Pulmonary Antrum Radial–Linear Ablation for Paroxysmal Atrial Fibrillation
Interim Analysis of a Multicenter Trial

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Background—Substrate abnormality in pulmonary vein (PV) antrum plays a critical role in mechanism of atrial fibrillation (AF). The present study compares the strategy of PV antrum radial–linear (PAR) ablation to encircling PV isolation for paroxysmal AF.

Methods and Results—A total of 86 patients with paroxysmal AF were randomly assigned to PAR ablation group or PV isolation group. The average procedure time was 161±21 minutes in PAR ablation group and 199±39 minutes in PV isolation group (P<0.01). The average fluoroscopy time was 25±5 minutes in PAR ablation group and 32±9 minutes in PV isolation group (P<0.001). At 14 (15–12) months of follow-up after single procedure, 31 of 42 (74%) patients in PAR ablation group and 26 of 44 patients (59%) in PV isolation group had no recurrence of AF off antiarrhythmic drug (P=0.0249); and 36 of 42 patients (86%) in PAR ablation group and 26 of 44 patients (59%) in PV isolation group had no recurrence of AF with antiarrhythmic drug (P=0.006). In addition, PAR ablation resulted in greater reduction of left atrial diameter than encircling PV isolation. Multivariable Cox regression analysis showed that only ablation strategy was independently associated with AF recurrence (hazard ratio, 0.31; 95% confidence interval, 0.12–0.78; P=0.013). No major adverse event related to the procedures occurred.

Conclusions—This study suggests that PAR ablation is a potentially effective strategy for treatment of paroxysmal AF warranting further investigation.

Clinical Trial Registration—URL: http://www.chictr.org; Unique identifier: ChiCTR-TRC-11001191.

Key Words: atrial fibrillation • catheter ablation • pulmonary vein

Curative ablation of atrial fibrillation (AF) serves 2 import purposes: elimination of all potential triggers and modification of atrial substrate.1 Although pulmonary vein (PV) isolation remains essential for most ablation procedures, the role of substrate modification has been increasingly emphasized.2 Although the triggers and substrate may play a different role in individual patients, considerable experimental and clinical evidence suggests that as AF progresses from paroxysmal to persistent, the atrial substrate becomes increasingly abnormal and may be a dominant factor for maintaining AF.3 PV isolation has been the main ablation strategy for AF ablation; however, its long-term outcome remains suboptimal.2 Although a significant volume of reports have claimed procedural success rates of 76% to 91%, carefully monitored clinical trials performed by experienced operators have indicated a true success rate of 66%.4,5 It is, therefore, important to develop alternative strategies to achieve an optimal long-term outcome for AF ablation.6

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Encircling PV ablation or left atrial (LA) linear ablation without complete PV electric isolation has been reported to produce a long-term benefit of maintaining sinus rhythm for most of the patients with paroxysmal or even persistent AF.6–10 The areas with complex fractionated atrial electrograms (CFAEs) have been reported to represent AF substrate sites and target sites for AF ablation potentially.1 Multiple reentrant
circuits with or without mother rotors in the antral area have been proposed to be the substrate for AF. Alternatively, the maintenance of AF needs a critical number of circulating wavelets, each of which requires a critical excitable mass of atrial tissue. The mechanism of Maze procedure is thought to be the creation of multiple strategically placed incisions across the atria to reduce the critical excitable mass.

We have proposed a novel strategy of PV antrum radial–linear (PAR) ablation as an organized modification of substrate to interrupt the possible mechanisms for AF initiation and maintenance effectively. This prospective, multicenter, randomized study was designed to compare the efficacy and safety of the new approach with the conventional PV isolation in patients with paroxysmal AF.

### Methods

#### Patient Enrollment

The study protocol was approved by Shanghai Municipal Health Bureau and the Institutional Review Board and Ethics Committee at each of the 4 centers in Shanghai, China. All patients enrolled in the study provided written informed consent. Enrollment required at least 3 symptomatic AF episodes (at least 2 episodes verified by ECG) within 6 months before randomization and did not respond to at least 1 antiarrhythmic drug (AAD; class I/III). Exclusion criteria included any of the following conditions: (1) patients with AF of >30 days in duration; (2) an ejection fraction (EF) of <40%; (3) previous AF ablation; (4) documented LA thrombus; (5) myocardial infarction within 6 months; (6) thromboembolic event in the previous 12 months; (7) severe pulmonary disease; (8) a prior valvular cardiac surgical procedure; (9) contraindication to antiarrhythmic or anticoagulation medications; and (10) LA posterioanterior diameter >50 mm in the parasternal long axis view (Figure 1).

The enrollment occurred between March 7, 2011, and June 12, 2011, with the last follow-up on June 18, 2012. In this randomized trial, investigators used a computer program to assign each study participant to 1 of the 2 groups by a block randomization.

#### Electrophysiology Study and Ablation Procedure

Eighty-six consecutive patients with paroxysmal AF were enrolled in this study. AAD were discontinued for a period of at least 5 half-lives before the procedure. Amiodarone was replaced with propafenone for at least 3 months before randomization except 1 patient in PAR ablation and 2 in PV isolation. Therapeutic anticoagulation with heparin was achieved for at least 3 days before the procedure. The procedure was performed under sedation with midazolam and fentanyl citrate. A 6F multipolar electrode catheter was placed into the coronary sinus (CS) via the left subclavian vein. Right femoral vein was used for transseptal access and ablation. Two separate transseptal procedures were made with 8F sheaths (SL1, St. Jude Medical Inc, St. Paul, MN). A 20-mm, decapolar Lasso catheter (Lasso, Biosense-Webster, Baldwin Park, CA) was used for mapping in PV areas. After transseptal access, intravenous heparin was administered. Following transseptal puncture, PV venography was performed with selective delivery of contrast into each of the PV ostia using a multipurpose angiography catheter at left anterior oblique 45° for left PVs and right anterior oblique 45° for right PVs. A 3-dimensional geometry of LA was reconstructed with CARTO system (Carto XP Navigation System, Biosense-Webster, Diamond Bar, CA). No CARTO-merge system was used in the present study.

Before ablation, a standardized atrial pacing protocol was conducted to determine AF inducibility in both groups as previously described. In brief, atrial burst pacing was performed in decrements from a cycle length of 250 ms down to refractoriness from the distal CS and LA appendage. The minimum 1:1 atrial capture cycle length was identified and used to determine the pacing frequency. A train of burst pacing with 2× thresholds, pulse width of 2 ms, and duration of 10 s was delivered for AF induction. A total of 10 attempts of burst pacing were made with 5 attempts from CS and 5 from LA appendage. Irregular atrial tachyarrhythmia of ≥30 s was defined as inducible AF.

Radiofrequency energy was delivered to the PV antrum in the patients at a maximum temperature of 43°C, power between 25 and 35 W and 17 mL/min saline flow for 30 s at each lesion site with a 3.5-mm irrigated-tip ablation catheter (ThermoCool, Biosense-Webster). If for some reason the voltage reduction criteria were not met with the power of 35 W, the saline flow was increased up to 25 mL/min. During PAR ablation, if energy delivering inside PV ostium was necessary, the power was limited to 15 to 20 W. A successful lesion creation at each point was considered to be completed when the local bipolar voltage was decreased by 90% or to <0.05 mV. For patients with documented atrial flutter (AFL), the cavotricuspid isthmus was also ablated with an end point of bidirectional conduction block.

#### PAR Ablation

The ablation lines were designed based on the morphology of PVs on computed tomography angiography before the procedure and PV venography during the procedure (Figure 2A–2D). The ablation was targeting local double potentials (the combined potentials from PV ostia).
and LA) in PV antrum, which were usually characterized by atrial electrogamds with deflections over 3 phases and a duration of ≥50 ms or CFAEs if AF was present. All the radial–linear lesions were created with radiofrequency ablation (with the energy settings as described above) from PV ostium to the PV–LA junction, where no PV potential was present. Each PV ostium was viewed as a clock and the ablation lines were marked as line 1, 2, and 3 separately. In the left superior PV (LSPV), line 1 started at about 2 o'clock, the anterosuperior wall of LSPV ostium, along the upper edge of left appendage to the anterosuperior wall; line 2 started at 12 o'clock toward the superior wall; and line 3 started at 9 o’clock toward the posterior wall. In the left inferior PV, line 1 started at 3 o’clock toward the anterior wall along the lower edge of left appendage; line 2 started at 6 o’clock toward the inferior wall; and line 3 started at 9 o’clock toward the posterior wall. In the right superior PV (RSPV), line 1 started at 9 o’clock toward the anterior wall; line 2 started at 12 o’clock toward the superior wall; and line 3 started at 3 o’clock toward the posterior wall in the right inferior PV, line 1 started at 9 o’clock toward the anterior wall; line 2 started at 6 o’clock toward the inferior wall; and line 3 started at 3 o’clock toward the posterior wall. The completeness of linear lesions was confirmed by moving the ablation catheter back and forth along the ablation lines to check the local voltage for 2x, if necessary pacing maneuvers were performed to assess line completeness.16

The procedural end point was the completion of all the designed ablation lines, conversion of AF to normal sinus rhythm, and AF becoming noninducible with the atrial burst pacing protocol as described above. If AF was still inducible after the designed lines were completed, 1 or 2 lines in each PV would be extended for ≤5 mm described above. If AF was still inducible after the designed lines were completed, 1 or 2 lines in each PV would be extended for ≤5 mm toward distal PV, or 1 more line created in each PV antrum. Before and after ablation, the PV electrograms were recorded with Lasso catheter and or ablation catheter.

**PV Isolation**

Encircling PV ablation was performed as previously described.17 Septal and lateral continuous circular lesions around the ipsilateral PVs were created ≥10 mm posterior and 5 mm anterior from the angiographically defined PV ostia. The procedural end point was PV bidirectional conduction block identified with Lasso catheter at least 30 minutes after ablation during sinus rhythm. LA roof line and mitral isthmus line were created if macro-reentrant atrial tachycardia (AT) occurred during the procedure.

**Follow-up Protocol**

After randomization, patients in PAR ablation group received radial–linear ablation in PV antrum, and patients in PV isolation group received encircling PV ablation. Patients were followed up for at least 12 months. Immediately after the procedure, all the patients were anticoagulated with warfarin with an international normalized ratio of 2 to 3, and AAD was given for 3 months (then discontinued), followed by metoprolol, if indicated clinically. AAD was restarted for 1 day with recurrent AF at the time of first recurrence in both groups and continued during the follow-up. Amiodarone was administered only if propafenone was ineffective (Table I in the online-only Data Supplement). Electrocardiograms were obtained at every follow-up visit. After a 3-month blanking period, the patients were evaluated with an event ECG recorder (Prince 180B, China) every 3 months for 3 days each time until the final visit. By the end of 3 days of monitoring each time, the patient was evaluated by the follow-up doctor. 24-Hour Holter monitoring was conducted at 6 months and the final visit for all patients. The patients were also instructed to check and record their pulses for regularity and rate every day (at least 5 days a week) for 3 minutes each time and whenever they had symptoms (including palpitations, shortness of breath, chest discomfort, fatigue, or dizziness) suggestive of AF.

Computed tomography angiography of LA was obtained for all patients during sinus rhythm before the procedure and 6 months after the procedure. The maximal diameter of each ostium was measured semiautomatically from the outer edges of the individual vein on computed tomography images at the level of the ostium. Transesophageal echocardiography was obtained in sinus rhythm for all patients before the procedure and at the final visit. EF was calculated using the modified Simpson’s method from apical 4- and 2-chamber views. LA diameter was determined in the parasternal long axis view.

All rhythm tracings were interpreted in a blinded fashion by 2 physicians who did not participate in the study. Recurrent AF was defined as an occurrence of AF (including AFL and AT) with a duration of at least 30 s documented by an ECG or device recording system after the 3-month blanking period until the final visit after the procedure.

Major adverse events were defined as occurrence of 1 of the followings: cardiac tamponade, significant PV stenosis (at least 50% reduction of PV diameter over the baseline), esophageal injury, bleeding requiring blood transfusion, pericardial effusion requiring pericardiocentesis, phrenic nerve paralysis, stroke, and acute coronary artery occlusion.

The primary end point was the proportion of patients free of recurrent AF 3 months after ablation. The secondary end points consisted of time to AF recurrence, complications and other adverse effects, change in LA dimensions, and left ventricular EF.

**Statistics**

The primary efficacy analysis was based on an intention-to-treat analysis of all randomized patients. With an estimated success rate of 90% for PAR ablation and 70% for PV isolation, 76 patients should have been enrolled for each group, allowing for 5% dropout, for a power of 80% with χ² test with 0.05 as significance level. The preplanned interim analysis was conducted when it showed the predictive probability of success to be 97.5%. The trial was stopped (although follow-up was continued) when this analysis showed the predictive probability of success to be 99%. On the basis of the updated study results of 86 patients, the probability of superiority was 97.51% for single procedure off AAD and 99.4% for single procedure with AAD.

Continuous variables were reported as mean±SD or median. Data for pre ablation and post ablation were performed with paired sample
Comparison between groups was performed with 2 independent sample t test or Mann–Whitney U test (for non-normally distributed data). The categorical variables were reported as number and percentage and were analyzed using $\chi^2$ test. The absolute change in LA diameter among subgroups was calculated using the formula (post ablation–pre ablation) and analyzed using multiple comparisons in ANOVA (Dunnett’s T3). Kaplan–Meier curves were produced to obtain freedom from AF probabilities over time with 1 month interval, and log-rank test was used for comparison. Multivariable Cox regression analysis was used to identify significant predictors of AF recurrence with consideration of clinically relevant covariates and usage of discrete time option. Variable candidates include age, sex, left ventricular EF, LA diameter, AF duration, hypertension, diabetes mellitus, ablation strategy (PAR ablation or PV isolation), and procedure time. Variables with a $P<0.05$ were entered into the model, and no formal test of the proportional hazards assumption was applied. All tests were 2-tailed, and statistical significance was established at $P<0.05$. Analyses were performed using SPSS version 17.0.

Results

Patient Characteristics

A total of 86 patients, 54 men (63%) and 32 women (37%), with the average age of 64.1±6.1 years, were enrolled. Forty-two and 44 patients were randomized to PAR ablation and PV isolation groups, respectively. The clinical characteristics of patients in both groups are shown in the Table.

Procedural Results

All the patients in both groups had inducible AF before ablation. In PAR ablation group, the designed ablation lines were completed and AF was noninducible in all 42 patients. Of them, 3 radial–linear lesions were performed in each PV in 38 patients; and 4 radial–linear lesions were created in LSPV and RSPV in 4 patients. One or 2 linear ablation lesions were extended <5 mm into PV ostium where CFAEs were recorded during AF episode in 3 patients, of whom AF episode was terminated and became not inducible. In 1 patient, ablation was performed in LA appendage to eliminate a focal trigger. In addition, the cavotricuspid isthmus linear ablation was performed on 2 patients with bidirectional block. The representative CARTO images for the ablation lesions are shown in Figure 3A–3D. After PAR ablation, no PVs were incidentally isolated, and there were persistent PV potentials in the PVs. Delayed PV spikes might be found sometimes adjacent to ablation lines but not remote from the lines. The timing from stimulus to PV spikes was not prolonged during pacing from the CS. In the control group, PV isolation was achieved in all 44 patients with LA roof line in 2 patients, mitral isthmus line in 3 patients, and cavotricuspid isthmus line in 1 patient. No burst pacing was used to assess the effect of PV isolation. Therefore, the acute procedural success as defined was 100% in each group. The average procedure time was 161±21 minutes in PAR ablation group and 199±39 minutes in PV isolation group ($P<0.01$). The average fluoroscopy time was 25±5 minutes in PAR ablation group and 32±9 minutes in PV isolation group ($P<0.001$). During follow-up, 2 (5%) patients underwent a second procedure in PAR ablation group, in whom no PV isolation was found before the redo procedure. One patient accepted PV isolation, and the other underwent a focal ablation at LA appendage. Four (9%) patients had repeat procedure in PV isolation group, and PV reconnection was found in all of these 4 patients during the redo procedure. There was no significant difference in patients with repeat procedure between the 2 groups ($P=0.43$).

Effectiveness Outcome Analyses

The median (interquartile range) for follow-up times was 14 (15–12) months in both groups. Kaplan–Meier curves for the effectiveness outcomes are shown in Figure 4. At 14 months after a single ablation procedure of AAD, 31 of 42 patients (74%) in the PAR ablation group were free of AF (including

Figure 3. Three-dimensional map of the left atrium (LA) in different views using CARTO system. Pulmonary vein (PV) ostia were highlighted with white circles. Red dots indicated the linear ablation lesions. Top, A case with 3 radial–linear lesions created in each PV. A, The ablation pattern in left PV antrum. B, The ablation pattern in right PV antrum. Bottom, A case with 4 radial–linear lesions created in left superior PV and right superior PV, and 3 radial–linear lesions created in left inferior PV and right inferior PV. C, The ablation patterns in both left and right PV antrum. D, The ablation pattern in right PV antrum.
AFL (atrial fibrillation) and AT (atrial tachycardia) as compared with 22 of 44 (50%) in PV isolation group (P=0.0249) (Figure 4A). At 14 months after a single ablation procedure with AAD, 36 of 42 patients (86%) in PAR ablation group were free of AF as compared with 26 of 44 (59%) in PV isolation group (P=0.006) (Figure 4B). There were 5 patients free of AF in PAR ablation and 4 patients in PV isolation after a single ablation procedure on AAD. In PAR ablation group, 6 (14%) patients had recurrent AF on AAD, including 3 patients with AF, 2 with AFL, and 1 with AT. In PV isolation group, 18 (41%) patients developed recurrent AF on AAD, including 16 patients with AF, 1 with AFL, and 1 with AT (Figure 5). Multivariable Cox regression analysis demonstrated that only ablation strategy was identified to be independently associated with AF recurrence (hazard ratio, 0.31; 95% confidence interval, 0.12–0.78; P=0.013).

LA Dimension
Overall, the LA diameter was significantly decreased in patients who received PAR ablation as compared with PV isolation (Figure 6A). Subgroup analysis showed that the decrease in LA diameter occurred predominantly in patients without recurrent AF and was more prominent in PAR ablation than PV isolation (Figure 6B). Left ventricular EF was not significantly different post ablation from pre ablation in patients with PAR ablation (71.4±6.2 versus 70.7±4.6; P=0.16) and PV isolation (71.8±5.8 versus 70.7±5.0; P=0.16).

Adverse Events
No major adverse events, including cardiac tamponade, significant PV stenosis (>50% narrowing), phrenic nerve paralysis, procedure-related transient ischemic attack or stroke, or atrioesophageal fistula, were observed. The diameter of each PV before and after ablation is listed in Table II in the online-only Data Supplement. A sterile pericardial effusion developed within 2 days after ablation in 2 of 86 patients (2%), 1 in each group, but did not require pericardiocentesis. In addition, transient sinus bradycardia occurred during ablation in 7 patients in PAR ablation group and 4 patients in PV isolation group (P>0.05; all these patients did not require placement of a permanent pacemaker).

Discussion
This was the first prospective multicenter randomized study showing that the novel PAR ablation was a simple, safe, and effective ablation strategy for the treatment of paroxysmal AF. The new approach seemed to be more effective than PV isolation, suggesting that an organized modification of substrate in PV antria is important in eliminating the initiation and maintenance of AF. Indeed, multiple random propagating wavelets, autonomic innervations, ligament of Marshall, CFAE areas, and even potential arrhythmogenic ostial foci have been observed in the atrial areas as possible mechanisms for the initiation and perpetuation of AF. All of these important mechanisms could be interrupted with PAR ablation.

The present study demonstrated the superiority of PAR ablation over PV isolation in patients with paroxysmal AF with regard to the maintenance of sinus rhythm and improvement in LA remodeling. At 14 months of follow-up, a success rate of 74% was achieved with PAR ablation after a single procedure off antiarrhythmic medication in patients with paroxysmal AF. Multivariable Cox regression analysis showed that only ablation strategy was the independent predictors for AF recurrence. Wilber et al recently reported that PV isolation resulted in a success rate of 66% in patients with paroxysmal AF at the end of 9-month follow-up, and PV antrum isolation achieved a success rate of 57% in patients mostly with paroxysmal AF after a single ablation procedure at 2 years of

### Table. Baseline Patient Characteristics

<table>
<thead>
<tr>
<th></th>
<th>PAR Ablation (n=42)</th>
<th>PV Isolation (n=44)</th>
<th>P Value†</th>
</tr>
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<tbody>
<tr>
<td>Age (mean±SD), y</td>
<td>65.1±5.7</td>
<td>63.1±6.5</td>
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<tr>
<td>Sex, n (%)</td>
<td></td>
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<tr>
<td>Women</td>
<td>15 (36)</td>
<td>17 (39)</td>
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<tr>
<td>Men</td>
<td>27 (64)</td>
<td>27 (61)</td>
<td>0.78</td>
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<tr>
<td>AF duration, median (IQR), mo</td>
<td>54 (108–24)</td>
<td>48 (96–18)</td>
<td>0.92‡</td>
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<td>Hypertension, n, %</td>
<td>21 (50)</td>
<td>18 (41)</td>
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<tr>
<td>Diabetes mellitus, n, %</td>
<td>8 (19)</td>
<td>7 (16)</td>
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<tr>
<td>Cerebrovascular accident, n, %</td>
<td>1 (2)</td>
<td>1 (3)</td>
<td>0.97</td>
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<td>LVEF (mean±SD), %</td>
<td>71.4±6.2</td>
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<td>LA diameter (mean±SD), mm</td>
<td>44.3±4.9</td>
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<td>Antiarrhythmic drugs</td>
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<td></td>
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<td>Metoprolol, n, %</td>
<td>15 (36)</td>
<td>24 (55)</td>
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<tr>
<td>Propafenone, n, %</td>
<td>16 (38)</td>
<td>23 (52)</td>
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<td>Amiodarone, n, %</td>
<td>32 (76)</td>
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<tr>
<td>Antiarrhythmic drugs (class I/III), mean</td>
<td>1.14</td>
<td>1.27</td>
<td>0.14‡</td>
</tr>
</tbody>
</table>

AF indicates atrial fibrillation; IQR, interquartile range; LVEF, left ventricular ejection fraction; LA, left atrial; PAR, pulmonary vein antrum radial–linear; and PV, pulmonary vein.

†For continuous variables, comparison by t test; for categorical variables, comparison by χ² test.
‡By Mann–Whitney U test.
follow-up. The outcomes of these studies were comparable to that observed in the patients with paroxysmal AF and PV isolation in the present study. Interestingly, we have also observed that PAR ablation, not PV isolation, resulted in a significant decrease in LA diameter. These data were consistent with the previous report and supported the conclusion that maintenance of sinus rhythm was one of the key determinants for reduction in LA size. In addition, no significant complications occurred to the patients receiving the new ablation procedure, suggesting that it was at least as safe as PV isolation.

PAR ablation was a completely different strategy for AF ablation from PV isolation. The radial–linear ablation was designed to achieve an organized substrate modification in PV antria, whereas encircling PV ablation was intended to isolate the triggers in PVs electrically with some impact on the substrate. Another ablative strategy for substantial substrate modification was to target the CFAEs. However, this technique could involve an extensive amount of ablation in almost the entire atrium without a specific pattern anatomically. On the other hand, PAR ablation had a unified ablation pattern for all the patients with minimal individual variability, making it much easier to go through the procedure technically with shorter procedure time and less radiation exposure than PV isolation. In addition, the electric connections from the LA to the PVs were preserved in the regions between 2 neighboring linear lesions during PAR ablation, thus, PV was not isolated electrically. Therefore, Lasso catheter might not be necessary, and a single transseptal puncture could be enough for the procedure.

The double potentials were the major targets of PAR ablation on the designed ablation lines, which were usually characterized by atrial electrograms with deflections over 3 phases and duration of >50 ms. During episodes of AF, CFAEs inside the PV ostia may suggest the existence of AF nests. We observed that if CFAEs were recorded along any of the linear lesions, a <5-mm extension of ablation into the PV ostium sometimes terminated AF, which was consistent with previous observation, suggesting that it usually needed more current delivering at the PV ostia. It had been reported that linear lesions were often arrhythmogenic due to the existence of gaps along the ablation lines, which could be identified with pacing capture test on the ablation lines. With the technique described in the present study, all the linear lesions were short that could not take a long time to check the ablation lines to confirm the line completeness.

The present study did not explore the mechanism(s) for PAR ablation. However, the favorable clinical outcome of the present strategy could be related to multiple factors. The substrates for AF initiation and maintenance were frequently located within the PV antrium. Usually with a total of 12 linear lesions, the radial–linear ablations could well cover both PV antral areas. Because the PV antrum was divided longitudinally by
the radial–linear lesions into small regions, any current impulse would be unlikely conducted circumferentially, and thus, the localized reentrant circuits could be interrupted. The multiple random propagating wavelets could not be produced due to the loss of the structure integrity and decreased critical tissue mass in PV antrum as that in the surgical Maze procedure.13 Focal electric discharges along the linear lesions would be eliminated as well in PV antrum or even in the ostium. In addition, the 4 major LA autonomic ganglionic plexi (GP) and axons were possibly targeted as well during the creation of the ablation lesions, especially the superior left GP by line 2 and line 3 in LSPV, inferior left GP by line 2 and 3 in left inferior PV, anterior right GP by line 1 in RSPV and line 1 in right inferior PV, inferior right GP by line 2 and line 3 in right inferior PV. The ligament of Marshall could be interrupted with ablation line 1 and line 2 in left inferior PV as well as line 1 in LSPV. The GP were consistently located within the areas of CFAEs24 that were the main target of the radial–linear ablation as well as double potentials. In addition, ablation of the nerve cell bodies, by targeting the GP, might permanently denervate the PVs.25

Study Limitations
The present study was focused on investigating the efficacy and safety of PAR ablation in the treatment of paroxysmal AF. Further study is needed to evaluate the therapeutic value in the patients with persistent and chronic AF. The follow-up was relatively short; however, a longer follow-up is ongoing for these patients. The PAR ablation was primarily performed within PV antria. It was not clear if it could be a valuable approach to the treatment of AF with its origination outside the PVs, such as right atrium or CS.

Conclusion
In the present study, we described a simple, safe, and effective new method for paroxysmal AF ablation with shorter procedure time and less radiation exposure than PV isolation. It required only a single transseptal puncture without the unnecessary use of Lasso catheter. The findings suggest that PAR ablation is a potentially effective strategy for the treatment of paroxysmal AF warranting further investigation.

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Disclosures
None.

References

**CLINICAL PERSPECTIVE**

Electrical isolation of the pulmonary venous antrum (PV) is considered a cornerstone of catheter ablation for paroxysmal atrial fibrillation. This randomized trial in patients with paroxysmal atrial fibrillation compared an ablation strategy of pulmonary venous radial-linear (PAR) lesions to encircling PV isolation. PAR lesions were designed based on PV anatomy, and electrogram characteristics with lines extending from the antrum toward the PV. Despite the presence of potentials between PAR lines, indicating absence of isolation, PAR patients had less recurrence of atrial fibrillation during follow-up than patients who had encircling PV isolation. PAR patients had shorter procedure and fluoroscopy times. Thus, PV isolation is not always required for effective atrial fibrillation ablation. Modification of the arrhythmia substrate with the PAR approach warrants further study.
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SUPPLEMENTAL MATERIAL
Supplemental Table 1. AAD Administration During Follow-up

<table>
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<th>Blanking period (1-3 months after procedure)</th>
<th>Follow-up period (4-15 months after procedure)</th>
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<td>PAR ablation (42)</td>
<td>PAR ablation (42)</td>
</tr>
<tr>
<td></td>
<td>PV isolation (44)</td>
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<tr>
<td>Free of AF off AAD</td>
<td>Free of AF on AAD</td>
<td>Free of AF off AAD</td>
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<tr>
<td>(31)</td>
<td>(5)</td>
<td>(22)</td>
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<tr>
<td>Free of AF on AAD</td>
<td>Recurrence with AAD</td>
<td>Free of AF on AAD</td>
</tr>
<tr>
<td>(5)</td>
<td>(6)</td>
<td>(4)</td>
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<tr>
<td>Recurrence with AAD</td>
<td></td>
<td>Recurrence with AAD</td>
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<tr>
<td>(6)</td>
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<td>(18)</td>
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<table>
<thead>
<tr>
<th></th>
<th>Propafenone</th>
<th>Amiodarone</th>
<th>Beta-blocker</th>
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<td>7</td>
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</tbody>
</table>

AAD indicates antiarrhythmic drug class I/III
**Supplemental Table 2. Diameter of PV Ostium**

<table>
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<tr>
<th></th>
<th>PAR ablation</th>
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<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>LSPV</td>
<td>21.1 ± 3.1</td>
<td>19.6 ± 4.0</td>
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<tr>
<td>LIPV</td>
<td>16.7 ± 2.9</td>
<td>16.3 ± 3.3</td>
</tr>
<tr>
<td>RSPV</td>
<td>19.7 ± 3.5</td>
<td>19.3 ± 3.9</td>
</tr>
<tr>
<td>RIPV</td>
<td>16.9 ± 2.8</td>
<td>16.4 ± 3.0</td>
</tr>
</tbody>
</table>

No significant difference between before and after ablation.