Impact of pulmonary vein isolation on atrial late potentials: association with the recurrence of atrial fibrillation

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Aims
In patients with paroxysmal atrial fibrillation (AF), the P-wave signal-averaged electrocardiogram often demonstrates a low-amplitude potential at the terminal part of filtered P-wave (atrial late potential: ALP), which would originate from delayed pulmonary vein (PV) potentials. The aim of this study was to investigate the impact of PV isolation on P-wave morphology and explore the association between A LP and AF recurrence after ablation.

Methods and results
We enrolled 88 consecutive paroxysmal AF patients scheduled for ablation. The signal-averaged electrocardiogram was obtained at baseline and 1 day after ablation. An A LP was defined as a P-wave duration of ≥ 130 ms and a root-mean-squared voltage of the terminal 20 ms of ≤ 2.0 mV. A pre-procedural A LP was found in 37 (42%) patients and a post-procedural A LP was found in 26 (30%) patients. We completed PV isolation in all patients and followed them for 16 ± 4 months. The AF recurrence rate was 30% (26 patients) and was similar between patients with and without pre-procedural A LP (27 vs. 31%, respectively, P = 0.66); however, AF recurrence was significantly higher in patients with than without post-procedural A LP (54 vs. 19%, respectively, P = 0.001). In multivariate logistic regression analysis, post-procedural A LP was independently associated with AF recurrence (odds ratio = 4.22, 95% confidence interval = 1.52—11.7).

Conclusion
Pulmonary vein isolation can modify A LP in a substantial number of patients with paroxysmal AF. Post-procedural A LP is associated with increased risk of future AF recurrence.

Keywords
Signal-averaged electrocardiogram • Late potential • Atrial fibrillation • Pulmonary vein isolation • Recurrence

Introduction
Pulmonary vein (PV) isolation has been shown to be effective for the treatment of atrial fibrillation (AF). However, AF recurs in 10–30% of patients after PV isolation. Although left atrial (LA)-PV reconnection was reported to be one of the main causes of AF recurrence, there is no established method to estimate LA-PV reconnection and future AF recurrence non-invasively.

The P-wave signal-averaged electrocardiogram (P-SAECG) provides detailed information about atrial electrical activation. Patients with paroxysmal AF often have a low-amplitude potential in the terminal part of filtered P-wave (atrial late potential: A LP) that is represented by a prolonged P-wave duration (PWD) and a decreased root-mean-squared voltage of the terminal 20 ms (RMS20). Okumura et al. used three-dimensional electroanatomical mapping and showed that the latest atrial activation site was located within the PVs in most cases. They also suggested that A LP is derived from delayed activation of the muscle sleeves within the PVs, and successful PV isolation eliminates A LP.

We hypothesized that the disappearance of A LP after PV isolation would be a useful index of the completion of LA-PV disconnection, and that residual A LP after AF ablation represents reconnection of LA-PV conduction and may predict future AF recurrence. The purpose of this study was to investigate the impact of PV isolation on P-wave morphology in patients with and without

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What’s new

- Atrial late potential was modified by pulmonary vein isolation in substantial patients.
- Post-procedural atrial late potential predicted the recurrence of atrial fibrillation.

Methods

Study patients

From September 2010 to June 2011, consecutive patients who underwent initial ablation for paroxysmal AF in our hospital were enrolled. Patients were excluded if P-SAECG was not appropriately recorded. Other exclusion criteria were as follows: prior cardiac surgery, prior catheter ablation, implanted pacemaker, severe mitral valve disease, and poor left ventricular systolic function (left ventricular ejection fraction <50%). Written informed consent for ablation and participation in the study was obtained from all patients. This study complied with the Declaration of Helsinki. The protocol was approved by our institutional review board.

P-wave signal-averaged electrocardiogram

All antarrhythmic drugs were discontinued five half-lives before baseline P-SAECG. P-wave signal-averaged electrocardiograms were obtained at baseline and on the day after the ablation procedure with patients in the supine position and covered with an antistatic sheet. The skin at the site of electrode placement was cleaned with alcohol and thereafter scrubbed with a rubbing pad. Then, the reference P-wave was selected to create an averaging template. The averaging endpoint was a noise amplitude of <0.3 μV. The P-wave signals from X, Y, and Z leads were filtered bidirectionally (with forward and backward filters) using a filter setting of 40–300 Hz, and combined to obtain a vector magnitude of the P-wave. Measurements of PWD and RMS20 were done automatically and, if necessary, corrected manually by one physician blinded to clinical information of the patient. Study patients were divided into two groups according to the presence or absence of ALP that was to clinical information of the patient. Study patients were divided into two groups according to the presence or absence of ALP that was to clinical information of the patient. Study patients were divided into two groups according to the presence or absence of ALP that was to clinical information of the patient.

Baseline assessment

Transthoracic echocardiography was performed at baseline to obtain standard measurements. In addition, 64-detector contrast-enhanced computed tomography was performed, and left atrial volume and emptying fraction were calculated excluding the PVs and appendage.

Electrophysiological study and ablation

A straight decapolar catheter was placed between the superior vena cava and right atrium, and a deflectable 20-pole catheter was positioned in the coronary sinus. After transseptal puncture at the fossa ovalis, direct visualization of all four PVs was performed using a selective venography to show the venous anatomy and the location of the LA-PV junctions. The LA-PV junctions were also determined by a three-dimensional mapping system (CARTO). Then, double circular catheters (20-pole catheters) were placed first at the ipsilateral superior and inferior LA-PV junctions and then at the contralateral LA-PV junctions. Prior to ablation, the latest atrial and PV activation sites among the above-mentioned electrodes were determined in each patient.

A PV isolation procedure was performed guided by a three-dimensional mapping system. An irrigated ablation catheter with a 3.5-mm tip (Navi-Star Thermocool, Biosense Webstar) was used for mapping and ablation. Radiofrequency energy was applied for 15–30 s at each site using a maximum temperature of 45 °C, a maximum power of 25 W and a flow rate of 17 mL/min. Atrial circumferential ablation was performed to encircle the left- and right-sided PVs. The procedural endpoint was electrical isolation of all PVs from the left atrium. We also eliminated LA-PV dormant conduction that was induced by adenosine as reported previously. If isthmus-dependent atrial flutter was clinically documented or induced by atrial programmed stimuli after PV isolation, cavo-tricuspid isthmus ablation was performed. Atrial premature contractions derived from non-PV foci especially that those triggered an immediate recurrence of AF, were eliminated as much as possible.

Follow-up

Patients were discharged 3 ± 1 days after ablation and were seen in our hospital at 1–2-month intervals. Antiarrhythmic drugs were not used except for cases of frequent recurrences of atrial tachyarrhythmias. Arrhythmic events were assessed by symptoms, serial 12-lead ECGs and 24 h Holter recordings. An AF recurrence was defined as...
the detection of AF and/or atrial tachycardia that occurred 3 months or more after AF ablation.

**Statistical analysis**

Continuous data are expressed as the mean \(\pm\) SD. Categorical data are presented as absolute values and percentages. Tests for significance were conducted using the Student’s t-test for continuous variables and the chi-square test or Fisher’s exact test for categorical variables. Survival rates free from AF were calculated using the Kaplan–Meier method. Comparison of survival curves between groups was assessed with a two-sided Mantel–Haenszel (log-rank) test. Univariate and multivariate logistic regression analyses were used to determine the clinical factors that were associated with AF recurrence. Variables with a \(P\) value \(<0.10\) in the univariate models were included in the multivariate analysis. All analyses were performed using SPSS for Windows version 15.0.

**Results**

**Baseline and procedural characteristics**

Of the 101 patients who underwent initial ablation for paroxysmal AF during the study period, 88 patients were enrolled in this study. We excluded eight patients because of inappropriate P-SAECG recordings due to AF or frequent atrial premature beats, or overlap between the end of P-wave and the beginning of QRS complex. Other reasons for exclusion were prior cardiac surgery (three patients) and a previously implanted permanent pacemaker (two patients).

Study patients were divided into two groups based on the presence \((n = 37)\) or absence \((n = 51)\) of ALP in the baseline P-SAECG. As shown in Table 1, there were no differences in the baseline characteristics between the two groups.

Pulmonary vein isolation was completed in all patients. Cavo-tricuspid isthmus ablation was performed in 13 (35\%) patients with ALP and 16 (31\%) patients without ALP \((P = 0.71)\).

**Association between atrial late potential and delayed pulmonary vein potentials**

Prior to ablation, we investigated the latest atrial and PV activation sites during sinus rhythm among the electrodes positioned in the superior vena cava, right atrium, coronary sinus, and LA-PV junctions. The latest activation site was located at one of four PVs in 69 of 88 (78\%) patients and mitral isthmus in 19 (22\%) patients.

More patients with the latest activation site at one of four PVs demonstrated pre-procedural ALP than those with latest activation at some other site \([34 of 69 (49\%)\) vs. 3 of 19 (16\%) patients, respectively, \(P = 0.009\)].

**Impact of pulmonary vein isolation on P-wave morphology**

Changes in P-SAECG parameters after PV isolation are shown in Table 2. The decrease in PWD was larger in patients with than without pre-procedural ALP \((14 \pm 19 \text{ vs. } 3 \pm 12, \text{ respectively, } P = 0.003)\). Atrial late potential disappeared after PV isolation in 20 of 37 (54\%) patients who had pre-procedural ALP, although a residual ALP was observed in 17 (46\%) patients (Figure 1). On the other hand, in 9 of 51 (18\%) patients without ALP at baseline, a new ALP was observed after ablation.

**Table 1 Baseline characteristics**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre-procedural ALP</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With (n = 37)</td>
<td>Without (n = 51)</td>
</tr>
<tr>
<td>Age, years</td>
<td>62 \pm 11</td>
<td>65 \pm 11</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>28 (76)</td>
<td>30 (59)</td>
</tr>
<tr>
<td>Period of atrial fibrillation, months</td>
<td>45 \pm 40</td>
<td>43 \pm 40</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>21 (57)</td>
<td>38 (75)</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>5 (14)</td>
<td>5 (10)</td>
</tr>
<tr>
<td>Antiarrhythmic drugs</td>
<td>28 (76)</td>
<td>36 (71)</td>
</tr>
<tr>
<td>Class I, n (%)</td>
<td>1 (3)</td>
<td>5 (10)</td>
</tr>
<tr>
<td>Class III, n (%)</td>
<td>35 \pm 4</td>
<td>37 \pm 6</td>
</tr>
<tr>
<td>Left atrial diameter, mm</td>
<td>69 \pm 9</td>
<td>68 \pm 10</td>
</tr>
<tr>
<td>Left ventricular ejection fraction, %</td>
<td>20 ms.</td>
<td>21b 130</td>
</tr>
<tr>
<td>Computed tomography</td>
<td>Left atrial volume, cm(^3)</td>
<td>79 \pm 24</td>
</tr>
<tr>
<td></td>
<td>Left atrial emptying fraction, %</td>
<td>36 \pm 12</td>
</tr>
</tbody>
</table>

\*ALP was defined as a PWD \(\geq\) 130 ms and a RMS\(_{20}\) \(\leq\) 2.0 \(\mu\)V.

\(A_{LP}\), atrial late potential; PWD, P-wave duration; RMS\(_{20}\), root-mean-squared voltages of the terminal 20 ms.

**P-wave signal-averaged electrocardiogram parameters and atrial fibrillation recurrence**

Among the total study population, AF recurred in 26 of 88 patients (30\%) during a mean follow-up period of 16 \pm 4 months. The AF

**Table 2 Comparison of P-SAECG parameters between patients with and without pre-procedural ALP**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre-procedural ALP</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With (n = 37)</td>
<td>Without (n = 51)</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>Baseline</td>
<td>67 \pm 12</td>
</tr>
<tr>
<td></td>
<td>After ablation</td>
<td>89 \pm 18(^a)</td>
</tr>
<tr>
<td>PWD (ms)</td>
<td>Baseline</td>
<td>159 \pm 19</td>
</tr>
<tr>
<td></td>
<td>After ablation</td>
<td>146 \pm 21(^b)</td>
</tr>
<tr>
<td>RMS(_{20}) ((\mu)V)</td>
<td>Baseline</td>
<td>1.3 \pm 0.5</td>
</tr>
<tr>
<td></td>
<td>After ablation</td>
<td>2.5 \pm 1.5(^a)</td>
</tr>
<tr>
<td>Post-procedural ALP</td>
<td>17 (46%)</td>
<td>9 (18%)</td>
</tr>
</tbody>
</table>

\(A_{LP}\), atrial late potential; PWD, P-wave duration; RMS\(_{20}\), root-mean-squared voltages of the terminal 20 ms.

\(^a\) \(P < 0.05\).

\(^b\) \(P < 0.0005\).
recurrence rate was similar between patients with and without pre-procedural ALP (27 vs. 31%, respectively, \( P = 0.66 \)); however, it was significantly higher in patients with than without post-procedural ALP (54 vs. 19%, \( P = 0.001 \)). Figure 2 shows Kaplan–Meier curves for survival free from AF recurrence based on the presence or absence of post-procedural ALP. The AF recurrence rate was significantly higher in patients with than without post-procedural ALP.

There were no differences in the following P-SAECG parameters between patients with and without AF recurrence: baseline PWD (146 ± 23 vs. 144 ± 21 ms, respectively, \( P = 0.65 \)), baseline RMS20 (3.8 ± 3.1 vs. 3.7 ± 2.7 \( \mu \)V, \( P = 0.85 \)), PWD after ablation (143 ± 23 vs. 135 ± 18 ms, \( P = 0.11 \)), RMS20 after ablation (3.5 ± 2.4 vs. 3.8 ± 2.2 \( \mu \)V, \( P = 0.60 \)), change in PWD after ablation (−4 ± 19 vs. −10 ± 15 ms, \( P = 0.12 \)), and change in RMS20 after ablation (−0.5 ± 2.0 vs. 0.1 ± 2.3 \( \mu \)V, \( P = 0.34 \)).

Among 37 patients with pre-procedural ALP, AF recurrence was observed more frequently in patients with than without post-procedural ALP after ablation [8 of 17 (47%) vs. 2 of 20 (10%) patients, respectively, \( P = 0.02 \)]. Figure 3 shows that

**Figure 2** Kaplan–Meier curves for survival free from AF recurrence Kaplan–Meier curves for survival free from AF recurrence in patients with and without post-procedural ALP are depicted. Patients with post-procedural ALP demonstrated higher risk of AF recurrence than those without it (\( P = 0.0007 \) by log rank test). AF, atrial fibrillation; ALP, atrial late potential.

**Figure 3** Changes of P-SAECG parameters after ablation: association with AF recurrence Pre- and post-procedural PWD and RMS20 stratiﬁed according to the presence or absence of AF recurrence are shown. Among patients with pre-procedural ALP, a shortening of PWD and an increase in RMS20 were observed only in patients without AF recurrence, but not in those with AF recurrence (A, B). In patients without pre-procedural ALP, PWD did not change and RMS20 decreased irrespective of AF recurrence (C, D). \(^*P < 0.05\) compared between patients with and without AF recurrence. P-SAECG, P-wave signal-averaged electrocardiogram; AF, atrial fibrillation; ALP, atrial late potential; PWD, P-wave duration; RMS20, root-mean-squared voltages of the terminal 20 ms.
Discussion

We investigated the impact of PV isolation on P-wave morphology in 37 paroxysmal AF patients with and 51 without pre-procedural ALP. The main findings of this study were as follows. Patients with pre-procedural ALP had delayed PV potentials more frequently than those without pre-procedural ALP. Pulmonary vein isolation eliminated pre-procedural ALP in a substantial number of patients, although it sometimes caused post-procedural ALP in patients without pre-procedural ALP. Furthermore, the presence of post-procedural ALP independently predicted AF recurrence. As far as we know, this is the first report evaluating the association between ALP and AF recurrence after ablation.

Atrial late potential in paroxysmal atrial fibrillation patients

In this study, pre-procedural ALP was observed in 42% of the study population that included only paroxysmal AF patients scheduled for catheter ablation. Previous studies reported a highly variable prevalence of ALP in paroxysmal AF patients. When the definition of ALP was a PWD of > 120 ms and an RMS of ≥ 3.5 μV, 90% of paroxysmal AF patients demonstrated ALP. When the criterion for ALP was a PWD of ≥ 145 ms and an RMS of < 3.0 μV, only 19% of paroxysmal AF patients had ALP. In addition to different definitions of ALP, a different severity of atrial electrical remodelling among the study populations in these previous studies may account for the variable prevalence of ALP.

Table 3 Clinical and P-wave signal averaged electrocardiogram parameters associated with recurrence of atrial fibrillation

<table>
<thead>
<tr>
<th>Variables</th>
<th>Univariable</th>
<th>Multivariable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
</tr>
<tr>
<td>Age</td>
<td>1.05</td>
<td>0.97–1.13</td>
</tr>
<tr>
<td>Male gender</td>
<td>1.40</td>
<td>0.24–8.24</td>
</tr>
<tr>
<td>Hypertension</td>
<td>2.17</td>
<td>0.46–10.2</td>
</tr>
<tr>
<td>Period of atrial fibrillation</td>
<td>0.996</td>
<td>0.98–1.02</td>
</tr>
<tr>
<td>Left atrial volume</td>
<td>1.03</td>
<td>0.997–1.07</td>
</tr>
<tr>
<td>Pre-procedural ALP</td>
<td>0.81</td>
<td>0.32–2.07</td>
</tr>
<tr>
<td>Post-procedural ALP</td>
<td>4.86</td>
<td>1.80–13.2</td>
</tr>
</tbody>
</table>

Variables with a P value ≤ 0.10 in the univariable model were included in the multivariable analysis.

OR, odds ratio; CI, confidence interval.

Predictors of atrial fibrillation recurrence

We assessed whether a post-procedural ALP predicted AF recurrence even after adjustment for other associated factors using univariate and multivariate analyses. As shown in Table 3, post-procedural ALP was independently associated with future AF recurrence (odds ratio = 4.22, 95% confident interval = 1.52–11.7).

The presence of post-procedural ALP predicted AF recurrence with a sensitivity of 54%, specificity of 91%, and positive predictive accuracy of 73%.

Post-procedural atrial late potential and left atrial-pulmonary vein reconnection

We performed a second AF ablation in nine (10%) patients at 5 ± 2 months after the initial ablation; three of these patients had pre-procedural ALP at baseline and six did not have pre-procedural ALP. All three patients with pre-procedural ALP had residual ALP after the initial ablation, and demonstrated LA-PV reconnection at the time of the second ablation. In the six patients without pre-procedural ALP, three patients demonstrated post-procedural ALP by P-SAECG recorded on the day after the initial ablation, and all of six patients had reconnected LA-PV conduction and PV activation that occurred later than any other atrial sites recorded at the time of the second ablation.

Compared with baseline, the PWD was shorter after ablation in patients without AF recurrence (158 ± 18 vs. 140 ± 14 ms, respectively, P < 0.0001); however, it remained unchanged in those with AF recurrence (163 ± 21 vs. 161 ± 29 ms, P = 0.80). In addition, post-procedural PWD was significantly longer in patients with AF recurrence than in those without it (161 ± 29 vs. 140 ± 14 ms, respectively, P = 0.009). Furthermore, compared with baseline, a significant increase in RMS20 was observed in patients without AF recurrence (1.3 ± 0.5 vs. 2.7 ± 1.4 μV, respectively, P < 0.0001), although it was not observed in those with AF recurrence (1.4 ± 0.5 vs. 1.8 ± 1.7 μV, P = 0.38).

Among patients without pre-procedural ALP, more patients with than without post-procedural ALP had AF recurrence [6 of 9 (67%) vs. 10 of 42 (24%), respectively, P = 0.02]. Compared with baseline, PWD did not change in patients with AF recurrence (136 ± 17 vs. 133 ± 13 ms, respectively, P = 0.36) or those without AF recurrence (133 ± 15 vs. 129 ± 20 ms, P = 0.07), as demonstrated in Figure 3. In addition, compared with baseline, RMS20 decreased in both patients with AF recurrence (5.3 ± 3.0 vs. 4.2 ± 2.5 μV, respectively, P = 0.04) and those without AF recurrence (5.5 ± 2.3 vs. 4.7 ± 2.3 μV, P = 0.04).

Impact of pulmonary vein isolation on atrial late potentials
Okumura et al.\(^7\) reported that the latest atrial activation site was located within the PVs in most cases. In addition, they suggested that \(A_{LP}\) was derived from delayed activation of the muscle sleeves within the PVs, and that successful PV isolation eliminated \(A_{LP}\). In contrast, other studies reported that different regions of the atrium contributed to the terminal portion of P-wave.\(^{12,13}\) These inconsistent results may be attributed to a variety of atrial activation sequences among patients with paroxysmal AF. Our results suggest that delayed activation of PV muscle sleeves is the cause of \(A_{LP}\).

Our hypothesis was that \(A_{LP}\) would disappear after the disconnection of LA-PV conduction by ablation in the majority of study patients with pre-procedural \(A_{LP}\). In this study, residual \(A_{LP}\) after PV isolation was associated with AF recurrence and reconnection of LA-PV conduction in all three patients that required a second AF ablation. These results suggest that PV isolation eliminated \(A_{LP}\) derived from delayed PV potentials and that residual \(A_{LP}\) represented delayed PV potentials derived from LA-PV reconnection.

An interesting finding in the present study was that a new \(A_{LP}\) was found after PV isolation in nine patients without pre-procedural \(A_{LP}\). We speculate that delayed LA-PV conduction caused by an incomplete PV isolation resulted in the appearance of \(A_{LP}\) after ablation. However, in six patients without pre-procedural \(A_{LP}\) that required a second AF ablation, only three patients demonstrated post-procedural \(A_{LP}\) in spite of the presence of delayed PV potentials due to LA-PV reconnection in all six patients. Since the post-procedural P-SAECG was recorded on the day after the first ablation, this may have been too early to detect reappearance of delayed PV potentials. It is also possible that the amplitude of these reconnected PV potentials was too small to be recorded by P-SAECG, and/or activation of the reconnected PV was delayed so much that the late potentials in the P-SAECG were hidden by the QRS complex.

**Prediction of atrial fibrillation recurrence using P-wave signal-averaged electrocardiogram**

We demonstrated that \(A_{LP}\) observed on the day after ablation predicted future AF recurrence. Our ablation procedure included PV isolation in all patients, but did not include any LA linear ablation or defragmentation. Therefore, post-procedural \(A_{LP}\) was assumed to originate from acutely reconnected PV potentials.

Several studies reported that early LA-PV reconnection occurred 30–60 min after the completion of PV isolation;\(^{14,15}\) however, there is no information on the timing of post-procedural LA-PV reconnection that accounts for AF recurrence. The results of this study demonstrated that residual \(A_{LP}\) in the P-SAECG recorded on the day after ablation predicted future AF recurrence, and this suggests that substantial LA-PV reconnection may occur within 1 day after ablation.

Other predictors of AF recurrence using P-SAECG were reported previously. Okumura et al. reported that a pre-procedural PWD of \(>150\) ms predicted AF recurrence after PV isolation; however, we could not verify this. This discrepancy is possibly due to a difference in study populations; our study population consisted of paroxysmal AF, whereas 20% of their study population was persistent AF patients. Generally, electrical and anatomical remodelling of the atria is greater in persistent AF than in paroxysmal AF patients. Atrial scarring outside the isolated PVs and atrial conduction delay due to advanced atrial remodelling might have been more closely related to AF recurrence in their study population. Shortening of PWD after PV isolation was also reported to be a predictor of successful AF ablation.\(^{16,17}\) This finding was similar to our result that residual \(A_{LP}\) after ablation was a predictor of AF recurrence. However, theoretically, PV isolation should shorten PWD only in patients with delayed PV potentials prior to ablation. In this study, therefore, we distinguished patients with delayed PV potentials prior to ablation from those without delayed PV potentials based on the presence of pre-procedural \(A_{LP}\).

**Clinical implications**

This study showed that post-procedural \(A_{LP}\) is a useful predictor of AF recurrence after PV isolation only in patients with pre-procedural \(A_{LP}\). Precise estimation of AF recurrence risk may improve clinical management of patients performed with AF ablation.

**Limitations**

There are several limitations of this study. Measurement of P-SAECG is sometimes difficult because of the noise from environmental electromagnetic interference, inappropriate cardiac rhythm, or overlap between the end of the P-wave and the beginning of QRS complex. Therefore, we excluded 8 of 101 (8%) patients in whom P-SAECG was not measured appropriately, and selection bias may exist. In addition, our definition of \(A_{LP}\) was arbitrary because there are no established criteria for \(A_{LP}\). In addition, we determined the latest atrial and PV activation site using a limited number of catheters, and did not map the entire atrium and PVs. Hence, it is possible that our results of the latest activation site were not accurate. Furthermore, the P-SAECG was recorded only at 1 day after ablation, and we did not obtain any recordings after a longer duration of follow-up.

**Conclusion**

In patients with paroxysmal AF, PV isolation may eliminate pre-procedural \(A_{LP}\) in a substantial number of patients, although it would sometimes cause the emergence of post-procedural \(A_{LP}\) in patients without pre-procedural \(A_{LP}\). Post-procedural \(A_{LP}\) may be associated with an increased risk of future AF recurrence.

**Conflict of interest:** none declared.

**References**


