Catheter Ablation for Paroxysmal Atrial Fibrillation
Segmental Pulmonary Vein Ostial Ablation Versus Left Atrial Ablation

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Background—Segmental ostial catheter ablation (SOCA) to isolate the pulmonary veins (PVs) and left atrial catheter ablation (LACA) to encircle the PVs both may eliminate paroxysmal atrial fibrillation (PAF). The relative efficacy of these 2 techniques has not been directly compared.

Methods and Results—Of 80 consecutive patients with symptomatic PAF (age, 52±10 years), 40 patients underwent PV isolation by SOCA and 40 patients underwent LACA to encircle the PVs. During SOCA, ostial PV potentials recorded with a ring catheter were targeted. LACA was performed by encircling the left- and right-sided PVs 1 to 2 cm from the ostia and was guided by an electroanatomic mapping system; ablation lines also were created in the mitral isthmus and posterior left atrium. The mean procedure and fluoroscopy times were 156±45 and 50±17 minutes for SOCA and 149±33 and 39±12 minutes for LACA, respectively. At 6 months, 67% of patients who underwent SOCA and 88% of patients who underwent LACA were free of symptomatic PAF when not taking antiarrhythmic drug therapy (P=0.02). Among the variables of age, sex, duration and frequency of PAF, ejection fraction, left atrial size, structural heart disease, and the ablation technique, only an increased left atrial size and the SOCA technique were independent predictors of recurrent PAF. The only complication was left atrial flutter in a patient who underwent LACA.

Conclusions—In patients undergoing catheter ablation for PAF, LACA to encircle the PVs is more effective than SOCA.

Key Words: fibrillation • catheter ablation • veins • lung • atrium

Because arrhythmogenic activity that originates in the muscle sleeves of the pulmonary veins (PVs) may trigger or perpetuate atrial fibrillation (AF), segmental ostial ablation to electrically isolate the PVs from the left atrium has been performed to eliminate paroxysmal AF (PAF). Another technique that has been used to eliminate PAF has been left atrial ablation to encircle the PVs. Because no previous studies have directly compared the 2 ablation techniques, it has been unclear whether either technique has an advantage over the other. Therefore, the purpose of this prospective, randomized study was to compare the efficacy and risk of segmental PV ostial ablation and left atrial ablation in patients with PAF.

Methods

Study Subjects
The subjects of this study were 80 consecutive patients with symptomatic PAF selected to undergo catheter ablation. Exclusion criteria consisted of congestive heart failure, an ejection fraction <35%, a left atrial diameter >55 mm, and a previous ablation procedure. The clinical characteristics of the patients are described in the Table.

Electrophysiological Study
The Institutional Review Board approved the study protocol, and all patients provided written informed consent. All catheters were introduced through a femoral vein. A quadripolar electrode catheter (EP Technologies, Inc) was positioned in the coronary sinus. After transseptal catheterization, systemic anticoagulation was achieved with intravenous heparin to maintain an activated clotting time of 250 to 350 seconds. Angiograms of the PVs were performed in all patients. Bipolar and unipolar electrograms were filtered at band-pass settings of 30 to 500 and 0.05 to 200 Hz, respectively, and were recorded digitally (EPMed Systems, Inc). Pacing was performed from the coronary sinus or left atrial appendage with a stimulator (EP-3 Clinical Stimulator, EPMed Systems, Inc).

Study Protocol
Eighty patients were randomized to undergo PV isolation by segmental ostial ablation (n=40) or by left atrial ablation (n=40). The clinical characteristics of the patients in the 2 groups did not differ significantly (Table).

Segmental Ostial Ablation
Electrograms were recorded at the ostia of the PVs with a decapolar ring catheter (Lasso, Biosense-Webster). PV isolation was performed by applying radiofrequency energy at ostial sites at which the earliest bipolar PV potentials and/or unipolar electrograms with the most rapid intrinsic deflection were recorded.
Clinical Characteristics of Patients Who Underwent Segmental Ostial Ablation and Left Atrial Ablation

<table>
<thead>
<tr>
<th></th>
<th>Segmental Ostial Ablation (n=40)</th>
<th>Left Atrial Ablation (n=40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>51±10</td>
<td>54±11</td>
<td>0.3</td>
</tr>
<tr>
<td>Sex, M/F, n</td>
<td>31/9</td>
<td>31/9</td>
<td>1.0</td>
</tr>
<tr>
<td>Duration of AF, y</td>
<td>7±6</td>
<td>7±6</td>
<td>0.6</td>
</tr>
<tr>
<td>No. of episodes of AF/mo</td>
<td>12±12</td>
<td>12±13</td>
<td>0.9</td>
</tr>
<tr>
<td>LVEF</td>
<td>0.55±0.04</td>
<td>0.57±0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>Left atrial diameter, mm</td>
<td>39±5</td>
<td>41±6</td>
<td>0.1</td>
</tr>
<tr>
<td>Structural heart disease, n</td>
<td>3</td>
<td>1</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Data are shown as mean±SD. LVEF indicates left ventricular ejection fraction.

Radiofrequency energy was delivered with a temperature-controlled, 4-mm-tip, deflectable catheter (EP Technologies, Inc). Radiofrequency energy (EP Technologies, Inc) was delivered at a target temperature of 52°C and maximum output of 35 W for 20 to 45 seconds at each ostial site. The end points of ostial ablation were the elimination of all ostial PV potentials and complete entrance block into the PV (Figure 1).3–6 All PVs were targeted for isolation.

Left Atrial Ablation

An 8-mm-tip, deflectable catheter (Navistar, Biosense-Webster) was introduced into the left atrium. A 3D shell representing the left atrium was constructed by use of an electroanatomic mapping system (CARTO, Biosense-Webster).

Left atrial ablation was performed 1 to 2 cm from the PV ostia to encircle the left- and right-sided PVs (Figure 2). However, because there was a narrow rim of atrial tissue between the anterior aspect of the left superior PV and the left atrial appendage in ~50% of patients, ablation was sometimes performed within 1 cm of the ostium of this vein.7 In addition to the lesions that encircled the left- and right-sided PVs, first described by Pappone et al.,4,5 the 2 circumferential ablation lines were connected with an ablation line along the posterior left atrium. In addition, to prevent left atrial flutter, ablation also was performed along the mitral isthmus, between the inferior portion of the left-sided encircling lesion and the lateral mitral valve annulus (Figure 2). The completeness of conduction block across the ablation lines was not routinely assessed.

Radiofrequency energy was delivered at a target temperature of 55°C and a maximum power of 60 W (Stockert 70 RF, Biosense-Webster). Ablation sites were tagged on the model of the left atrium created with the electroanatomic mapping system. At tagged sites, radiofrequency energy was applied for ≥20 seconds and until the maximum local electrogram amplitude decreased by ≥50% or to <0.1 mV (Figure 3).

After completion of the circular lesions around the left- and the right-sided PVs, the area within the ablation lines was explored with the ablation catheter, and radiofrequency energy was applied at sites that had a local electrogram amplitude >0.1 mV. Additional ablation within the encircling ablation lines near the ostia of the PVs was performed in 13 of the 40 patients (32%).

Study End Point

The primary end point of the study was freedom from recurrent PAF after a single ablation procedure. Freedom from recurrent PAF was defined as the absence of symptomatic PAF off antiarrhythmic drug therapy. Because early recurrences of PAF within the first 2 to 4 weeks after PV isolation may be a transient phenomenon, PAF that was limited to the first month of follow-up was excluded from the analysis.8

Postablation Care

After the ablation procedure, patients were hospitalized overnight. Heparin was infused until the next morning, at which point the patient was treated with low-molecular-weight heparin for 4 to 5 days and warfarin for 2 to 3 months. Patients in both ablation groups who had a recurrence of PAF within 4 weeks after the procedure were treated with a class I or III antiarrhythmic drug for 4 to 6 weeks.

Follow-Up

All patients were seen in an outpatient clinic 4 to 6 weeks and every 3 to 6 months after the ablation procedure. Patients were instructed to report symptoms suggestive of PAF and were provided with an event recorder to document the cause of their symptoms. During a mean follow-up period of 164±100 days, no patient was lost to follow-up.

Figure 1. Elimination of PV potentials by segmental ostial ablation. Shown are leads I and V6, distal bipolar of an ablation catheter (Abld), bipolar electrograms recorded with a decapolar ring catheter positioned at ostium of left superior PV (L1–2 → L9–10), and proximal and distal bipole of a quadripolar catheter positioned within coronary sinus (CSL and CSL1). Before ablation (A), several PV potentials were recorded at ostium (arrows). After segmental ostial ablation (B), PV potentials were no longer present.
Statistical Analysis
Continuous variables are expressed as mean±SD and were compared by Student’s t test. Categorical variables were compared by χ² analysis or with Fisher’s exact test. A Kaplan-Meier analysis with the log-rank test was used to determine the probability of freedom from recurrent PAF. A multivariate Cox regression analysis was performed to determine the independent predictors of recurrence of PAF. A value of \( P<0.05 \) was considered statistically significant.

Results

Segmental Ostial Ablation
All PVs in each of the patients in this group were successfully electrically isolated. The mean total duration of radiofrequency energy applications needed to isolate the PVs was 18±9 minutes per patient.

Left Atrial Ablation
The mean number of minutes of radiofrequency energy required to encircle the PVs was 22±8 for the left-sided PVs and 18±8 for the right-sided PVs. The mean total duration of radiofrequency energy applications for the entire left atrial ablation procedure was 42±14 minutes.

Total Procedure and Fluoroscopy Times
The mean total duration of the procedure was 156±45 minutes for segmental ostial ablation, compared with 149±33 minutes for left atrial ablation \( (P=0.7) \). The mean total fluoroscopy times were 50±17 minutes for segmental ostial ablation, compared with 39±12 minutes for left atrial ablation \( (P=0.06) \).

Freedom From Recurrent AF
After the first ablation procedure, PAF recurred in 13 of the 40 patients (32%) who underwent segmental ostial ablation and in 4 of the 40 patients (10%) who underwent left atrial ablation. At 6 months of follow-up, with no repeat ablation procedures, 67% of patients who underwent segmental ostial ablation were free of symptomatic PAF, compared with 88% of patients who underwent left atrial ablation \( (P=0.02, \text{log-rank test, Figure 4}) \).

Repeat Ablation Procedures
A repeat ablation procedure was performed 165±93 days after the initial procedure in 7 patients (18%) in the segmental ostial ablation group and in none of the patients who underwent left atrial ablation. During the repeat procedures, recovery of conduction was found in ≥1 PV in all patients.

During the repeat ablation procedures, left atrial ablation was performed in 6 patients, and segmental ostial ablation was repeated in 1 patient. All patients who underwent a repeat...
ablation procedure subsequently remained free of symptomatic PAF.

After 87 procedures in 80 patients, there was freedom from symptomatic PAF at 6 months of follow-up (after the most recent ablation) in 67% of patients who underwent only segmental ostial ablation, compared with 89% of patients who underwent left atrial ablation with or without previous segmental ostial ablation (P=0.01).

Predictors of Outcome
Among the variables of age, sex, duration of symptoms, frequency of symptomatic episodes of PAF, presence of structural heart disease, left atrial diameter, left ventricular ejection fraction, and the ablation technique, only the left atrial diameter and the use of segmental ostial ablation were independent predictors of recurrent PAF (P<0.01 for both).

Complications
One patient in the left atrial ablation group developed left atrial flutter. Additional ablation in the mitral isthmus abolished the flutter. There were no other complications.

Discussion
Main Findings
In this study, symptomatic PAF was eliminated more reliably by left atrial ablation that encircled the PVs than by segmental ostial ablation of the 4 PVs. The total procedure time was ≈2.5 hours with both approaches, but there was a trend toward a shorter duration of fluoroscopy with the left atrial ablation approach. Complications were rare, and the only complication in this study was a left atrial flutter that developed after left atrial ablation.

These findings suggest that left atrial ablation to encircle the PVs is preferable to segmental ostial ablation as the first approach in patients with symptomatic PAF who are appropriate candidates for catheter ablation.

Mechanistic Considerations
Segmental ostial ablation electrically isolates the PVs, thereby eliminating the arrhythmogenic activity in the PVs that triggers and/or perpetuates episodes of PAF. However, sources of AF that do not originate in the PVs are not addressed by PV isolation.

By encircling the PVs, left atrial ablation may eliminate the triggers and driving mechanisms of PAF that arise in the PVs. However, the left atrial ablation technique used in this study also may have other effects that may be helpful in preventing PAF: (1) the ablation lines may eliminate anchor points for rotors or mother waves that drive AF; (2) the vein of Marshall, which has a left atrial insertion in close proximity to the left superior PV and which may be a source of triggers for AF, may be excluded by the ablation line that encircles the left-sided PVs; (3) the ablation line that connects the 2 encircling ablation lines may eliminate sources of AF that arise on the posterior wall of the left atrium, and (4) 25% to 30% of the left atrial myocardium is excluded by the encircling lesions, thereby limiting the area available for circulating wavelets that may be needed to perpetuate AF.

These effects of left atrial ablation are incremental to the effects of segmental ostial ablation and may account for the greater efficacy of left atrial ablation in eliminating PAF.

Comparison of Technical Aspects
Segmental ostial ablation requires the insertion of 2 catheters into the left atrium, whereas left atrial ablation requires only a single catheter in the left atrium. Left atrial catheter ablation necessitates the use of a 3D mapping system, which increases the cost of the procedure. However, the use of the 3D mapping system has the advantage of limiting radiation exposure to patients and operators.

A notable difference between the 2 approaches to ablating PAF is that segmental ostial ablation requires the identification of PV potentials, which may be difficult to distinguish from atrial electrograms. In contrast, left atrial ablation is primarily an anatomic approach to ablation.

Regarding the practical aspect of procedure duration, segmental ostial ablation and left atrial ablation were comparable, with both approaches taking <3 hours in most patients. However, procedure times are operator-dependent, and our experience with segmental ostial ablation has been approximately twice as large as with left atrial ablation. Nevertheless, in a center that has performed more than 1000 left atrial ablation procedures, the mean procedure time was reported to be 148±26 minutes, which is almost identical to the mean procedure time of 149 minutes in the present study. This suggests that the comparison of procedure times between the 2 techniques in this study was valid.

Repeat Ablation Procedures
To minimize the risk of PV stenosis, a 4-mm-tip ablation catheter was used, and the power of radiofrequency energy applications was limited to 35 W in the segmental ostial ablation group. Recovery of conduction over a previously ablated PV fascicle was a consistent finding among patients in the segmental ostial ablation group who underwent a repeat procedure, and it is likely that incomplete ablation was related to inadequate energy delivery.

During left atrial ablation, most ablation sites are >1 cm away from a PV. Therefore, it is possible to safely deliver
more energy with an 8-mm-tip catheter, and a power setting of 60 W was used during left atrial ablation. The larger ablation electrode and the higher power setting may have resulted in lesions that were more permanent than during segmental ostial ablation, and this may have been another factor explaining the higher success rate of left atrial ablation.

Left Atrial Size
An enlarged left atrium was an independent predictor of recurrent PAF. Left atrial enlargement is likely to be an indicator of atrial anatomic remodeling. The probability of completely eliminating PAF is likely to be inversely related to the extent of anatomic remodeling of the atria. Therefore, regardless of whether segmental ostial ablation or left atrial ablation is performed, the best candidates for ablation are patients who do not have marked left atrial dilatation.

Safety
There were no complications in this study except for a left atrial flutter that was a proarhythmic effect of left atrial ablation. No instances of PV stenosis occurred, but only 40 patients underwent segmental ostial ablation. When radiofrequency energy is delivered at the ostium and the maximum power is limited to 35 W, the risk of PV stenosis is low, \( \approx 3\% \).\textsuperscript{19} However, the risk of PV stenosis may be even lower during left atrial circumferential ablation.\textsuperscript{5} because radiofrequency energy usually is applied \( >1 \) cm from the PVs. Because radiofrequency energy was applied within the encircling lesions in \( \approx 30\% \) of the patients, caution should still be exercised to avoid applications of radiofrequency energy within the PVs. Furthermore, complete electrical isolation of PVs may not be necessary for a successful outcome after encirclement of the PVs.\textsuperscript{20}

Previous Studies
No previous studies have compared the efficacy of segmental ostial ablation and left atrial ablation. In previous studies of segmental ostial ablation to isolate the PVs, success rates of 60\% to 70\% were achieved in patients with PAF with the use of standard or irrigated tip catheters, and a repeat ablation was performed in 10\% to 40\% of patients.\textsuperscript{2,3,6,21,22} Also consistent with the findings of the present study, 85\% of patients with PAF who underwent left atrial ablation for PAF in a previous study were free from recurrent AF during a mean follow-up of 10 months.\textsuperscript{3} Therefore, the 67\% success rate in the segmental ostial ablation group and the 88\% success rate in the left atrial ablation group at 6 months of follow-up in the present study are in line with the results of these previous studies. However, unlike previous studies, the left atrial ablation approach used in this study included a posterior line between the left- and right-sided circles and another line along the mitral isthmus in addition to the encircling lesions around the left- and right-sided PVs.\textsuperscript{4,5}

Limitations
A limitation of this study is that asymptomatic episodes of PAF may not have been recognized after the ablation procedures. However, all patients had symptomatic PAF before the procedure. Furthermore, because patients were randomly assigned to undergo the 2 ablation techniques, asymptomatic episodes of PAF would not be expected to occur more frequently in one ablation group than the other.

Another limitation of this study is that segmental ostial ablation was performed with a 4-mm-tip catheter and left atrial ablation was performed with an 8-mm-tip catheter. However, when segmental ostial ablation was performed with a catheter capable of delivering more energy, long-term freedom from recurrent AF was similar to that reported in this study.\textsuperscript{21} The mean duration of follow-up in this study was 164 days. Long-term follow-up will be important to determine the long-term safety and efficacy of both ablation strategies.

Conclusions
The 2 ablation techniques for PAF that have been used most commonly in clinical practice have been segmental ostial ablation to isolate the PVs and left atrial ablation to encircle the PVs. Although several centers have reported the clinical results of segmental ostial ablation,\textsuperscript{2,3,21} only 1 center has reported outcomes after left atrial ablation.\textsuperscript{4,5} Whether one ablation technique is superior to the other has been a matter of controversy, and the controversy has been fueled in part by the absence of previous studies that have directly compared the 2 approaches in a randomized, prospective fashion. The present study demonstrates for the first time that left atrial ablation that includes encirclement of the PVs eliminates PAF more reliably than does segmental ostial ablation. On the basis of the findings of this study, it seems appropriate to use left atrial ablation as first-line therapy in patients with PAF who are appropriate candidates for catheter ablation.

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References


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