MEDICAL SCIENCE MONITOR

CLINICAL RESEARCH

e-ISSN 1643-3750
© Med Sci Monit, 2016; 22: 2616-2623
DOI: 10.12659/MSM.896675

Received: 2015.11.13
Accepted: 2015.12.29
Published: 2016.07.24

Novel P Wave Indices to Predict Atrial Fibrillation Recurrence After Radiofrequency Ablation for Paroxysmal Atrial Fibrillation

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Source of support: This work was supported by the Science and Technology Research and Development Program of Guangdong Province (Grant No. 2012B031800296) and the Sun Yat-Sen University Clinical Research 5010 Program (No. 2007011)

Background: Circumferential pulmonary vein isolation (CPVI) is a widely used treatment for paroxysmal atrial fibrillation (AF). Several P wave duration (PWD) parameters have been suggested to predict post-ablation recurrence, but their use remains controversial. This study aimed to identify novel P wave indices that predict post-ablation AF recurrence.

Material/Methods: We selected 171 consecutive patients undergoing CPVI for paroxysmal AF. Electrocardiography (ECG) recordings were obtained at the beginning and the end of ablation. PWD was measured in all 12 leads. The PWD variation was calculated by subtracting the pre-ablation PWD from the post-ablation PWD.

Results: PWD was significantly shortened in leads II, III, aVF, and V1 after ablation. During a mean follow-up of 19.96±4.32 months, AF recurrence occurred in 32 (18.7%) patients. No significant differences in baseline characteristics or pre- or post-ablation PWD were observed between the AF recurrence and non-recurrence groups. Patients with AF recurrence exhibited a smaller PWD variation in leads II (1.21(–0.56, 2.40) *vs.* –5.77(–9.10, –4.06) ms, P<0.001), III (–5.92(–9.87, 3.27) *vs.* –9.44(–11.89, –5.57) ms, P=0.001) and V1 (–4.43(–6.64, –3.13) *vs.* –6.33(–8.19,–4.59) ms, P=0.003). Multivariable logistic regression analysis demonstrated that smaller PWD variations in lead II and III were independent risk factors for AF recurrence. PWD variation ≥–2.21 ms in lead II displayed the highest combined sensitivity and specificity (85.29% and 83.94%, respectively) for predicting post-ablation AF recurrence. A PWD variation ≥0 ms displayed the best practical value in predicting AF recurrence.

Conclusions: PWD variation in lead II is an effective predictor of post-ablation AF recurrence.

MeSH Keywords: Atrial Fibrillation • Catheter Ablation • Electrocardiography

Full-text PDF: http://www.medscimonit.com/abstract/index/idArt/896675

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Background

Atrial fibrillation (AF) is one of the most common sustained cardiac arrhythmias observed in clinical practice [1]. AF is not immediately life-threatening but can result in significant complications if not properly treated. This arrhythmia can increase the risk of stroke and thrombus events. The irregular heartbeats can also cause atrioventricular desynchrony and hemodynamic disturbances, which are associated with congestive heart failure [2,3]. Given that pulmonary veins (PVs) are critical sites for AF initiation, circumferential pulmonary vein isolation (CPVI) is currently considered as the cornerstone ablation strategy for paroxysmal AF [4,5]. However, post-ablation AF recurrence remains high in some patients. Patients at risk of AF recurrence require additional therapy, emphasizing the importance of identifying these patients. Multiple independent factors related to post-ablation AF recurrence have been identified, including age, hypertension, $CHADS_2$ value, left atrium (LA) size, and several inflammation markers [6–11]. However, practical, quantitative, non-invasive markers are still lacking.

Electrocardiography (ECG) is a simple, non-invasive diagnostic method for establishing diagnosis and prognosis for cardiovascular disease. Previous studies [12–16] have identified aspects of P wave morphology, such as mean P wave duration (PWD), P wave dispersion, P terminal force and P wave area, as novel indicators of AF recurrence. However, accurately obtaining these data in clinical practice is difficult and discussion of the specific leads displaying the greatest diagnostic efficacy has been limited, hindering the application of these methods in clinical practice. Therefore, the aim of the present study was to identify feasible P wave indices that predict post-ablation AF recurrence.

Material and Methods

Study population

We retrospectively analyzed 171 consecutive patients who underwent initial catheter ablation for paroxysmal AF at the First Affiliated Hospital of Sun Yat-sen University from January 2013 to June 2014. Paroxysmal AF was defined as 2 or more episodes of recurrent AF terminating spontaneously within 7 days. The exclusion criteria were as follows: persistent or permanent AF, valvular heart disease, previous catheter ablation, pacemaker implantation, additional roofline, mitral isthmus line, tricuspid isthmus line, fractionated atrial electrogram ablation except CPVI, and poor-quality ECG. All patients were informed of the investigation and nature of the ablation strategy, and written informed consent for ablation was obtained. Of the 171 analyzed patients, 109 were male. Their mean age was 57.70±12.12 years, 69 had hypertension, and 23 had diabetes. The mean LA size was 34.57 mm. The $CHADS_2$ value was ≥2 in 32 patients and 110 (64.33%) patients were prescribed antiarrhythmic drugs prior to catheter ablation.

Radiofrequency catheter ablation procedure

All antiarrhythmic drugs except amiodarone were discontinued 2 weeks before the procedure. Amiodarone was discontinued 6 months prior to catheter ablation. All patients underwent a transesophageal echocardiogram to exclude intracardiac thrombus before ablation. The procedure was performed under sedation. For CPVI, 3-dimensional electro-anatomical mapping was performed using the Carto 3 system (Biosence Webster). Contiguous lesions were created at the level of the LA antrum (approximately 2 cm from the PV ostia) and encircling the right and left PVs using an open irrigation, 3.5-mm tip deflectable catheter (30–35 W; 43°C, 30–60 s at each point). The endpoint of CPVI was the isolation of all PV potentials, which was confirmed by Lasso catheter mapping during sinus rhythm or coronary sinus pacing. We reconfirmed pulmonary vein isolation with isoproterenol infusion before completing the procedure.

Post-ablation follow-up

After the procedure, anticoagulation was initiated using warfarin at a target international normalized ratio from 2.0 to 3.0, and was then maintained for 3 months in all patients. Subsequent warfarin administration was based on the $CHADS_2$ value. Patients unable to tolerate warfarin were prescribed novel oral anticoagulation drugs. Amiodarone was also administered for the first 3 months post-ablation. Amiodarone was discontinued afterward and restarted only if an arrhythmic event was documented. Outpatient follow-up were performed at 1 and 3 months post-ablation and every 3 months thereafter. ECG was performed at each visit. Holter monitor recordings were evaluated every 6 months, according to the 2012 HRS/EHRA/ECAS Expert Consensus Statement guidelines [4]. If a patient reported any symptoms of palpitations suggestive of arrhythmia recurrence, Holter or event monitor recordings were obtained. Three months was defined as the blanking period. AF recurrence was defined as any episode of AF at least 30 s in duration after the blanking period.

ECG recording and data analysis

Standard 12-lead ECG measurements were recorded during sinus rhythm at the beginning and the end of the ablation procedure. ECG data were obtained in the supine position under resting conditions. We recorded the ECG with a speed of 25 mm/s and 1 mV/cm standardization with a band pass filter for frequencies between 0.05 and 40Hz. ECGs were digitized and measured using Engauge Digitizer 5.1 software (M. Mitchell, Engauge Digitizer, *http://digitizer.source-forge.net*).

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Table 1. Characteristics of the patients included in this study.

Parameter	The all (n=171)	Recurrence (n=32)	Non-recurrence (n=139)	*P*
Age/years	57.70±12.12	60.25±11.28	57.12±12.27	0.188
Male (%)	109 (63.7%)	19 (59.4%)	90 (64.7%)	0.105
Hypertension (%)	69 (40.4%)	14 (43.8%)	55 (39.6%)	0.664
Diabetes (%)	23 (13.5%)	5 (15.6%)	18 (12.9%)	0.910
LA diameter, mm	34.57±5.89	34.75±6.55	36.53±5.75	0.846
EF (%)	67.88±7.23	69.13±6.13	67.59±7.45	0.280
BMI	24.01±3.31	23.74±3.31	24.07±3.32	0.626
CHADS2				0.574
0	79	13	66	
1	60	14	46	
≥2	32	7	25	
Prior AADs (%)	110 (64.33)	22 (68.75)	88 (63.31)	0.562
Metoprolol	24 (14.04)	4 (12.50)	20 (14.39)	1.000
Bisoprolol	71 (41.52)	13 (40.63)	58 (41.73)	0.909
Diltiazem	3 (1.75)	1 (3.13)	2 (1.44)	0.465
Verapamil	5 (2.92)	2 (6.25)	3 (2.16)	0.235
Amiodarone	3 (1.75)	1 (3.13)	2 (1.44)	0.465
Propafenone	4 (2.34)	1 (3.13)	3 (2.16)	0.567

AADs – antiarrhythmic drugs; BMI – body mass index; EF – ejection fraction; LA – left atrium.

All ECG recordings were measured by 2 independent readers who were blinded to this clinical research.

We measured PWD in 12 leads and expressed the results in milliseconds. When P waves exhibited biphasic forms, the latter negative phase was also included in the analysis. Briefly, PWD was defined as the time difference between P wave onset and offset from the equipotential reference line. The equipotential reference line was determined by the position of the interval between the T wave end and QRS complex. P wave onset was defined as the point of first visible upward departure from the reference line for positive waveforms or the point of first downward departure from the reference line for negative waveforms. The return to the equipotential reference line was considered to be the offset of the P wave.

In each lead, the mean value for 3 consecutive complexes was defined as the final PWD. The PWD variation was measured by subtracting the pre-ablation PWD from the post-ablation PWD ($PWD_{post} – PWD_{pre}$). The Pearson correlation coefficient for PWD data between 2 independent readers was 0.92 (P<0.001)

Statistical analysis

Statistical analysis was performed using SPSS 12.0 (SPSS Inc., Chicago, IL). Continuous variables are presented as means ± standard deviation. Abnormally distributed data are expressed as medians (upper and lower quartiles). Groups were compared using the chi-square test or Fisher's exact test when necessary for discrete variables. Within-group comparisons of normally distributed data were performed using paired *t* tests. Between-group comparisons of normally distributed data were performed using independent-sample *t* tests. The Mann-Whitney-Wilcoxon test was used to analyze abnormally distributed data. Logistic regression analysis was performed to identify independent predictors of AF recurrence. A receiver operation characteristic (ROC) curve was constructed to evaluate the sensitivity and specificity of various cut-off values

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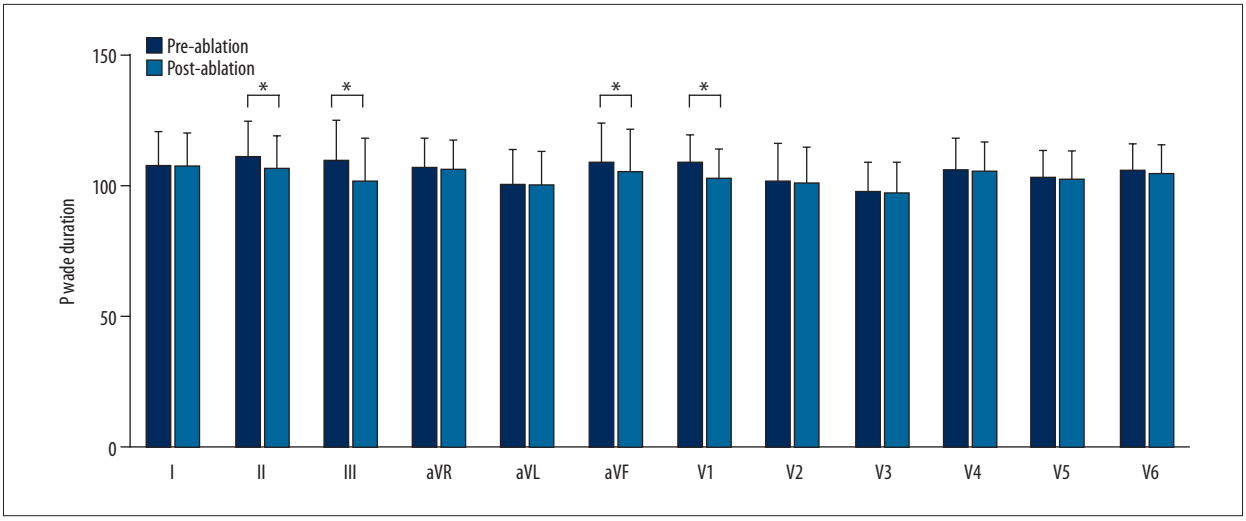

Figure 1. P wave duration before and after catheter ablation on 12-lead ECG. * *P*<0.01.

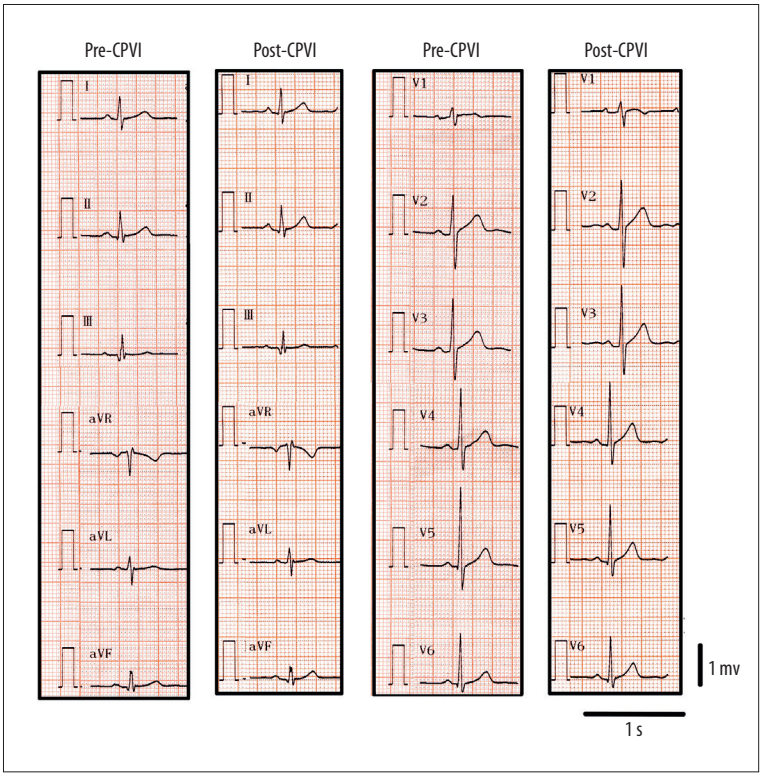

Figure 2. Representative 12-lead ECGs before and after CPVI showing reduction in P wave duration.

of P wave indices for predicting post-ablation AF recurrence. Statistical significance was denoted at P<0.05.

Results

Procedural characteristics

Pulmonary vein isolation was confirmed in all patients. Five patients underwent accessory pathway ablation and 2 underwent atrioventricular nodal reentrant tachycardia ablation during AF ablation. One patient had cervical hematoma and 1 patient had groin hematoma post-ablation, which were both resolved by local compression. During a mean follow-up of 19.96±4.32 months, AF recurrences occurred in 32 patients (18.7%). Among patients with AF recurrence post-ablation, 10 were prescribed amiodarone, 8 were prescribed bisoprolol, 12 were prescribed metoprolol, and 2 were prescribed propafenone. The clinical characteristics of all patients and the recurrence and non-recurrence groups are presented in Table 1. Age, sex, LA size,

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Table 2. Comparison of P wave duration between recurrence and non-recurrence group.

Parameter	P wave duration (ms)		*P*
	Recurrence (n=32)	Non-recurrence (n=139)	
I pre	107.22±11.43	108.33±12.92	0.658
I post	107.39±11.69	107.79±12.96	0.873
II pre	109.00±10.43	112.43±13.67	0.185
II post	109.23±10.15	106.31±13.05	0.237
III pre	108.71±11.78	110.38±16.43	0.507
III post	105.04±11.72	101.62±16.95	0.180
aVR pre	107.04±12.15	107.47±11.15	0.847
aVR post	106.96±11.63	106.73±10.92	0.916
aVL pre	100.65±13.42	101.41±12.78	0.764
aVL post	100.70±13.19	100.76±12.73	0.979
aVF pre	107.90±17.53	109.33±15.43	0.647
aVF post	107.54±16.85	107.35±16.85	0.949
V1 pre	110.68±9.29	109.08±11.00	0.445
V1 post	105.93±9.42	102.62±11.42	0.130
V2 pre	103.46±11.63	102.13±14.54	0.628
V2 post	102.45±10.27	100.88±14.62	0.566
V3 pre	99.76±12.63	98.06±10.86	0.439
V3 post	99.79±11.97	97.37±11.12	0.277
V4 pre	108.64±12.40	106.27±11.63	0.306
V4 post	108.34±12.23	106.27±11.63	0.173
V5 pre	103.88±13.69	103.41±9.89	0.855
V5 post	104.21±13.76	102.96±9.94	0.628
V6 pre	107.17±9.63	106.11±10.82	0.608
V6 post	106.76±9.13	105.01±10.74	0.395

BMI, and prior AADs use were not significantly associated with AF recurrence.

P wave duration before and after ablation

Univariate analysis revealed a significant reduction in PWD in leads II (111.79±13.17 *vs.* 106.86±12.59 ms, P<0.001), III (110.07±15.65 *vs.* 102.26±16.13 ms, P<0.001), aVF (109.06±15.80 *vs.* 107.38±15.42 ms, P<0.001) and V1 (109.38±10.70 *vs.* 103.24±11.13 ms, P<0.001) after catheter ablation. A tendency toward shorter PWD was observed in other leads but did not reach statistical significance (Figure 1). A representative example is given in Figure 2. There was a significantly shorter PWD after catheter ablation, especially in lead II.

A comparison of PWD data between the recurrence and non-recurrence groups indicated that neither pre- nor post-ablation PWD differed in any of the 12 leads between the 2 groups (Table 2). The PWD variations in the recurrence and non-recurrence groups are presented in Table 3. These data were expressed as the medians (upper and lower quartiles) because the data were abnormally distributed. Patients in the recurrence group tended to have a smaller PWD variation than those in the non-recurrence group. The PWD variation in leads II (1.21(–0.56, 2.40) *vs.* –5.77(–9.10, –4.06) ms,

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Table 3. Comparison of P wave duration variation between recurrence and non-recurrence group.

Parameter	P wave duration (ms)		P
	Recurrence (n=32)	Non-recurrence (n=139)	
Variation I	0.76 (–1.16,1.31)	–0.03 (–1.89,0.74)	0.062
Variation II	1.21 (–0.56,2.40)	–5.77 (–9.10,–4.06)	<0.001
Variation III	–5.92 (–9.87,3.27)	–9.44 (–11.89,–5.57)	0.001
Variation aVR	–0.99 (–6.41,2.64)	–0.76 (–3.31,1.44)	0.809
Variation aVL	–0.64 (–2.00,1.69)	–0.56 (–2.66,1.27)	0.601
Variation aVF	–1.41 (–2.87,0.58)	–0.77 (–2.54,0.18)	0.730
Variation V1	–4.43 (–6.64,–3.13)	–6.33 (–8.19,–4.59)	0.003
Variation V2	–2.05 (–3.24,–0.13)	–0.67 (–3.63,1.98)	0.205
Variation V3	0.04 (–3.07,2.63)	–0.15 (–3.69,3.17)	0.577
Variation V4	0.07 (–3.66,3.44)	–0.91 (–4.19,2.24)	0.601
Variation V5	–0.77 (–4.10,4.25)	–0.91 (–3.25,2.44)	0.623
Variation V6	–0.67 (–3.78,2.72)	–1.32 (–3.99,1.91)	0.281

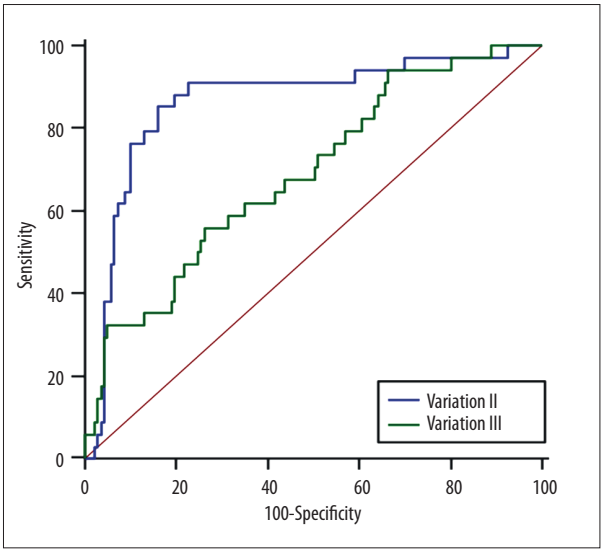

Figure 3. Receiver operating characteristic curves for relationship between predictors and AF recurrence.

P<0.001), III (–5.92(–9.87, 3.27) *vs.* –9.44(–11.89, –5.57) ms, P=0.001) and V1 (–4.43(–6.64, –3.13) *vs.* –6.33(–8.19,–4.59) ms, P=0.003) differed significantly between the recurrence and non-recurrence groups. Consequently, these 3 parameters were used in the logistic regression. Multivariable logistic regression analysis demonstrated that a smaller PWD variation in lead II (P<0.001, OR=0.73, 95%CI 0.648-0.824) and III (P=0.006, OR=0.904, 95% CI 0.84–0.972) independently predicted post-ablation AF recurrence.

Value of P wave parameter for predicting atrial fibrillation

ROC curve analysis was performed to evaluate the ability of the PWD variation in leads II and III to predict AF recurrence (Figure 3). The area under the ROC curve for the PWD variation was 0.868 (95% CI 0.789–0.946) for lead II and 0.688 (95% CI 0.588–0.788) for lead III. The PWD variation in lead II exhibited better diagnostic efficacy than that in lead III (P=0.01). A PWD variation ≥–2.21 ms in lead II exhibited the best combined sensitivity and specificity for AF recurrence (85.29% and 83.94%, respectively). When a PWD variation in lead II of 0 ms was used as the cut-off value, the sensitivity and specificity for AF recurrence were 65.62% and 91.37%, respectively.

Discussion

The main finding of this retrospective study is that significant shortening of the PWD in leads II, III, aVF, and V1 can be detected after ablation. Smaller PWD variations in leads II, III, and V1 were observed in the recurrence group compared with the non-recurrence group. The PWD variation in lead II was a better predictor of AF recurrence than that in lead III. A PWD variation ≥0 ms (PWD post-ablation exceeding pre-ablation) in lead II is a simple and effective predictor of AF recurrence.

Our results are in agreement with several previous studies on P wave morphology changes after pulmonary vein isolation. Van Beeumen et al. [17] reported significant PWD shortening after AF ablation (132±14 *vs.* 126±16 ms, P<0.001) using

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signal-averaged ECG as well as greatly shortened PWD in the patients without AF recurrence. Caldwell et al. [13] reported similar changes in P wave indices and concluded that a prolonged maximum PWD indicates AF recurrence (129±14 *vs.* 139±17 ms, P<0.01). Salah et al. [15] evaluated post-ablation P wave indices and identified PWD ≥125 ms, P wave dispersion ≥40 ms, and PTV1 ≤–0.04 mm/s as good predictors of post-ablation AF recurrence.

The pathogenesis of PWD shortening and its predictive value for AF recurrence after CPVI remain unclear. The underlying mechanism may involve myocardial sleeves within PVs. Ogawa et al. [14] reported that the terminal part of the P wave was represented by the activation of pulmonary vein muscle sleeves. CPVI can terminate the electrical conduction between the atrium and PVs, resulting in shortening of the PWD after ablation. However, Date et al. [18] detected that the activation of myocardial sleeves within PVs formed the middle part of the P wave. No decrease in PWD after ablation was detected, but this study included only 21 patients, and such a limited sample size may not have sufficient power to detect a difference. Udyavar et al. [19] reported that changes in the earliest LA breakthrough site could decrease total atrium activation time post-ablation. In their study, the earliest breakthrough shifted from Bachmann's bundle to midseptum and posterior septum in 24% of patients. Other patients exhibited a consistent downward shift from the original breakthrough location. This shift results in earlier activation of the medial isthmus, midposterior wall, and posterior lateral wall, resulting in a significant reduction in total LA excitation time. This observation is also supported by another study evaluating LA electrophysiology change after cryoablation [20]. Shortened PWD post-ablation may also result from ablation-mediated vagal denervation. Studies have reported that atropine-induced vagal denervation can significantly shorten PWD [21]. In our cohort, some patients exhibited a transient vagal reflex (hypotension or bradycardia) during the ablation procedure and a significantly accelerated heart rate after ablation. This phenomenon, in which ablation leads to vagal denervation, could also be a factor contributing to shortened PWD after ablation.

Patients experiencing AF recurrence exhibited smaller PWD variations compared with the non-recurrence group. Multiple mechanisms may explain this discrepancy. Excessive ablation within the atrium may cause damage to normal conduction bundle tissues, which could cause abnormal electric propagation and increase the probability of local reentry [22]. These changes in electrophysiology will increase inter- and intra-atrial conduction times and prolong PWD after ablation. As discussed above, isolation of the myocardial sleeves within pulmonary veins only leads to shortened PWD in patients with broad LA-PV connections. Therefore, CPVI might not result in significant shortened PWD in patients with discrete LA-PV connections. In these patients, there is a higher AF recurrence rate after ablation because of non-PV triggered AF.

In this study, we found that the PWD variation in lead II displayed the greatest diagnostic value. Generally, P wave morphology mainly reflects the whole atrial electrical conduction. The normal atrial depolarization vector is directed downward and toward the subject's left, which is nearly parallel to the axis of lead II. As a result, any P wave morphology change may be magnified in this lead. PWD variations in lead II greater than –2.21 ms provided the highest diagnosis efficacy. However, measuring this value in clinical practice is difficult. We then adjusted the PWD variation cut-off value to 0 ms, which indicates that post-ablation PWD exceeds pre-ablation PWD, to predict AF recurrence. This cut-off value reduced the sensitivity to 65.62% and increased the specificity to 91.37%. A higher degree of specificity is acceptable because the purpose of this measure is to identify the subgroup requiring restart of anti-arrhythmia therapy or even repeated ablation.

There were several limitations in this study. This study featured a retrospective design and was conducted at a single center with highly selected patients. We excluded patients who underwent additional ablation (beyond CPVI) because these patients may represent more advanced substrate remodeling and the impact of additional ablation on PWD is difficult to evaluate. The AF follow-up data were derived from ECGs and patient symptoms. Therefore, we may have underestimated AF recurrence due to asymptomatic recurrence. Furthermore, we recorded post-ablation ECG only once, but P wave duration may change during follow-up [23]. Finally, the sample size was relatively small, and the follow-up duration was short. Therefore, the results of this study should be confirmed by large, high-quality, prospective studies.

Conclusions

An increase in PWD post-ablation compared to pre-ablation in lead II is a useful and feasible indicator of AF recurrence. In patients without PWD shortening in lead II, additional substrate modification may be necessary. Further studies are needed to evaluate whether these indices can be used as an on-line method to guide ablation.

Conflict of interest

The authors declare that they have no conflicts of interest concerning this article.

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