Circumferential Mapping and Electric Isolation of Pulmonary Veins in Patients With Atrial Fibrillation

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Information about the clinical efficacy and complications of the circumferential mapping and isolation of the pulmonary veins (PVs) in patients with atrial fibrillation (AF) is still limited. The present study included 75 patients (mean age 58 ± 11 years, 20 women) with paroxysmal (n = 69) or persistent AF (n = 6). Mapping of PVs was performed with a circumferential mapping catheter. After preferential PV–left atrium (LA) electric inputs were defined, radiofrequency ablation was performed until complete isolation of the PVs from the LA was achieved. A total of 226 PVs were mapped; 195 (86%) showed typical PV potentials. Complete isolation of PVs from the LA was achieved in 173 PVs (89%). Detailed follow-up, including 7-day Holter monitoring at 1, 4, 9, and 12 months after intervention was performed. If AF recurred, PVs were mapped and reisolated. After a mean follow-up period of 230 ± 133 days, 38 of 75 patients (51%) were in sinus rhythm. At 1, 4, and 9 months of follow-up, 31 of 65 patients (48%), 36 of 53 patients (68%, p = 0.04 as compared with the first month), and 21 of 28 patients (75%, p = 0.025 as compared with the first month), respectively, were in sinus rhythm. During follow-up, 30 patients (40%) underwent a second ablation procedure due to recurrence. Recurrences were related to resumption of PV muscle–left atrial conduction (27 patients) and/or extra PV foci (12 patients) or nonablated PVs (8 patients). Complications occurred in 17 patients (22%). PV stenosis was detected in 13 patients (25% to 50% in 7 patients and >50% in 6 patients). Pericardial effusion occurred in 4 patients. It was concluded that isolation of the PV from the LA is moderately effective in the prevention of AF recurrence and could be associated with serious acute and long-term complications. ©2003 by Excerpta Medica, Inc. (Am J Cardiol 2003;91:159–163)

The pioneering work of Haissaguerre et al1 regarding the treatment of atrial fibrillation (AF) by radiofrequency ablation of the initiating triggers within the pulmonary veins (PVs) led to a paradigm shift in the management of this complex arrhythmia. It has been shown that left atrial muscle extensions or “muscular sleeves” surrounding the PVs generate spontaneous atrial premature beats that could trigger the onset of AF.2–4 Moreover, PV muscle sleeves have been identified as the most frequent site of cardiac foci that trigger AF.5–6 Initial ablation technique directly targeting the triggering foci within the PV have appeared to be ineffective because of the high rate of arrhythmia recurrences and local complications, such as PV stenosis.7 Circumferential PV mapping has shown that there are preferential PV–left atrium (LA) connections and that effective electric isolation of PVs from the LA can be achieved by applying segmental ablative lesions directed at these connection sites.8–10 In the present study, we report our clinical experience with the use of circumferential mapping catheters to guide PV isolation in patients with AF.

METHODS

Patient characteristics: This study included 75 consecutive patients (mean age 58 ± 11 years, 20 women) with symptomatic paroxysmal (n = 69) or persistent (n = 6) AF referred to our clinic for radiofrequency ablation between January 2001 and May 2002. Mean duration of symptomatic AF before the ablation procedure was 58 ± 68 months. Antiarrhythmic drug therapy with ≥2 antiarrhythmic drugs (class I to IV) had been tried unsuccessfully. Amiodarone was used in 7 patients. AF was associated with structural heart disease in 41 patients (56%), arterial hypertension with left ventricular hypertrophy and/or dilatation in 34 patients, coronary artery disease in 10 patients, and inflammatory heart diseases in 3 patients. Mean left atrial diameter was 39 ± 7 mm. Oral anticoagulants were discontinued 2 days before the procedure. All antiarrhythmic drugs were discontinued ≥5 plasma half-lives before the procedure. Before the ablation procedure, transthoracic and transesophageal echocardiography were performed to exclude intracardiac thrombi and to screen for an open foramen ovale. All patients gave written informed consent for the procedure.

Electrophysiologic study: In 75 consecutive patients, a 3-catheter approach (1 catheter in the coronary si-
nus, 1 circumferential mapping catheter, and 1 mapping and ablation catheter in the LA) was used. The coronary sinus was mapped with a nonsteerable 16-polar catheter (50 patients) or a steerable 8-polar catheter (25 patients).

Transseptal access to the LA was obtained by a patent foramen ovale (n = 21) or by transseptal puncture (n = 54). After access to the LA, a circular steerable 10-polar mapping catheter (Lasso, Biosense Webster, Inc., Diamond Bar, California) and an ablation catheter (RFMarinr, Medtronic, Minneapolis, Minnesota) were inserted (Figure 1). Preablation angiograms of all accessible PVs were performed. Circumferential mapping of the PV was performed by obtaining 10 bipolar electrograms (1 to 2, 2 to 3, up to 10 to 1 electrode pairs) with the circular arranged electrodes of the Lasso catheter. The selection of a 15-, 20- or 25-mm diameter Lasso catheter was guided by the angiographically estimated size of the PVs. During the procedure, a continuous heparin infusion was administered, aimed at an activated clotting time of 300 seconds in the first series of patients (n = 26) and 200 seconds in the remaining 49 patients. If necessary, internal cardioversion was performed using a single-lead system (Alert, EPMedSystems, West Berlin, New Jersey) as previously described.11

Mapping and ablation of the PV: The circular mapping catheter was positioned in the left superior, left inferior, and right superior PVs consecutively. If accessible, the right inferior PV was also mapped. Initially, the Lasso catheter was inserted in the PVs and withdrawn gradually to achieve a position as close to the PV ostium as possible. Thereafter, the PVs were mapped circumferentially to document the presence of typical sharp local PV potentials during sinus rhythm (for the right PVs) or during steady-state coronary sinus stimulation with a cycle length of 500 to 600 ms (for the left PVs). The presence of the PV potentials along the PV circumference and the position of the electrode pairs showing the earliest PV potential were defined (Figure 2). The ablation catheter was directed to the earliest electric input location corresponding to the Lasso catheter bipole showing the earliest PV potential; ablation was then performed even without further evidence of the presence of arrhythmogenic foci located inside the targeted PV.

Ablation procedure: Ablation was performed with a standard 4-mm tip catheter with the maximum temperature set at 45°C to 50°C and the power set at 30 to 35 W. Disappearance or constant dissociation of the distal PV potentials during sinus or paced rhythms was considered as a criterion for an effective electric isolation of the PV (Figures 2 and 3). After ablation, provocative maneuvers (atrial burst pacing, oriprenaline infusion) were performed to assess the acute ablation results. Angiograms of all targeted PVs were performed after the ablation procedure.

Management after the ablation procedure: In the 3 days after the ablation procedure, all patients were screened continuously with 24-hour in-hospital monitoring. Seven-day Holter monitoring was performed at 1, 4, 9, and 12 months after ablation. Additionally, patients were questioned intensively for arrhythmia recurrence and/or symptoms since the last follow-up.

FIGURE 1. Fluoroscopic view of the mapping ablation design and the electrograms recorded within the left superior PV during sinus rhythm and coronary sinus pacing. (A) Fluoroscopic view of the circumferential mapping catheter (Lasso) and the ablation catheter in the left atrium (MAP) and the coronary sinus catheter (CS). The circumferential mapping catheter is positioned at the ostium of the left superior PV. (B) Circumferential mapping catheter recordings from the left superior PV during sinus rhythm (SR). The 2 surface electrocardiographic leads, 2 local electrograms recorded from the ablation catheter, 8 circumferential mapping catheter, and 3 coronary sinus electrograms are shown. (C) Left superior PV electrograms recorded during coronary sinus pacing. Typical PV potentials widely separated from the left atrial signals are seen (arrow). Electrographic type and arrangement as in (B).
visit. AF recurrence was defined if AF episodes of >30 seconds were recorded or patients reported symptoms suggestive of intermittent AF episodes. After the ablation procedure, 64 patients were discharged on β-blocker therapy, 6 patients on β blockers plus amiodarone, 1 patient on amiodarone alone, and 1 patient on β blockers plus flecainide. No therapy was prescribed for 3 patients. Oral anticoagulants were prescribed for 6 months and discontinued if no recurrences occurred during this time.

In the patients who developed AF relapses, ablation was performed if they were willing to undergo a repeated procedure. During reablation procedures, all previously isolated PVs were mapped to seek the resumption of conduction. Arrhythmogenic foci in nontargeted PVs or in extravenous locations were searched for and ablated.

**Statistical analysis:** Data are presented as mean ± SD, counts, or percentages. Continuous data were compared using 2-tailed Student’s t test. Discrete variables were compared with Fisher’s exact test. A p value >0.05 was considered significant.

**RESULTS**

**Procedural data:** Mapping of the right superior, left superior, and left inferior PV was performed in 73 patients. The right inferior PV was mapped in 7 patients. In 2 patients, PVs could not be mapped due to development of cardiac tamponade at an early stage of the procedure. Mean procedure time was 353 ± 143 minutes. Mean fluoroscopic time was 82 ± 20 minutes. Overall, 109 procedures (mean 1.45), including repeated ablations, were performed.

**Mapping results:** During the first ablation procedure, 226 PVs were mapped and 195 of them (86%) showed typical PV potentials (Table 1). In 13 patients with atrial flutter, ablation of the right atrial isthmus was performed besides PV ablation.

**Ablation results:** During the first ablation procedure, the effective PV isolation from the LA was achieved in 173 of 195 PVs (89%). After complete PV isola-

**TABLE 1** Summarized Data of the Mapping and Ablation of the Pulmonary Veins (PVs) During the First Ablation Procedure

<table>
<thead>
<tr>
<th>PVs</th>
<th>Local PV Potentials</th>
<th>Electric Isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left superior PV (n = 73)</td>
<td>68</td>
<td>63</td>
</tr>
<tr>
<td>Left inferior PV (n = 73)</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Right superior PV (n = 73)</td>
<td>62</td>
<td>56</td>
</tr>
<tr>
<td>Right inferior PV (n = 7)</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Total (n = 226)</td>
<td>195</td>
<td>173</td>
</tr>
</tbody>
</table>
tion, no local PV potentials were observed during sinus rhythm and coronary sinus pacing (Figures 2 and 3). In 22 PVs, a decrease in signal amplitude and a shift in LA–PV conduction was observed, but no complete disappearance of PV local potentials could be achieved.

**AF recurrence and repeated ablation procedures:** Within the first week after the ablation procedure, 34 patients developed an early AF recurrence, 23 of whom underwent a second ablation procedure. Of the 11 patients who were not willing to undergo another ablation procedure, 8 patients continued β-blocker therapy, 2 patients were put on amiodarone, and 1 patient underwent external defibrillation. Eighteen patients developed late AF recurrences (from 1 week to 12 months after the ablation procedure) and 7 of them were reablated. Eleven patients were not willing to undergo reablation. Ten of these patients continued β-blocker therapy and 1 patient was defibrillated. Four patients had a third ablation procedure because of AF recurrences 8 to 12 months after the second procedure. In 22 of the reablated patients, a Lasso catheter-based mapping was performed, whereas in 8 patients, in addition to PV circumferential mapping with a Lasso catheter, another mapping system was used (noncontact mapping in 3 patients, basket catheter in 2 patients, and electroanatomic mapping in 3 patients).

During reablation procedures, all previously successfully isolated PVs were checked for recovery and/or remnants of PV potentials. In 27 of 30 patients (90%) who underwent a repeat ablation procedure, resumption of conduction through previously isolated PV–LA connections was observed. The resumption of PV–LA conduction occurred in 20 left superior PVs, 10 right superior PVs, and 13 left inferior PVs. Seven patients showed resumption of conduction in >1 previously ablated PV. The radiofrequency current application time needed to reisolate PVs that showed resumption of conduction after the first procedure was shorter than the time needed to isolate the intact PVs during first ablation procedures (684 ± 288 vs 966 ± 412 seconds, p < 0.01). In 12 patients who underwent a repeat procedure, extravenous foci triggering the onset of AF were mapped and ablated. Extravenous foci triggering AF were located in the LA in 8 patients and in the right atrium in 4 patients. In 8 patients, PVs that were not ablated during the first procedure (4 right inferior, 3 right superior, 1 left superior, and 1 left inferior) showed typical PV potentials and were ablated during the second ablation procedure.

**Complications:** Acute complications were observed in 17 patients (22%). An immediate angiography after ablation revealed PV stenosis in 13 patients (25% to 50% in 7 patients and >50% in 6 patients). PVs affected by stenosis were left inferior in 4 patients, right superior in 4 patients, and left superior in 5 patients. In 3 patients (1 with a 75% stenosis), ablation lesions were placed within 2 to 5 mm from the PV ostium. In the remaining patients, ablation lesions were placed >5 mm from the ostial area. In 4 patients, pericardial effusion resulting in cardiac tamponade occurred and was treated with pericardiocentesis.

**Follow-up results:** After a mean follow-up of 230 ± 133 days, 38 of 75 patients (51%) were in sinus rhythm. Follow-up intervals of 1, 4, and 9 months were completed by 65, 53, and 28 patients, respectively. At 1, 4, and 9 months of follow-up, 31 of 65 patients (48%, 23 patients were reablated), 36 of 53 patients (68%, 20 patients were reablated), and 21 of 28 patients (75%, 14 patients were reablated) remained in sinus rhythm. The percentage of patients in sinus rhythm at 4 and 9 months was significantly higher than the percentage of the patients who were in sinus rhythm 1 month after the first ablation procedure.
(p = 0.04 and 0.025, respectively). No deaths or minor or major cardiovascular cerebral events occurred during the procedures or during the follow-up period. One patient developed severe coughing attacks and hemothysis 6 months after ablation. Computed tomography revealed high-grade stenosis of both superior PVs. The patient underwent a repeat PV angiography that showed severe stenoses of the right and left superior PVs (Figure 4).

DISCUSSION

The present study shows that circumferential segmental ablation was moderately effective in maintaining sinus rhythm in patients with predominantly paroxysmal AF. Thus, at 1 month of follow-up, only 31 of 65 patients remained in sinus rhythm, with 23 patients having undergone a repeated ablation procedure. The results improved after the extension of the follow-up period to 4 or 9 months. The reasons for the late improvement are unclear. Disappearance of acute trauma and the maturity of the ablation lesions may explain, at least in part, the late ablation success. Our data also showed that most of the AF recurrences after a prior successful PV isolation were related to the resumption of PV muscle—LA conduction. Less frequently, AF recurrences were related to extra-PV foci. Our data are less favorable than those recently reported by Haïssaguerre et al9 and Oral et al.10 One explanation for the discrepancies may be the presence of structural heart disease in 56% of our patients. The previously cited studies included patients mainly with lone AF.9,10 Another factor that may have influenced the outcome in our study could be the low percentage of right inferior PV ablation. Although the reablation data did not substantiate any significant role of the right inferior PV in AF recurrences in our patients, the arrhythmogenic potential remains unclear. Finally, stringent criteria used in this study during the follow-up period to detect AF recurrences, including repeated 7-day Holter monitoring, may explain the higher rates of AF recurrences compared with other studies.

Two principal limitations of the “PV isolation approach” for ablation of AF may be of crucial importance. First, the true impact of extra-PV located atrial foci for the initiation and the maintenance of AF is still unclear. A recent study12 with biaxial mapping using simultaneous 3-dimensional mapping systems has shown that 47% of the foci that trigger AF could be located outside the PV. Second, with this mapping and ablation approach, the PV ostial regions could still remain connected with the LA and could generate ectopic beats or serve as a substrate for AF maintenance. In another approach guided by electroanatomic mapping, Pappone et al13 performed encircling of all 4 PVs by applying linear lesions outside the ostial regions. With this approach, besides the isolation of PVs, the modification of the arrhythmogenic substrate of the AF located in the posterior LA appears to be an important factor for ablation success.

Complications related to the mapping and ablation procedure: Our study showed that mapping and ablation of the PVs using circumferential mapping and ablation catheters may be associated with severe complications such as cardiac perforation and acute—or more importantly—late severe symptomatic PV stenosis. Pericardial effusions were observed in the first series of patients in whom an activated clotting time was maintained at >300 seconds. The decrease in the amount of heparin needed to maintain an activated clotting time to >200 seconds, and possibly the effect of the learning curve in using the circumferential mapping catheter, may explain why we did not observe hemorrhagic complications in the second series of patients. In this study we reported only the rate of acute PV stenosis as assessed by PV angiography after the ablation procedure. With the exception of 1 symptomatic patient 6 months after ablation, no information about the rate of the late PV stenosis could be provided.