Feasibility and Safety of Pulmonary Vein Isolation Using a New Mapping and Navigation System in Patients With Refractory Atrial Fibrillation

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Background—Ostial pulmonary vein (PV) isolation by radiofrequency (RF) catheter ablation can cure patients with atrial fibrillation (AF); however, this procedure carries the risk of PV stenosis. The aim of this study was to assess the feasibility of a new mapping and navigation technique using a multipolar basket catheter (BC) for PV isolation in patients with refractory AF and to analyze its safety with regard to PV stenosis at long-term follow-up.

Methods and Results—We studied 55 patients (mean age, 53±11 years; 40 male) with drug-refractory AF (paroxysmal, n=37; persistent, n=18). A 64-pole BC was placed transseptally into each of the accessible PVs. By use of a nonfluoroscopic navigation system, the ablation catheter was guided to the BC electrodes at the PV ostium, with earliest activation during sinus rhythm. RF was delivered by use of maximum settings of temperature at 50°C and power at 30 W. The end point of the procedure was the complete elimination of all distal and fragmented ostial PV potentials. Of 165 targeted veins, 163 were successfully isolated with a mean RF duration of 720±301 seconds per vein. At 1-year follow-up, 62% of the patients were in sinus rhythm without antiarrhythmic drugs. Contrast-enhanced magnetic resonance angiography revealed 2 PV stenoses of >25% out of 165 treated vessels.

Conclusions—The use of a multipolar BC allowed effective and safe PV isolation by combining 3D mapping and navigation. At 1-year follow-up, 62% of the patients were in sinus rhythm without antiarrhythmic drugs, and the incidence of relevant diameter reduction of the treated PVs was 1.2%. (Circulation. 2003;108:2484-2490.)

Key Words: fibrillation ■ ablation ■ lung ■ veins ■ imaging

Atrial fibrillation (AF) is the most common arrhythmia encountered in clinical practice.1,2 Medical therapy with antiarrhythmic drugs is difficult and characterized by recurrences, drug-related side effects, and the potential for drug-induced proarrhythmia. Recently, spontaneously discharging pulmonary vein (PV) focal activity has been demonstrated to trigger AF.3,4 The pathoatomic substrate for these arrhythmogenic PV triggers are muscle fibers extending from the left atrium into the PVs in a complex architecture.5,6 Even though the conduction pattern of these arrhythmogenic PV foci are poorly understood, electrical disconnection of the PV from the left atrium by radiofrequency catheter (RF) ablation has been successfully performed with elimination of paroxysmal AF in 70% of the patients.7 A circular mapping catheter pioneered by Haissaguerre and others8,9 facilitates the identification of the conduction pathways from the left atrium into the PVs, permitting focal ablations to achieve PV isolation. However, RF ablation inside the PV carries a high risk of PV stenosis of up to 40%.10–13 Systematic follow-up examination of the PVs by magnetic resonance angiography (MRA) after ostial isolation guided by a circular mapping catheter has shown an incidence of relevant diameter reduction of 18% of the treated PVs, with risk of progression in 8%.14

The purpose of the present study was to evaluate a new mapping and navigation technique using a multipolar basket catheter (BC) to perform a guided ablation at the entrance(s) of the impulse propagation from the left atrium into the PV during sinus rhythm or coronary sinus pacing. The main outcome measures were the success rate (no AF without antiarrhythmic drugs) and the number of PV stenoses determined by MRA 1 year after the ablation procedure.

Methods

Patient Characteristics
Patients with highly symptomatic drug-refractory (class I and III antiarrhythmic drugs) paroxysmal (more than 2 episodes per week) or persistent (>2 recurrences of AF after cardioversion and lasting >4 weeks) AF were referred for electrophysiological (EP) evaluation and catheter ablation. Written informed consent was obtained from all patients.
Electrophysiological Study

All antiarrhythmic drugs except amiodarone were discontinued for >6 half-lives. Anticoagulation with warfarin (INR >2.5 for >4 weeks) was stopped 2 days previously (INR 1.8 to 2.0 at the beginning of the procedure). MRA and transesophageal echo were performed before the procedure. Standard multipolar catheters were positioned in the right atrium and coronary sinus. If a patient did not have a patent foramen ovale, 2 guidewires were introduced in the LA by transeptal puncture with the introducer from the 8F sheath (Preface, Biosense Webster). A stiff guidewire (Amplatz super stiff, 35 inches, Boston Scientific) was used to facilitate the transseptal crossing of the 8F soft-tip sheath with a 90° curve (Boston Scientific), which is necessary to use the BC (Constellation, Boston Scientific).

The sheaths were perfused during the procedure with heparinized NaCl 0.9%. After the transeptal puncture, 100 IU heparin/kg and 500 mg acetylsalicylic acid were given intravenously. During the procedure, heparinization was continued to maintain partial thromboplastin time between 70 and 90 seconds.

Five surface ECG leads (I, II, III, V1, and V6) and multiple intracardiac bipolar electrograms filtered at 30 to 500 Hz were recorded by use of a computerized electrophysiological recording system (Bard Labsystem). It is useful to connect the BC to the recording system by direct cables (Scart connector) to eliminate artifacts. If the patient presented with AF, sinus rhythm was restored by external electrical cardioversion at the time of study. If necessary, antiarrhythmic drugs (lecaride 0.1 to 0.3 mg) or by pacing maneuvers (incremental pacing or isoproterenol 0.1 to 0.3 mg) were given intravenously to stabilize sinus rhythm.

BC Mapping

The BC is composed of 64 electrodes mounted on 8 flexible, self-expanding nitinol splines (Figure 1, left). Each spline is identified by a letter (from A to H) and each electrode by a number (distal 1 to proximal 8). The 32 bipolar electrograms provide a 3D mapping of PV activation. After transeptal access was gained, the BC was inserted directly into the upper PVs. For introduction into the inferior PVs, the sheath was inserted first with the help of the steerable catheter while simultaneously withdrawing the sheath. A BC with a diameter of 38 mm was used when the PV diameter was >26 mm or when there was a common ostium. The PV diameter was determined by MRA.

The position of the BC in relation to the PV ostium was determined by angiography (Figure 1, right). If necessary, the BC was retracted to obtain optimal contact to the main trunk and ostium of the PV. The activation of the PV can be followed during sinus rhythm or coronary sinus pacing passing the 4 levels of bipolar electrograms from proximal ostial (7/8) to distal inside the PV (1/2) (Figure 2). During ectopic beats or initiation of AF, the activation can be followed from the source of ectopy to its exit to the left atrium.

Navigation System

The Astronomer system (Boston Scientific) was used for navigation inside the BC. This system consists of a switching/location device and an off-the-shelf laptop computer. The device and the laptop communicate on a standard RS-232 interface. The device delivers AC current (32 kHz, 320 μA) between the ablation catheter-tip electrode and a reference (skin patch) electrode, and the resulting electrical potentials are sensed at each BC electrode. On the basis of the sensed voltages at each of the BC electrodes, the Astronomer device determines whether the roving electrode is in close proximity to a BC electrode and lights the corresponding electrodes of the BC displayed on the laptop (Figure 3).

RF Ablation

The first step of ablation was ostial PV isolation, the second step mapping and ablation of premature atrial contractions (PACs) from outside the PVs.

PV Isolation

All PVs with activation during sinus rhythm were a target for ablation. Guided by the BC and the Astronomer system, the ablation was performed at the junction between the PV and the left atrium, as ostial as catheter stability allowed at the shortest atrial-PV potential delay (Figure 4). The location of the ostium was determined both by electrogram morphology and by noting the shape of the BC as it conformed to the PV and ostial anatomy confirmed by angiography. If, for example, the ostium was localized by angiography at the level of the 5/6 electrodes of the BC, this level was not crossed during ablation, as verified by fluoroscopy, by the navigation system, or by artifacts from the corresponding electrodes of the BC during RF delivery. Successful disconnection of the PV was verified by the disappearance of all PV potentials distal to the ablation site (Figure 4) or the dissociation of the PV potentials to sinus rhythm. PV isolation was completed by elimination of all persisting fragmented ostial potentials.

Mapping and Ablation of PACs After PV isolation

If after PV isolation, PACs were present or provokable by orciprenaline (0.1 to 0.3 mg) or by pacing maneuvers (incremental pacing or programmed stimulation), the origin of the PACs was localized by activation mapping and ablation was performed at this site.

Ablation Technology

PV isolation was first performed with a conventional 4-mm-tip ablation catheter at maximum temperature of 50°C and maximum power of 30 W (83 PVs) (RF Generator HAT 300, Osypka). After observation of carbonizations (dark material caused by overheating)
on the splines of the BC, an irrigated-tip catheter (Thermocool from Biosense Webster) at a maximum temperature of 45°C, maximum power of 30 W, and maximum flow rate during ablation of 16 mL per minutes was used (82 PVs). A maximum power of 40 to 50 W and temperature of 50°C was chosen for ablation of foci outside the PVs for both catheters.

Postablation Care
After the procedure, heparinization was continued to maintain partial thromboplastin time between 70 and 90 seconds. After exclusion of bleeding complications, such as pericardial effusion or femoral hematoma, warfarin was readministered (INR 2.5) and was continued for a minimum of 3 months. Heparin was stopped once an INR of 2.5 was achieved.

A 48-hour Holter monitoring was performed in all patients. Patients left the hospital 3 days after the procedure if no complication occurred.

Follow-Up
All patients were scheduled for a follow-up examination 12 months after the procedure to determine success and PV patency of the PVs by MRA.

Success of the procedure was defined as absence of clinical symptoms of AF and documentation of stable sinus rhythm on 24 hours of Holter monitoring. Event monitoring was performed if there were symptoms suggestive of AF.

MRA of the PVs was performed with a 1.5-T imager (Magnetom Sonata; Siemens. Gadodiaamid (Nycomed) was used as the contrast agent and injected intravenously at a flow rate of 3 mL/s. The acquisition of the images was ECG- and respiratory cycle–gated. On the acquired images, the arterial phase was subtracted. PV anatomy was assessed on the MRA raw image and after 3D reconstruction. A comparison of the PV diameter measured by MRA before and 12 months after ablation revealing a decrease in PV diameter by ≥25% was considered significant.

Statistical Analysis
Parametric data are presented as mean±SD. The unpaired t test was used to compare continuous variables. To analyze nonparametric data, we used the χ² test or Fisher’s exact test as appropriate. Statistical significance was defined as P≤0.05.

Results
Study Patients
We included 55 patients (mean age, 53±11 years; 40 male); paroxysmal AF was present in 37 patients, persistent AF in 18 patients. A history of AF was present for 6.4±3.4 years; past drug therapy was unsuccessful for a mean number of 3.6±2.1 antiarrhythmic drugs. Thirteen patients had evidence of structural heart disease (hypertensive heart disease in 8, coronary artery disease in 2, and left ventricular dysfunction in 3). Seven patients were taking amiodarone at the time of study.

Figure 2. Recording from a right upper PV (200 mm/s). Distal electrodes of BC (A1/2, B1/2 . . . H1/2) are placed on top of figure under surface lead ECGs (I, aVR, aVF), and proximal electrodes (A7/8, B7/8 . . . H7/8) of BC on bottom. PV discharge is not conducted after first 2 beats (↓); third PV discharge (*) is conducted to left atrium with induction of AF. Note complex but identical activation pattern of PV during discharge. It was shown by overdrive pacing with disappearance of these potentials that they are “concealed” discharges of vein and not delayed conducted potentials.
Electrophysiological Study and Ablation

The mean procedure time was 235±76 minutes and total fluoroscopy time 40±17 minutes, including transseptal puncture, mapping, and ablation of foci outside the PVs (n=10) and tricuspid annulus/inferior vena cava isthmus ablation (n=17). The fluoroscopy time required for PV isolation was only 9.3±5.4 minutes. The BC could be introduced in all right and left upper and all left inferior PVs, but only in 3 right inferior PVs. The 31-mm BC was used in 50 patients and the 38-mm BC in 5 patients, 3 of them for a common ostium of the left PVs. The 31-mm BC had good contact (stable electrograms in all 32 bipoles of the BC) and stability (no dislocation during PV isolation) in PVs with a diameter between 12 and 26 mm, and the 38-mm BC in PVs up to 32 mm. In vessels smaller than 12 mm, overlapping or bunching of the splines inducing artifacts on the electrograms were observed. No interference between the ablation catheter and the BC was observed during mapping at the ostium.

A total of 163 of 165 mapped PVs with activation in sinus rhythm could be isolated successfully. The mean ablation time required to achieve complete isolation was 720±301 seconds per PV. On average, 2.5±1.2 distinct left atrium-to-PV connections were ablated per PV to achieve complete conduction block. The Table compares the ablation data with and without cooled-tip ablation technology. The main difference between cooled- and noncooled-tip technology is the appearance of carbonization on the splines of the BC, which was observed in 12 of 29 patients treated without cooled-tip technology and in 1 per 26 patients with cooled-tip technology.

In 9 patients, PV isolation was performed successfully during AF. After successful PV isolation, 3 ostial foci (Figure 5), 2 left atrial foci, 2 right atrial foci, and 3 foci in the superior vena cava were identified and ablated. In 18 patients, antiarrhythmic drugs were given intravenously to stabilize sinus rhythm during PV isolation (amiodarone, n=10; flecainide, n=8), which may have suppressed other arrhythmogenic foci.

In 17 patients, a tricuspid annulus/inferior vena cava isthmus ablation was performed for previously documented typical atrial flutter.

In 15 patients, a second ablation procedure was necessary for symptomatic recurrence of AF (1.27 procedures per patient). The reasons for recurrence of AF were recovery of conduction of a previously ablated PV (n=12), ostial foci (n=6), and left atrial foci (n=4). The only acute complication associated with all procedures was pericardial tamponade in 1

Figure 3. Exact localization of ablation catheter inside BC is given by Astronomer navigation system. Top, Fluoroscopic anteroposterior view of a right upper PV with BC and ablation catheter inside. Bottom, Localization of tip of ablation catheter by Astronomer navigation system at basket electrode D5.

Figure 3.
patient. The tamponade was caused by perforation of the left atrial appendage by the ablation catheter. The tamponade could be drained percutaneously. No PV stenosis was detected by angiography at the end of the procedure.

One-Year Follow-Up

Procedural Success

Of the 55 patients, 34 (62%) were free of AF (no symptoms of AF and no AF on 24 hours of Holter monitoring) without need for antiarrhythmic drug treatment. An additional 14 patients (25%) were in sinus rhythm with the aid of antiarrhythmic drug treatment, which was ineffective before the ablation. The success rate was higher in patients with paroxysmal AF; 26 of 37 (70%) were free of AF without antiarrhythmic drugs, whereas for persistent AF patients, the drug-free success rate was only 8 of 18 (44%) ($P=0.06$).

PV Stenosis

MRA was performed before and 12 months after the procedure in 50 of the 55 patients. Two patients refused the MRA, and 3 had a pacemaker. One mild diameter reduction of a right upper PV ($\approx 30\%$) and 1 severe ostial PV stenosis ($\approx 80\%$) of a left upper PV were detected by MRA. Both patients did not report any symptoms. There was no significant difference of the mean diameter of PVs before (16.1±2.8 mm) and 1 year after (15.5±3.1 mm, $P=0.5$) ablation.

**Table 1.** Data From Basket Catheter Guided PV Isolation With Conventional Noncooled Tip Ablation Catheters (30 W, 50°C) Versus Cooled Tip Ablation Catheter (Thermocool From Biosense Webster, 30 W, 45°C)

<table>
<thead>
<tr>
<th></th>
<th>Noncooled</th>
<th>Cooled</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pvs successfully isolated, n</td>
<td>81/83</td>
<td>82/82</td>
<td>...</td>
</tr>
<tr>
<td>RF/PV, s</td>
<td>691±299</td>
<td>748±308</td>
<td>0.7</td>
</tr>
<tr>
<td>W/PV</td>
<td>16 085±8186</td>
<td>20 762±8892</td>
<td>0.12</td>
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<tr>
<td>Electrophysiological study time, min</td>
<td>248±85</td>
<td>224±70</td>
<td>0.44</td>
</tr>
<tr>
<td>Fluoroscopy time, min</td>
<td>42±19</td>
<td>38±16</td>
<td>0.66</td>
</tr>
<tr>
<td>Carbonization, n</td>
<td>12</td>
<td>1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>PV stenosis</td>
<td>1</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>No electrophysiological study/patient</td>
<td>1.29</td>
<td>1.25</td>
<td>0.7</td>
</tr>
<tr>
<td>Success (sinus rhythm without antiarrhythmics)</td>
<td>65%</td>
<td>58%</td>
<td>0.7</td>
</tr>
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</table>
Discussion

With a multipolar BC, ostial PV isolation with disconnection of conduction pathways between the left atrium and the PVs can be performed successfully and safely. The multipolar BC allows 3D reconstruction of the PV activation from the ostium to deep inside the PV. The Astronomer navigation system permits precise and reproducible guidance of the ablation catheter-tip electrode to areas identified as left atrium–to-PV conduction pathways, thereby allowing efficient PV isolation. Without the use of this navigation system, it is difficult to identify the alphabetical order of the splines by fluoroscopic guidance. The distal poles of the BC can be used to monitor changes in the activation sequence in real time and thereby indicate the effects of ablation at the ostium as lesions are created. They also provide an immediate indication of a successful PV isolation by the disappearance of the distal PV potentials.

Initially, we were concerned about the carbonizations that were sometimes observed after ablation on the splines of the BC because they may potentially cause embolism. Carbonizations, which appear as dark material attached to the BC electrodes or splines, are thought to be caused by the concentration of RF energy on the thin splines, which results in very high local temperatures that induce denaturation of proteins. However, carbonization was greatly diminished (only 1 of 26 patients versus 12 of 29 with conventional ablation catheters) with the use of an irrigated-tip catheter.

In comparison to a circular mapping catheter, which is placed 10 to 15 mm inside the PV, the BC provides the following potential advantages: (1) the nonfluoroscopic navigation system (Astronomer); (2) identification of areas near the PV ostium with fragmented potentials and of discharging ostial foci, which can be localized in a single beat (Figure 5); and (3) information about the anatomy of the PV, such as exact ostium localization, because the BC takes the exact shape of the PV.

The described advantages of the BC versus circular mapping catheter-guided PV isolation do not yet result in a better success rate. This may be because a BC mapping and BC-guided ablation of the right inferior PV was possible in only 3 patients. Introduction of a steerable sheath will facilitate introduction of the BC into the right inferior PV and may improve the success rate. Our success rate was lower in patients with persistent AF than in patients with paroxysmal AF (P=0.06). This finding confirms the data published by Oral et al with circular mapping catheters. Linear lesions may be necessary in patients with persistent AF to achieve better success rates.

The risk of PV stenosis at long-term follow-up, which is high when using conventional mapping and ablation techniques, ≈40% after distal PV ablation and 18% of the treated vessels 3 months after ostial PV isolation guided by a circular mapping catheter, seems to be low (1.2%) with use of the BC-guided PV isolation. This technology may mini-

Figure 5. After isolation of a left upper PV, a discharge from an ostial focus at electrodes A 7/8 (arrow) was recorded. Ablation can now be performed at these electrodes guided by navigation system. Recording speed was 200 mm/s.
mize the risk of PV stenosis, first, by reducing the number of RF ablations, and second, by avoiding ablations inside the PV, because the BC allows an exact localization of the PV ostium during the entire procedure. Thus, the use of complementary navigation systems or intracardiac echo appears to be nonessential when using the BC for PV isolation.

Conclusions

In conclusion, the BC-guided PV isolation is an effective and safe procedure to cure patients of AF by integrating PV anatomy and electrophysiology in combination with a navigation system for the ablation catheter. Further randomized studies are necessary to compare BC and circular mapping catheter for PV isolation.

Limitations

AF after the procedure was screened by clinical symptoms and routine Holter monitoring at 12 months. Event monitoring was performed if there were symptoms suggestive of AF. However, there may be silent episodes of AF detectable only by systematic daily event monitoring.

References

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Circulation. 2003;108:2484-2490; originally published online October 27, 2003; doi: 10.1161/01.CIR.0000097118.75179.83

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