation lines are normally created starting at the lateral mitral annulus and withdrawing posteriorly then anterior to the left-sided PVs, passing between the left superior pulmonary vein (LSPV) and the left atrial appendage (LAA) before completing the circumferential line on the posterior wall of the LA. The "ridge" between the LSPV and LAA can be identified by fragmented electrograms due to collision of activity from the LAA and LSPV/LA. The appendage is identifiable by a significantly higher impedance ($>4 \Omega$ above LA mean), a high voltage local bipolar electrogram, with characteristically organized activity in fibrillating patients. The right PVs are isolated in a similar fashion, and then a posterior line connecting the two circumferential lines is performed to reduce the risk of macroreentrant atrial tachycardias. The endpoint for circumferential ablation is $>90\%$ reduction in voltage within the isolated regions. Gaps are defined as breakthroughs in an ablated area and identified by sites with single potentials and by early local activation. Usually, we do not validate circumferential lesions around PVs by pacing maneuvers. Rather, we validate the bipolar voltage abatement within the encircled areas by performing a voltage remap, acquiring new points on the existing geometry to give voltage measurements. This should characteristically show low voltage (red) with the PV encircling lines. Completeness of lesion lines, particularly at the mitral isthmus, are critical in preventing postablation macroreentrant LA tachycardias, which in the majority of cases are mitral-isthmus dependent and incessant. The completeness of the mitral isthmus line is demonstrated during CS pacing by endocardial and CS mapping looking for widely spaced double potentials across the

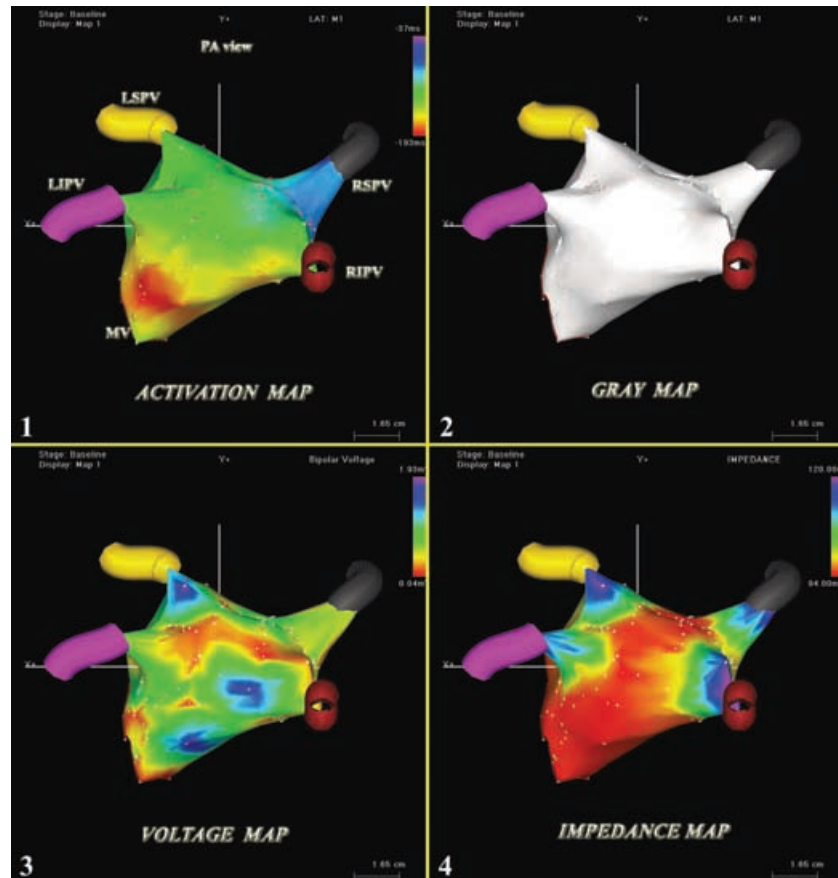


Figure 2. Panels 1 to 3 are examples of activation, location, and bipolar voltage maps in a posteroanterior view from a patient prior to circumferential pulmonary vein ablation (CPVA) created during coronary sinus (CS) pacing as indicated by the early timing, red, in the region of the distal CS on the activation map. Panel 4 is an endocardial impedance map created using manually entered impedance readings from the radiofrequency generator. LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; MV = mitral valve; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein.

line of block and confirmed by differential pacing. In our experience, the minimum double potential interval at the mitral isthmus during CS pacing after block is achieved between 150 and 300 ms, depending on the atrial dimensions and the extent of scarring and lesion creation. After the planned lines of block have been created, the LA is remapped, and the preablation and postablation activation maps are compared. Incomplete block is revealed by impulse propagation across the line; in such a case, further RF applications are given to complete the line of block. We observe termination of AF during the procedure in about one third of patients. If AF does not terminate during RF, then transthoracic cardioversion is performed at the end of the procedure. If AF recurs immediately after the cardioversion, then the completeness of the lines is reassessed. Once SR is restored with either RF or cardioversion, attempts to reinduce AF by rapid atrial pacing without and with infusion of isoproterenol are only made for investigational purposes in selected patients. Patients with a history of common atrial flutter also undergo ablation of the cavotricuspid isthmus line. We do not isolate the superior vena cava for AF treatment but have had to do so for some cases of atrial tachycardia.

Assessment of PV Innervation

Potential vagal target sites are identified during the procedure in at least one third of patients.³ Vagal reflexes are considered sinus bradycardia (<40 beats/min) or asystole, AV block, or hypotension occurring within a few seconds of the onset of RF application. If a reflex is elicited, RF energy is delivered until such reflexes are abolished, or for up to

30 seconds. The endpoint for ablation at these sites is termination of the reflex, followed by sinus tachycardia or AF. Failure to reproduce the reflexes with repeat RF is considered confirmation of denervation. Complete local vagal denervation is defined by the abolition of all vagal reflexes. The most common sites are tagged on electroanatomic maps (Fig. 3).

Remap Process and Lesion Validation

In patients in SR, postablation remap is performed utilizing the preablation map for acquisition of new points to allow accurate comparison of pre-RF and post-RF bipolar voltage (Fig. 3). We found a small inpatient difference between the anatomic map of a fibrillating noncontracting atrium and the map during pacing, in which locations are recorded at end diastole. This finding is validated by measuring the distance between corresponding locations acquired during AF and pacing. Lesion validation requires acquisition of two maps during CS and right atrial pacing for the lateral and septal PVs, respectively. The rationale behind this setting is to pace from a site close to the lesions and shorten conduction time to the ablation site, thereby allowing detection of delayed activation inside the circular line. At the end of procedure, protamine is injected to permit removal of sheaths. After 30 minutes, heparin infusion is restarted for 12 to 18 hours to maintain ACT between 200 and 250 seconds.

Postablation Care

After the ablation, patients are admitted to an inpatient telemetry bed for 24 hours. Heparin is administered

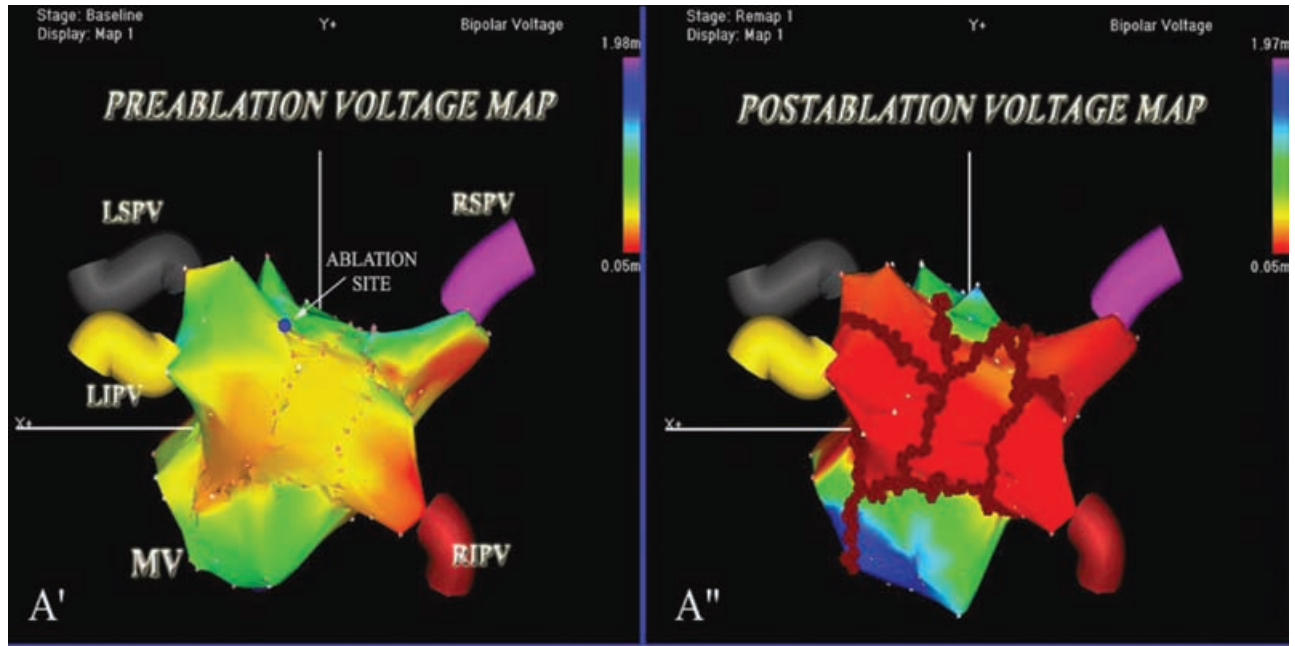


Figure 3. Preablation (A') and postablation (A'') three-dimensional left atrial voltage maps in a patient who had vagal reflexes that were evoked and then abolished by radiofrequency application around left superior PV (arrow). Red represents low voltage and purple high. LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; MV = mitral valve; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein.

intravenously for 24 hours, starting 3 hours after sheath removal at 1,000 U/hour without a bolus. Thereafter, oral anticoagulant therapy is transiently associated with subcutaneous Calciparin (12,500 units twice daily) for the first 3 days after discharge. Warfarin (Coumadin) is started immediately after the ablation.

Safety

Complications rates are given in Table 2. Postablation LA flutters usually do not require a redo procedure, as most of them resolve spontaneously within 5 months after the index procedure. Atrio-esophageal fistula rarely occurs but is dramatic and devastating.⁴ We now recommend lower RF energy applications when ablating on the LA posterior wall and making the line on the posterior wall near to the roof of the LA, where the LA is not in direct contact with the esophagus.

Efficacy

Success rates are approximately 90% for patients with paroxysmal AF and 80% for chronic AF. In patients with paroxysmal AF in whom vagal reflexes are elicited and abolished by RF applications, the long-term success rate is close to 100%. Early occurrences of AF occur within the first few

weeks after the index procedure, but they usually are a transient phenomenon that do not require a redo procedure as they resolve spontaneously during long-term follow-up.

Postprocedural Pharmacologic Management

All patients are anticoagulated with warfarin to maintain an INR of 2.0 to 3.0. Anticoagulation is discontinued if SR is maintained for >3 months without any episodes of AF.

Patients are supplied with a transtelephonic event recorder for at least 1 year after the procedure and are requested to send recordings weekly, irrespective of the presence or absence of symptoms. We arrange clinical assessment, TTE, and 24-hour ambulatory recordings 1, 3, 6, and 12 months after the procedure. Because some patients not uncommonly have early recurrence of AF following ablation, many patients are discharged on antiarrhythmic medication.

Patients with LA Diameter >55 mm and Chronic AF

In this patient group, we prescribe oral amiodarone at a total dose of 200 mg five days a week for 30 days and then 100 mg five days a week for the following 30 days. If TTE performed at 2 months shows a decrease in LA diameter (LAD) >3.5 mm associated with improved atrial transport function and persistent SR documented by daily transtelephonic recordings, amiodarone is replaced by oral sotalol (120 mg daily for 30 days). Usually, sotalol is discontinued after 30 days if SR persists. Angiotensin receptor (ATR) blockers usually are withdrawn 90 days after procedure but are maintained in patients who were undergoing ATR blocker therapy prior to the procedure.

Patients with LAD Between 55 and 40 mm and Paroxysmal AF

In this patient category, we prescribe sotalol 40 mg twice daily and flecainide 50 mg twice daily for 30 days. If the

Complication	Rate
Death	0%
Pericardial effusion	0.1%
Stroke	0.03%
Transient ischemic attack	0.2%
Tamponade	0.1%
Atrio-esophageal fistula	0.03%
Pulmonary vein stenosis	0%
Incisional left atrial tachycardia	6%

LAD decreases after this period, the patient continues taking sotalol for another 30 days.

Patients with LAD <40 mm and Paroxysmal AF

Among patients with paroxysmal AF and small atria, we prescribe sotalol 40 mg daily for 30 days.

Repeat Ablation Procedure

If recurrence of persistent AF or monthly episodes of symptomatic paroxysmal AF occur beyond the first month after ablation or incessant highly symptomatic left or right atrial flutter is present, then a redo procedure is scheduled for 6 months after the index procedure if the patient wishes. During the repeat ablation procedure, an isthmus line for typical atrial flutter, LA mapping, and ablation for LA flutter or a touchup of the prior ablation lines is performed. A maximum of three separate ablation procedures per patient is allowed.

Conclusion

Since we first began using this technique 6 years ago, the procedure duration time has decreased substantially and is now <90 minutes from the time of femoral sheath insertion. Circumferential LA PV ablation can be performed safely in

the majority of patients with AF, with high long-term success rates. With practice, procedure time can be short so that the procedure is well tolerated by the patient and exposes the patient to less risk. Hopefully these guidelines help centers embarking on an AF ablation program and provide useful information to more experienced centers.

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EDITORS' NOTE

This is the first of a series of three articles on techniques of ablation of atrial fibrillation. We invited three of the leading laboratories to explain their different approaches to this problem. The next two articles to appear will be from the laboratories of Drs. Andrea Natale and Michel Haissaguerre.