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ORIGINAL ARTICLE

Dynamic changes in signal-averaged P wave after catheter ablation of atrial fibrillation

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Abstract

Background: The comprehensive surveillance for interval changes in signal-averaged P-wave (SAPW) after pulmonary vein isolation (PVI) remains lacking. We aimed to analyze the SAPW parameters before and after PVI and explored their link to the left atrial electrical properties.

Methods: Eighteen patients with paroxysmal atrial fibrillation receiving primary catheter ablation were enrolled. SAPW parameters, including root mean square voltages in the last 40, 30, and 20 ms (RMS40, RMS30, and RMS20, respectively), the total P-wave (RMSt), the integral of P-wave potentials (Int-p), and P-wave duration (fPWD), were measured before and after PVI and correlated to the left atrial activation time (LAT) and mean left atrial voltage (LAV) from electro-anatomical mapping.

Results: Compared with the SAPW before PVI, fPWD (before vs after PVI: 144.1 ± 5.2 vs 135.1 ± 11.9 ms, p = 0.02), Int-p (687.4 ± 173.1 vs 559 ± 202.5 mVms, p = 0.01), and RMSt (6.44 ± 1.3 vs 5.44 ± 2.0 mV, p = 0.04) all decreased after PVI. RMS20, RMS30, and RMS40 showed no significant difference. Similarly, LAT (97.5 ± 9.3 vs 90.5 ± 9.3 ms, p = 0.008) and LAV (1.37 ± 0.27 vs 0.96 ± 0.31 mV, p = 0.001) decreased after PVI. Although consistent changes after PVI were observed between SAPW parameters and LAT or LAV, no linear correlation was observed among them.

Conclusion: The consistent changes in SAPW and left atrial electrical properties after PVI suggest that SAPW may be used as a noninvasive tool to monitor the responses to PVI.

Keywords: Atrial fibrillation; Left atrial activation time; Pulmonary vein isolation; Signal-averaged ECG

1. INTRODUCTION

Four pulmonary vein (PV) isolations (PVIs) by catheter ablation are considered as a standard therapy for atrial fibrillation (AF); these PVIs dramatically change atrial electrophysiology.[1] A noninvasive test to detect the functional changes in atrial electrophysiological properties may be used to detect the dynamic alternation after PVI and predict its recurrence. Signal-averaged P-wave (SAPW) measurement from the non-invasive electrocardiography (ECG) analysis of signal-averaged ECG (SAECG) is one of the candidate tools. SAECG provides many measures of SAPW, including root mean square voltages in the last 40, 30, and 20 ms of the filtered P-wave (RMS40, RMS30, and RMS20), the root mean square voltage of the total filtered P-wave potentials (RMSt), the integral of filtered P-wave potential (Int-p), and filtered P-wave duration (fPWD). The fPWD is correlated to bi-atrial activation time.[2] SAPW can predict the recurrence of AF in patients receiving catheter ablation.[2–8] Long fPWD is associated with a high risk of AF recurrence in the patients with paroxysmal and persistent AF.[6]

PVI will dramatically change the atrial electrical and structural properties; thus, two studies had worked on this issue and compared the interval changes in SAPW parameters before and after catheter ablation.[2,4] A shortened fPWD and increased RMS20 can be observed after catheter ablation. A reduced fPWD is associated with reduced AF recurrence.[2] The fPWD and RMS20 before catheter ablation are independent predictors for AF recurrence.[4] However, most studies focused on the clinical correlation of fPWD, and other parameters were mostly overlooked. A comprehensive surveillance of interval changes among these parameters before and after catheter ablation remains lacking. In addition, whether the changes in the left atrial electrical properties after PVI are linked to SAPW parameters remains unclear. The present study aimed to comprehensively analyze the SAPW parameters before and after PVI and explore its potential link to the left atrial electrical properties from electro-anatomical mapping.

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2. METHODS

The present study involved 18 patients with AF and who received catheter ablation for paroxysmal AF in Taipei Veterans General Hospital, Taipei, Taiwan.[9] Only the patients receiving the primary procedure for AF ablation were included. SAECG was performed in supine position during sinus rhythm 1 day before and after catheter ablation. The SAPW parameters before and after catheter ablation were compared to clarify the interval changes and correlated to intracardiac electrophysiological characteristics from three-dimensional (3D) electro-anatomical mapping. Patients who had AF during SAECG examination were excluded from this study. Ethical approval was granted by the Institutional Review Board of Taipei Veterans General Hospital, Taipei, Taiwan.

2.1. Signal-averaged ECG

The basic methodology of P-SAECG has been described previously.[10] The filtered P-wave measurements of SAPW were recorded in P-wave-triggered mode (MAC 5500 HD 12 SL Marquette; GE Healthcare, Chicago, USA). The P-wave signals (>250 beats) were recorded from a standard 12-lead ECG until the noise amplitude was reduced to <1 μV. These signals were amplified and filtered between 40 and 250 Hz using a bidirectional filter. P wave complexes acquired in X, Y, and Z leads were combined to a vector magnitude of $\sqrt{X^2+Y^2+Z^2}$. The SAPW measurements included the RMS40, RMS30, and RMS20; RMSt, Int-p, and fPWD. The fPWD was further verified by manual measurement of each lead by two independent investigators who were blinded to the patients' clinical data.

2.2. Catheter ablation for AF

The detailed protocol of the electrophysiology and ablation procedure used has been described in detail previously.[11] In brief, all patients underwent a standardized electrophysiological study in a fasting state. The antiarrhythmic agents except for amiodarone were withdrawn for at least five half-lives before the ablation procedure. The trans-septal puncture under the guidance of right atriography, a decapolar circular, or multielectrode catheter was placed in the left atrium (LA) through the femoral venous access. The electroanatomic geometries and contact voltage maps of LA were constructed using a 3D navigation system (NavX system from Abbott Medical, Minnetonka, MN, USA or Carto 3 System from Biosense Webster, Diamond Bar, CA, USA). Left atrial activation mapping and LA voltage mapping were performed before ablation. The total left activation time (LAT) was calculated by subtracting the latest atrial activated point to the earliest atrial activation point inside the LA. Mean left atrial voltage (LAV) was calculated by measuring the voltage of each point collected in LA and 4 PVs which was presented by mean data of voltage. PVI was performed in all patients. Continuous circumferential lesions were created by encircling the atrial side of the bilateral PV antra with either Tacticath ablation catheter (Abbott Medical) or SmartTouch (Biosense Webster) guided by a NavX or Carto system. Radiofrequency energies up to 50 (anterior wall) and 40 W (posterior wall) were applied for 10 seconds for each lesion. Successful PVI was confirmed by obtaining the bidirectional block, the entrance and exit blocks of the PVs, absence of any electrical activity inside the PV, or dissociated PV activity. After PVI, contact voltage mapping as well as activation mapping of LA was repeated. A right atrial cavotricuspid isthmus ablation was routinely performed at the end of the AF procedure, and bidirectional conduction block of linear ablation was confirmed.

2.3. Statistical analysis

Continuous variables are expressed as mean ± SD. The parameters before and after catheter ablation were compared by paired t-test. Pearson's correlation coefficients were used to determine the correlation between parameters. Categorical data were compared using Chi-square test. Analysis was performed using IBM SPSS statistic version 24. p-value <0.05 was considered statistically significant.

3. RESULTS

3.1. Study population

Eighteen patients (age: 53 years ± 10.8 years old) were enrolled for the analysis. Table 1 shows the baseline characteristics of the patients. Non-PV triggers were observed in six patients, who received the isolation of superior vena cava (n = 5) or ablation of mid-crista terminalis (n = 1). Clinically relevant atypical roof flutter was observed in one patient, who received the ablation over roof line.

3.2. SAPW measurements before and after catheter ablation

Fig. 1 shows the representative SAPW. The SAPW measurements were compared before and after catheter ablation (Fig. 2). After catheter ablation, the fPWD decreased from 144.1 ± 5.2 ms to 135.1 ± 11.9 ms (p = 0.02). The Int-p reduced significantly from 687.4 ± 173.1 mVms to 559 ± 202.5 mVms (p = 0.01). The voltage of RMSt decreased from 6.44 ± 1.3 mV to 5.44 ± 2.0 mV (p = 0.04). However, the RMS40, RMS30, and RMS20 showed no significant difference (RMS40: 4.6 ± 2.0 vs 4.3 ± 2.4 mV, p = 0.651; RMS30: 3.7 ± 1.7 vs 3.7 ± 2.1 mV, p = 1.00; RMS20: 3.3 ± 1.7 vs 3.1 ± 2.1 mV, p = 0.816).

3.3. Intracardiac electrical properties before and after catheter ablation

The LAT and LAV before and after catheter ablation were collected and compared during sinus rhythm (n = 10) (Fig. 3). The collecting points for the activation time and voltage were 2281 ± 883 points before ablation and 2537 ± 1194 points after ablation. We performed electro-anatomical mapping again after ablation for the LA and 4 PVs. Compared with the LAT before PVI, the LAT decreased after ablation (97.5 ± 9.3 vs 90.5 ± 9.3 ms, p = 0.008). The latest activation sites before PVI were inside the PVs (left superior PV, n = 1; left inferior PV, n = 8) or on the inferior ridge between the left atrial appendage and left PVs (n = 1). After PVI, the latest activation sites were posterolateral mitral annulus (n = 3) or on the inferior ridge between the left atrial appendage and left PVs (n = 7). Significant changes in the latest activation site before and after PVI (p < 0.001) were probably related to the interval changes in LAT after catheter ablation. The reduction in

Table 1

Baseline characteristics of study population

Parameters	Study population (n = 18)
Age (y)	53.3 ± 10.8
Male, n (%)	12 (66.7%)
Left atrial diameter (mm)	36.4 ± 4.9
Left ventricular ejection fraction (%)	55.3 ± 16.8
Diabetes mellitus, n (%)	0 (0%)
Hypertension, n (%)	4 (22.4%)
Coronary artery disease, n (%)	1 (5.6%)
Stroke, n (%)	3 (16.7%)
Heart failure, n (%)	1 (5.6%)

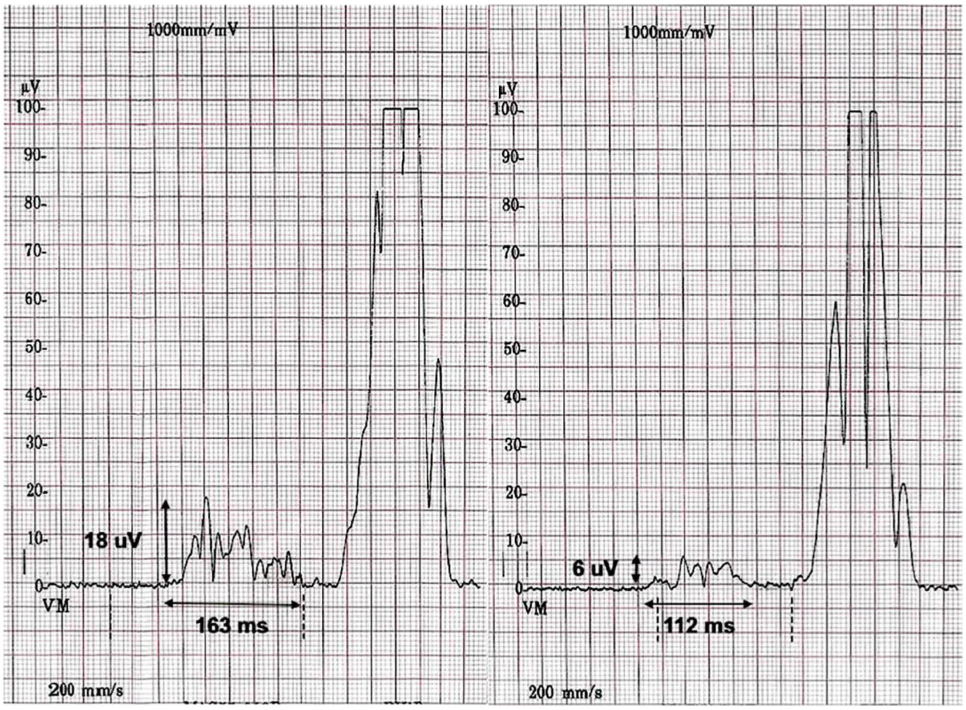

Fig. 1 Representative SAECG of filtered P-wave before and after catheter ablation. Compared with those before catheter ablation, the reduction in filtered P-wave amplitude and fPWD can be observed after catheter ablation. fPWD = filtered P-wave duration; SAECG = signal-averaged electrocardiography.

LAV was observed after PVI. The LAV (excluding 4 PVs) reduced from 1.37 ± 0.27 mV before ablation to 0.96 ± 0.31 mV after ablation (p = 0.001). If we included four PVs into consideration for the analysis of LAV, the interval changes of LAV remained significant (before and after catheter ablation, 1.37 ± 0.27 vs 0.64 ± 0.18 mV, p < 0.0001).

3.4. Correlation between SAPW and intracardiac electrical properties

The LAT before ablation was not correlated with any of the SAPW parameters and the LAV (Table 2). After catheter ablation, none of SAPW measurements showed correlation to the total LAT and mean LAV. The interval changes in LAT or LAV after PVI were not correlated to the SAPW measurements after PVI (Table 3).

4. DISCUSSION

The present study comprehensively addressed the interval changes in SAPW and its correlation to intracardiac left atrial electrical properties. PVI reduced fPWD, Int-p, RMSt, LAT, and LAV. Simultaneous interval changes in SAPW and intracardiac electrical properties were observed. These results provide insights to the contributing roles of four PVs to SAPW.

4.1. LAT and SAPW

The fPWD was shortened after PVI, which was consistent with the result of previous studies.[2,4] The differences in fPWD after catheter ablation were subtle (around 10 ms) in the present study, similar to those of previous reports. From computer simulation, Ogawa et al. suggested that the shortening of fPWD can be attributed to the changes in atrial activation pattern. The latest activation site changed from the left inferior PV before catheter ablation to the inferior portion of the LA.[2] In their report, the magnitude of shortening of LAT was less than the average shortening observed in fPWD, suggesting that the changes in the latest activation time probably partially explained the reduction of fPWD. Our data provide direct evidence from the electroanatomical mapping. The LAT was reduced after PVI. The latest activation sites changed from mostly the left inferior PV to the inferior portion of LA. This result echoed the findings from computer simulation. PVI changed the left atrial activation pattern, which contributed to the fPWD reduction after catheter ablation.

4.2. LAV and SAPW

The ablation line encircling the PVs can reduce the quantitative voltage inside the PVs at around 81% to 88% compared with the voltage before ablation.[12] Pappone et al showed that PVI can create a low-voltage zone inside the encircled ablation area. The surface area of the new low-voltage area after PVI accounted for around 23% ± 9% of the left atrial surface.[1] The present study showed a reduction in the mean LAV after PVI. The reduction of mean LAV excluding the PV showed that the ablation points along the antrum area gives a significant contribution to the decrease of mean LAV. Given the SAPW measurements, RMSt is the root mean square voltage of the total filtered P-wave, and Int-p is the area under the curve of vector magnitude curve from filtered P-wave onset to offset. Both are relevant parameters to P-wave voltage. Therefore, we hypothesized that these parameters of filtered P-wave can be correlated to LAV from electroanatomical mapping. The present study showed that the voltage of RMSt and Int-p simultaneously reduced after catheter ablation, which was concurrent with the reduction of LAV. However, no linear correlation was observed in either the baseline value or interval changes in RMSt and Int-p and those of LAV. The LAT was also not correlated to fPWD in Pearson correlation. These findings suggest the complex interactions behind these parameters and their probably nonlinear correlation.

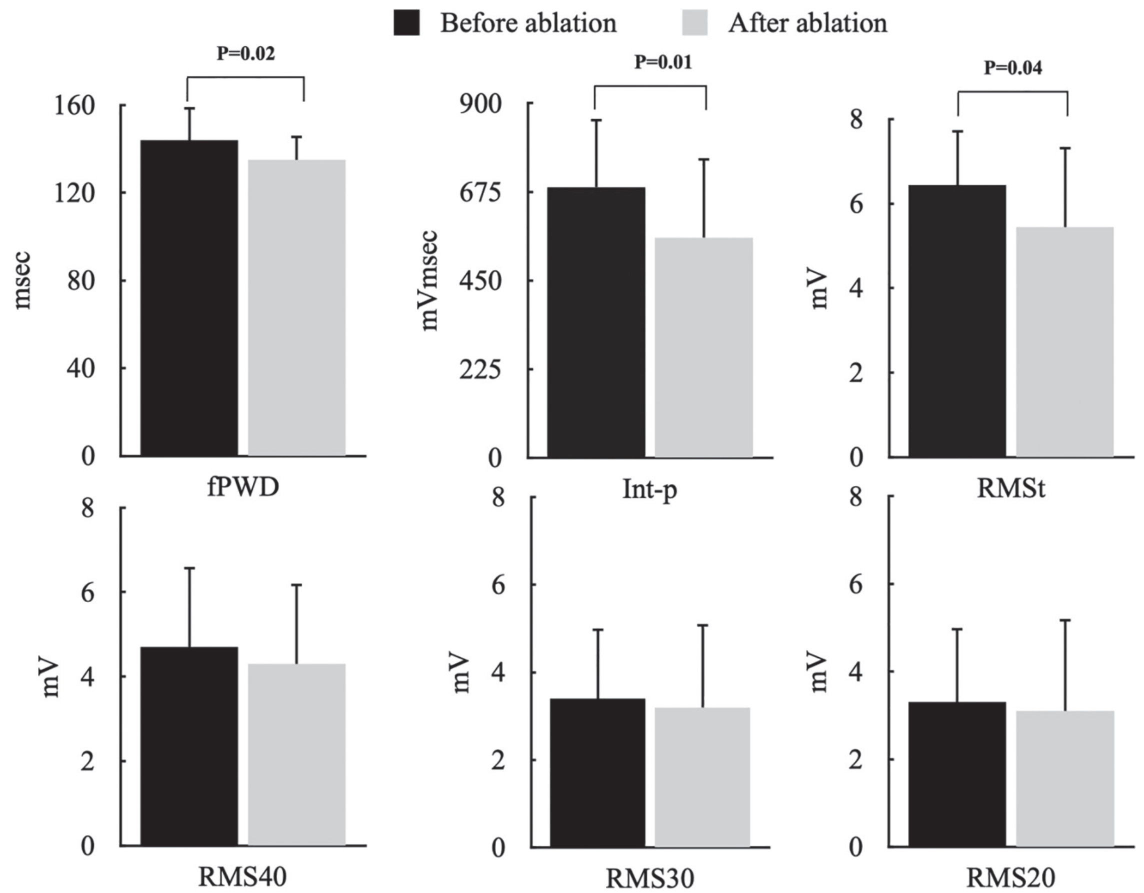

Fig. 2 Comparisons of SAPW measurements before and after catheter ablation. Int-p, RMSt, mean LAV, and fPWD significantly decreased after ablation. fPWD = filtered P-wave duration; Int-p = Integral P-wave; RMSt = root mean square total of P-wave; RMS40 = root mean square 40 ms; RMS30 = root mean square 30 ms; RMS 20 = root mean square 20 ms; LAT = left atrial activation time; PV = pulmonary vein; SAPW = signal-averaged P-wave.

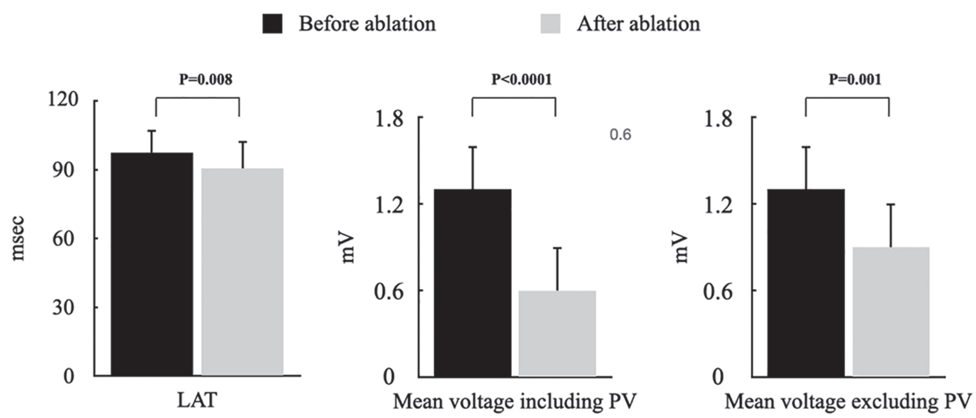

Fig. 3 Comparisons of LAT and mean LAV before and after catheter ablation. LAT and LAV (with/without PVs) all decreased after catheter ablation. LAT = left atrial activation time; LAV = left atrial voltage.

The simultaneous interval changes in intracardiac electrical properties and SAPW suggest that SAPW may be applied as a non-invasive tool to monitor the responses of successful PVI and predict future risk of AF recurrence.[6] Moreover, this non-invasive measurement could be applied as a part of the preoperative evaluation, different ablation strategies could be arranged in those with extremely high risk for recurrence after catheter ablation. Furthermore, anticoagulants after the procedure could also be one of the future applications. Those patients with no interval changes of SAPW after catheter ablation should be closely monitored for their cardiac rhythm and drug compliance of anticoagulants to reduce the risk of stroke.

4.3. Limitations

This study focused on the changes of signal-averaged P wave after catheter ablation. Although the interval changes after

Table 2

Correlation between LAV and LAT to SAECG parameters before and after ablation

	LAT before	*p*	Voltage before	*p*	LAT after	*p*	Voltage after	*p*
fPWD	0.122	0.737	−0.267	0.456	0.102	0.799	−0.166	0.646
Int-p	0.511	0.131	0.148	0.648	0.405	0.246	0.394	0.259
RMSt	0.391	0.264	0.188	0.602	0.526	0.119	0.570	0.072
RMS40	0.256	0.475	−0.093	0.799	0.405	0.246	0.348	0.324
RMS30	0.099	0.785	−0.235	0.514	0.473	0.167	0.261	0.466
RMS20	0.154	0.591	0.168	0.644	0.383	0.275	0.254	0.479

fPWD = filtered P-wave duration; Int-p = integral P-wave; RMSt = root mean square total of P-wave; RMS40 = root mean square 40 ms; RMS30 = root mean square 30 ms; RMS20 = root mean square 20 ms; LAT = left atrial activation time; LAV = left atrial voltage; SAECG = signal-averaged electrocardiography.

Table 3

Correlation between interval changes in SAPW measurements and intracardiac electrical properties

	LAT difference	*p*	Voltage difference	*p*
fPWD difference	−0.250	0.486	0.042	0.908
Int-p difference	0.423	0.224	−0.287	0.421
RMSt difference	0.558	0.094	−0.399	0.254
RMS40 difference	−0.59	0.872	0.017	0.963
RMS30 difference	0.550	0.879	−0.069	0.251
RMS20 difference	0.148	0.684	−0.121	0.740

fPWD = filtered P-wave duration; Int-p = integral P-wave; RMSt = root mean square total of P-wave; RMS40 = root mean square 40 ms; RMS30 = root mean square 30 ms; RMS20 = root mean square 20 ms; LAT = left atrial activation time; LAV = left atrial voltage; SAPW = signal-averaged P-wave.

catheter ablation were significant, the patient number in the present study remains limited. A large number of patients should be enrolled to validate the results further. The ablation outcome of the enrolled patients might be analyzed in the future prospective cohort to evaluate the predictive value of signal-averaged P wave for recurrent AF.

In conclusion, the interval changes in SAPW after PVI were consistent with the alterations in the intracardiac electrical properties of LA, which suggest that SAPW may be used as a noninvasive tool to monitor the responses of catheter ablation.

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