ARCHIVES OF THE TURKISH SOCIETY OF CARDIOLOGY

Official journal of the TURKISH SOCIETY OF CARDIOLOGY

An Effective Novel Index for Predicting the Recurrence of Atrial Fibrillation Ablation: P Wave Duration-to-Amplitude Ratio

Atriyal Fibrilasyon Ablasyonu Nüksünü Tahmin Etmede Etkili Yeni Bir İndeks: P Dalga Süresi-Amplitüd Oranı

ORIGINAL ARTICLE
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Received: March 22, 2022
Accepted: June 15, 2022

Cite this article as: Doğduş M, Turan OE, Başkurt AA, et al. An effective novel index for predicting the recurrence of atrial fibrillation ablation: P wave duration-to-amplitude ratio. *Turk Kardiyol Dern Ars.* 2022;50(7):498-504.

DOI:10.5543/tkda.2022.22416

ABSTRACT

Objective: Atrial fibrillation is the most common arrhythmia observed in the clinical practice. Pulmonary vein isolation is a well established treatment option for atrial fibrillation but is limited by recurrence. Previous studies have demonstrated that abnormal P wave indices were associated with adverse atrial remodeling and its role in predicting atrial fibrillation recurrence. In the present study, we aimed to evaluate the place of a novel index as we named P wave duration-to-amplitude ratio in predicting the recurrence of atrial fibrillation.

Methods: Patients who underwent pulmonary vein isolation for symptomatic drug-resistant atrial fibrillation between January 2016 and March 2018 were retrospectively screened. A total of 111 patients were enrolled in the current study. P wave indices of the patients were calculated by precisely measuring the electrocardiogram traces recorded with an electrophysiology recording system.

Results: While P wave duration (129 ± 18.4 vs. 109 ± 15.7 ms, $P < .001$), P wave duration-to-amplitude ratio (1072.7 ± 528.3 vs. 626.9 ± 368 ms/mV, $P < .001$), P wave peak time (65 ± 12 vs. 54 ± 10 ms, $P < .001$), and P wave dispersion (49 ± 14.1 vs. 27.9 ± 17 ms, $P = .001$) values were significantly higher in the atrial fibrillation recurrence (+) group, the P wave amplitude (0.12 ± 0.05 vs. 0.18 ± 0.02 mV, $P < .001$) value was found to be lower. A P wave duration-to-amplitude ratiovalue of >830 ms/mV has 61.8% sensitivity and 88.4% specificity for the prediction of the atrial fibrillation recurrence (area of under the curve [AUC], 0.727).

Conclusion: P wave duration-to-amplitude ratio, which may be considered as an indicator of the temporal and electrical propagation of the P wave in the atria, can predict atrial fibrillation ablation recurrence.

Keywords: Atrial fibrillation ablation, P wave amplitude, P wave duration, recurrence

ÖZET

Amaç: Atriyal fibrilasyon (AF) klinik pratikte en sık görülen aritmidir. Pulmoner ven izolasyonu (PVI), AF için iyi bilinen bir tedavi seçeneğidir ancak nüks ile sınırlıdır. Önceki çalışmalar, anormal P dalga indekslerinin ters atriyal yeniden şekillenme ile ilişkili olduğunu ve AF nüksünü tahmin etmedeki yerini göstermiştir. Bu çalışmada, P Dalga Süresi-Genlik Oranı (PWDAR) adını verdiğimiz yeni bir indeksin AF rekürrensini öngörmedeki yerini değerlendirmeyi amaçladık.

Yöntemler: Ocak 2016 ile Mart 2018 arasında semptomatik ilaca dirençli AF nedeniyle PVI uygulanan hastalar geriye dönük olarak tarandı. Mevcut çalışmaya toplam 111 hasta alındı. Elektrofizyoloji kayıt sistemi ile kaydedilen EKG traseleri hassas bir şekilde ölçülerek hastaların P dalga indeksleri hesaplandı.

Bulgular: PWD (129 ± 18,4 vs 109 ± 15,7 msn, $P < ,001$), PWDAR (1072,7 ± 528,3 vs 626,9 ± 368 mesc/mV, $P < ,001$), PWPT (65 ± 12 vs 54 ± 10 msn), $P < ,001$) ve PWdisp (49 ± 14,1'e karşı 27,9 ± 17 msn, $P = ,001$) değerleri AF nüksü (+) grubunda anlamlı olarak daha yüksek saptanırken, PWA (0,12 ± 0,05 vs 0,18 ± 0,02 mV, $P < ,001$) değerinin daha düşük olduğu bulundu. >830 msn/mV'lik bir PWDAR değeri, AF nüksünü öngörmede %61,8 duyarlılığa ve %88,4 özgüllüğe sahip olduğu saptandı (AUC 0,727).

Sonuç: P dalgasının atriyumda zamansal ve elektriksel yayılımının bir göstergesi olarak kabul edilebilecek P Dalga Süresi-Genlik Oranı (PWDAR), AF nüksünü öngörebilir.

Anahtar Kelimeler: Atriyal fibrilasyon ablasyonu, nüks, P dalga amplitüdü, P dalga süresi

Atrial fibrillation (AF) is the most common arrhythmia observed in the clinical practice and is associated with an increased risk of stroke, heart failure, and death.[1] Atrial fibrillation can be managed with pharmacotherapy, but percutaneous ablation modalities are used in symptomatic patients who wish to avoid, have not responded to, or cannot tolerate medical therapy. Catheter-based pulmonary vein isolation (PVI) is a well established, efective, and safe treatment option for drug-resistant AF with a success rate of 50%-70%.[2] However, there is still a risk of recurrence for patients.[3] Identification of patient groups at higher risk for developing recurrent AF can help in developing preventive strategies and tailoring of rhythm control therapy post-ablation.

The comorbidities contributing the development of AF, such as diabetes mellitus (DM), hypertension (HT), and cardiovascular disease (CVD), promote atrial remodeling that results in abnormal surface electrocardiogram (ECG) P wave indices such as prolonged P wave durations and decreased P wave voltages.[4-6] Previous studies have demonstrated that abnormal P wave indices were associated with adverse atrial remodeling and predicted AF recurrence after ablation.[7-10] In the present study, we aimed to evaluate the place of a novel index as we named P wave durat ion-to-amplitude ratio (PWDAR) in predicting the recurrence of AF.

Methods

Study Population

The patients who underwent PVI for symptomatic drug-resistant AF between January 2016 and March 2018 were retrospectively screened. After the exclusion criteria, 111 patients were included in the study. Atrial fibrillation recurrence was defined as an episode lasting longer than 30 seconds. New-onset atrial tachycardia and atrial flutter were also considered as recurrences. Atrial fibrillation recurrences were evaluated after a 3-month blanking period. Atrial fibrillation recurrence was observed in 25 of these patients during the 27-month follow-up. Study population were divided into 2 groups as follows: 25 patients with AF recurrence [AF recurrence (+) group] and 86 patients without AF recurrence [AF recurrence (–) group]. Patients with the history of prior AF ablation, acute cardiovascular or cerebrovascular events within 3 months, severe valvular heart diseases, history of valvular surgery, cardiac pacemaker, left ventricular ejection fraction < 50%, inflammatory and/or infectious diseases, malignancy, chronic renal and hepatic insufficiency, uncontrolled hypertension, and thyroid and parathyroid dysfunction were excluded from the study. Dokuz Eylül University Faculty of Medicine ethics committee approved the present study (decision number: 2021/13-27; date: April 19, 2021). Our study was carried out in compliance with the ethical guidelines of the Declaration of Helsinki.

Demographic characteristics, cardiovascular risk factors such as HT, DM, and CAD, and laboratory results were obtained from the medical records of the patients. Conventional transthoracic echocardiographic assessment of the patients before PVI was recorded. Echocardiographic evaluations were performed in accordance with the American Society of Echocardiography (ASE) criteria from the parasternal long-axis, parasternal short-axis, and apical 4 chamber sections in the left lateral position, and subcostal section in the supine position with one-lead ECG monitoring.[11]

Atrial Fibrillation Ablation Procedures and Calculation of P Wave Indices

For PVI, radiofrequency (RF) ablation with 3-dimensional (3D) mapping or cryoballoon ablation was performed according to operator preference. The patients underwent electrophysiological study and ablation after 8 hours of fasting. A 3D electroanatomical mapping system (CARTO, Biosense Webster, Inc. DiamondBar, Calif, USA) was used for RF ablation. Left PVs and then right PVs were isolated with RF energy. After the lines were formed, PVI was completed by showing the pulmonary vein entry and exit blocks. Cryoballoon ablation was performed using the Arctic Front™ Cardiac Cryoablation Catheter System (Minneapolis, Medtronic, USA). A 28 mm second-generation cryoballoon catheter (Arctic Front Advance, Medtronic Inc, Minneapolis, Minn, USA) was used for ablation. It was started with the lower left PV, followed by isolation of the upper left PV, the lower right PV, and the upper right PV. The duration of each freezing cycle was 240 seconds. Complete isolation was demonstrated again with Achieve mapping catheter after PVI.

The P wave indices of the patients were calculated on both standard surface 12-lead ECG and the electrophysiology (EP) system: P wave indices$^{12\text{-}ECG}$ and P wave indices^{EP}. Then, the correlation between these 2 measurement methods was examined. Surface 12-lead standard ECGs were recorded for each patient with a 25 mm/s paper speed at 10 mm/mV amplitude (Nihon Kohden Cardiofax M ECG-1350). Electrocardiogram images were amplified 8 times and P-wave duration was measured blindly by using semiautomatic digital calipers in all 12 leads to acquire the longest duration. All of the measurements were repeated 3 times and average values were obtained. The onset of the P-wave was the point of initial upward or downward deflection from ECG baseline, and the P-wave endpoint was determined as the point where the waveform returned to baseline. The P wave indices^{EP} of the patients were calculated by precisely measuring the ECG traces recorded with the CardioLab™ EP Recording System (GE Healthcare, USA) with calipers when the patients were admitted to the EP laboratory

ABBREVIATIONS

AF	Atrial fibrillation
ASE	American Society of Echocardiography
CAD	Coronary artery disease
CRP	C-reactive protein
CVD	Cardiovascular disease
DM	Diabetes Mellitus
ECG	Electrocardiogram
EP	Electrophysiology
HT	Hypertension
IAB	Interatrial block
LVEF	Left ventricular ejection fraction
PWA	P wave amplitude
PWD	P wave duration
PWDAR	P wave duration-to-amplitude ratio
PWDisp	P wave dispersion
PWPT	P wave peak time
PVI	Pulmonary vein isolation
RF	Radiofrequency
TSH	Thyroid-stimulating hormone
WBC	White blood cell

for AF ablation. P wave duration (PWD) was calculated as the difference between the onset and the offset of P wave and was measured in lead II. P wave amplitude (PWA) was measured from the peak of the P wave to the isoelectric line of the T-P interval in lead II. The PWD was measured when the ECG trace in the EP system was 100 mm/s and filter was 150 Hz. P wave amplitude was calculated by setting the amplitude in the range of 0-0.5 mV. The PWDAR was calculated for all patients. P wave dispersion (PWdisp) was quantified by the difference between the longest PWD and the shortest PWD. P wave peak time (PWPT) was described as the time from the beginning of the P wave to its peak, and it was measured in lead II.

The P wave indices were evaluated by 2 independent blinded investigators and Bland–Altman analyses were performed to assess the inter- and intra-observer reproducibility of PWD (3.2 ms and 2.8 ms, respectively), PWA (0.06 mV and 0.08 mV, respectively), PWPT (1.9 ms and 2.2 ms, respectively), and PWdisp (1.2 ms and 1.4 ms, respectively).

Statistical Analysis

Statistical Package for the Social Sciences 25.0 (IBM Corp., Armonk, NY, USA) program was used for variable analysis. Normally distributed continuous data were expressed as mean ± standard deviation. Continuous variables that are not normally distributed were expressed as median, and categorical variables were expressed as n and percentages. The normal distribution of the data was evaluated by Kolmogorov–Smirnov test and Shapiro–Wilk test and the variance homogeneity was evaluated by the Levene test. Data with a normal distribution were compared using Student's *t*-test and data with a non-normal distribution were compared using the Mann–Whitney *U* test. Pearson chi-square and Fisher's exact tests were tested using exact results to compare categorical variables. Spearman's correlation coefficient was used to disclose possible correlations between P wave indices^{EP} and P wave indices$^{12\text{-}ECG}$. Receiver operating characteristics (ROC) curves were performed to determine the cut-off values of PWDAR and PWPT to predict recurrence of AF. Multivariate logistic regression analysis was performed to identify the independent predictors of AF recurrence. Variables were examined at 95% CI. A *P*-value <.05 was considered as statistically significant.

Results

A total of 111 patients were enrolled in the current study [25 patients in AF recurrence (+) group and 86 patients in the AF recurrence (–) group]. The baseline clinical characteristics and laboratory results of the study population are shown in Table 1. The mean age of the study population was 56.2 ± 11.4 years, and 51% of the patients were female. Although the number of patients with paroxysmal AF was high in both groups (81.4% vs. 72%), there was no statistical difference ($P = .226$). There was no significant difference between the groups in terms of AF ablation procedure preference. The usage of amiodarone was significantly higher in the AF recurrence (+) group than in the AF recurrence (–) group (28% vs. 10.4%, $P = .036$). There were not any significant differences between groups in terms of age, gender, comorbidities (HT, DM, CAD), and laboratory results (Table 1).

Although the left atrium diameter was numerically larger in the AF recurrence (+) group compared to the other group (49.6 ± 5.2 mm vs. 44.7 ± 5.4 mm), it did not reach statistical significance ($P = .088$); other than this, there were no significant differences between the 2 groups regarding the 2-dimensional echocardiographic results (Table 2).

While PWD^{EP} (129 ± 18.4 vs. 109 ± 15.7 ms, $P < .001$), PWDAR^{EP} (1072.7 ± 528.3 vs. 626.9 ± 368 ms/mV, $P < .001$), PWPT^{EP} (65 ± 12 vs. 54 ± 10 ms, $P < .001$), and PWdisp^{EP} (49 ± 14.1 vs. 27.9 ± 17 ms, $P = .001$) values were significantly higher in the AF recurrence (+) group, the PWA^{EP} (0.12 ± 0.05 vs. 0.18 ± 0.02 mV, $P < .001$) value was found to be lower (Table 2; Figure 1A, 1A).

It was examined whether there were any significant correlations between P wave indices^{EP} and P wave indices$^{12\text{-}ECG}$. Positive significant linear correlations were observed between

Table 1. The Baseline Clinical and Laboratory Characteristics

	AF Recurrence (–) Group (n=86)	AF Recurrence (+) Group (n=25)	*P*
Age, years	57.3 ± 9.9	54.8 ± 13.3	.567
Female gender, n (%)	43 (50)	13 (52)	.521
Paroxysmal AF, n (%)	70 (81.4)	18 (72)	.226
RF ablation, n (%)	49 (57)	14 (56)	.554
Hypertension, n (%)	43 (50)	11 (44)	.199
Diabetes mellitus, n (%)	12 (14.6)	5 (20)	.514
CAD, n (%)	13 (15.1)	4 (16)	.317
Fasting glucose (mg/dL)	103.7 ± 36.6	112.5 ± 28.4	.192
Creatinine (mg/dL)	0.93 ± 0.22	0.84 ± 0.19	.362
Na (mmol/L)	140.2 ± 3.4	138.6 ± 2.5	.853
K (mmol/L)	4.23 ± 0.49	4.13 ± 0.65	.273
AST (U/L)	24 (10 / 95)	22 (8 / 74)	.913
ALT (U/L)	22 (5 / 60)	18 (6 / 83)	.632
CRP (mg/dL)	3.14 ± 1.02	3.58 ± 0.94	.562
TSH (mU/mL)	1.67 ± 0.5	1.89 ± 0.7	.061
WBC (K/μL)	7322 ± 1975	7700 ± 2269	.456
Neutrophil (K/μL)	4752 ± 2064	5126 ± 1984	.272
Hemoglobin (g/dL)	13.7 ± 1.5	13.3 ± 2.1	.411
Platelet (K/μL)	227000 ± 65000	196000 ± 68000	.173
ACE-I/ARB, n (%)	38 (44.1)	8 (32)	.154
Beta-blocker, n (%)	49 (56.9)	17 (68)	.351
Amiodarone, n (%)	9 (10.4)	7 (28)	.036
Propafenone, n (%)	22 (25.5)	6 (24)	.543

AF, atrial fibrillation; RF, radiofrequency; CAD, coronary artery disease; CRP, C-reactive protein; TSH, thyroid-stimulating hormone; WBC, white blood cell; AST, aspartate aminotransferase; ALT, alanine aminotransferase; ACE-I, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor blocker.

Table 2. The Echocardiographic and Electrocardiographic Results

	AF Recurrence (−) Group (n=86)	AF Recurrence (+) Group (n=25)	*P*
LVEF (%)	58.1 ± 4.2	56.4 ± 4.5	.376
Left atrium diameter (mm)	44.7 ± 5.4	49.6 ± 5.2	.088
LVSWT (mm)	10.5 ± 1.9	10.2 ± 2.3	.751
PWT (mm)	9.2 ± 1.5	9.6 ± 1.8	.952
LVEDD (mm)	49.5 ± 4.2	52.9 ± 3.8	.128
LVESD (mm)	34.2 ± 3.3	34.5 ± 3.6	.644
PWD (msec)^{EP}	109 ± 15.7	129 ± 18.4	<.001
PWD (msec)$^{12\text{-}ECG}$	112 ± 18.5	125 ± 17.6	.001
PWA (mV)^{EP}	0.18 ± 0.02	0.12 ± 0.05	<.001
PWA (mV)$^{12\text{-}ECG}$	0.2 ± 0.05	0.15 ± 0.05	.013
PWDAR (msec/mV)^{EP}	626.9 ± 368	1072.7 ± 528.3	<.001
PWDAR (msec/mV)$^{12\text{-}ECG}$	610 ± 345	1050.5 ± 540.5	.004
PWPT (msec)^{EP}	54 ± 10	65 ± 12	<.001
PWPT (msec)$^{12\text{-}ECG}$	50 ± 15	62 ± 15	.001
PWdisp (msec)^{EP}	27.9 ± 17	49 ± 14.1	.001
PWdisp (msec)$^{12\text{-}ECG}$	25.5 ± 15	46 ± 16	.012

AF, atrial fibrillation; LVEF, left ventricular ejection fraction; LVSWT, left ventricular septal wall thickness; PWT, posterior wall thickness; LVEDD, left ventricular end-diastolic diameter; LVESD, left ventricular end-systolic diameter; PWD, p wave duration; PWA, p wave amplitude; PWDAR, p wave duration-to-amplitude ratio; PWPT, p wave peak time; PWdisp, p wave dispersion; ^{EP}, electrophysiology-based data; $^{12\text{-}ECG}$, standard 12-lead ECG-based data.

the 2 measurement methods [r=0.794 for PWDAR (ms/mV)^{EP} and PWDAR (ms/mV)$^{12\text{-}ECG}$, r=0.708 for PWPT (ms)^{EP} and PWPT (ms)$^{12\text{-}ECG}$, and r=0.675 for PWdisp (ms)^{EP} and PWdisp (ms)$^{12\text{-}ECG}$] (Table 3).

Receiver operating characteristic analysis was performed to find out the ideal PWDAR^{EP} and PWPT^{EP} cut-off values for predicting the AF recurrence. A PWDAR^{EP} value of >830 msec/mV has 61.8% sensitivity and 88.4% specificity for the prediction of the AF recurrence (AUC, 0.727) (Figure 2A). A PWPT^{EP} value of >62.5 ms has 60% sensitivity and 86.1% specificity for the prediction of the AF recurrence (AUC, 0.671) (Figure 2A).

Table 3. Correlations Between P Wave Indices^{EP} and P Wave Indices$^{12\text{-}ECG}$

	PWDAR (ms/mV)$^{12\text{-}ECG}$	
	r	*P*
PWDAR (ms/mV)^{EP}	0.794	<.001
	PWPT (ms)$^{12\text{-}ECG}$	
	r	*P*
PWPT (ms)^{EP}	0.708	<.001
	PWdisp (ms)$^{12\text{-}ECG}$	
	r	*P*
PWdisp (ms)^{EP}	0.675	.002

Spearman's correlation coefficient
PWDAR, p wave duration-to-amplitude ratio; PWPT, p wave peak time; PWdisp, p wave dispersion; ^{EP}, electrophysiology-based data; $^{12\text{-}ECG}$, standard 12-lead ECG-based data.

In multivariate logistic regression analysis; PWDAR^{EP} (P < .001, odds ratio (OR)=3.47, 95% CI=1.15-5.64), PWDAR$^{12\text{-}ECG}$ (P=.001, OR=1.62, 95% C.I.=1.06-2.81), and PWPT^{EP} (P=.018, OR=1.21, 95% C.I.=1.02-1.75) were found to be independent predictors of AF recurrence (Table 4).

Discussion

The results of the present study demonstrated that the mean PWDAR^{EP} value was significantly higher in the AF recurrence (+) group compared to the AF recurrence (−) group, and a PWDAR^{EP} value of >830 ms/mV has 61.8% sensitivity and 88.4% specificity for the prediction of the AF recurrence. In multivariate logistic regression analysis, PWDAR^{EP} was found to be independent predictor of AF recurrence. As far as to our knowledge, this is the first study demonstrating the predictive value of PWDAR for recurrence of AF after PVI.

Multiple independent predictors of AF recurrences after AF ablation have been identified, such as age, persistent AF,[12] HT, HLP, left atrial diameter,[13,14] and atrial remodeling by delayed-enhancement MRI,[15] but quantitative non-invasive markers are still lacking. P wave indices obtained from ECG, which is one

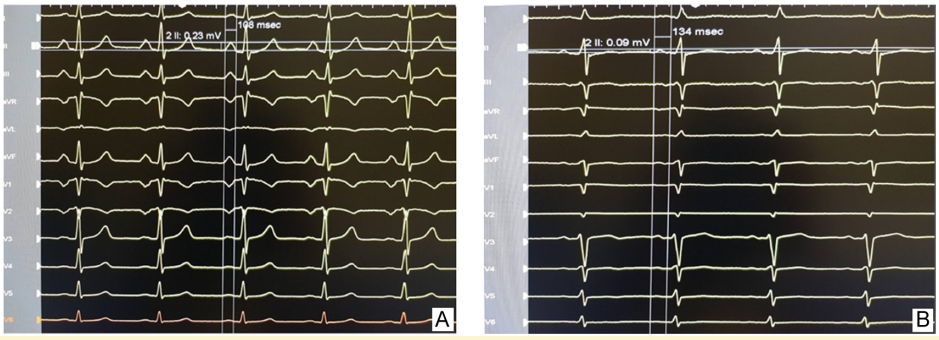

Figure 1. PWD and PWA values calculated using the CardioLab™ Electrophysiology Recording System in patients without (A) and with (B) AF recurrence. PWD, P wave duration; PWA, P wave amplitude.

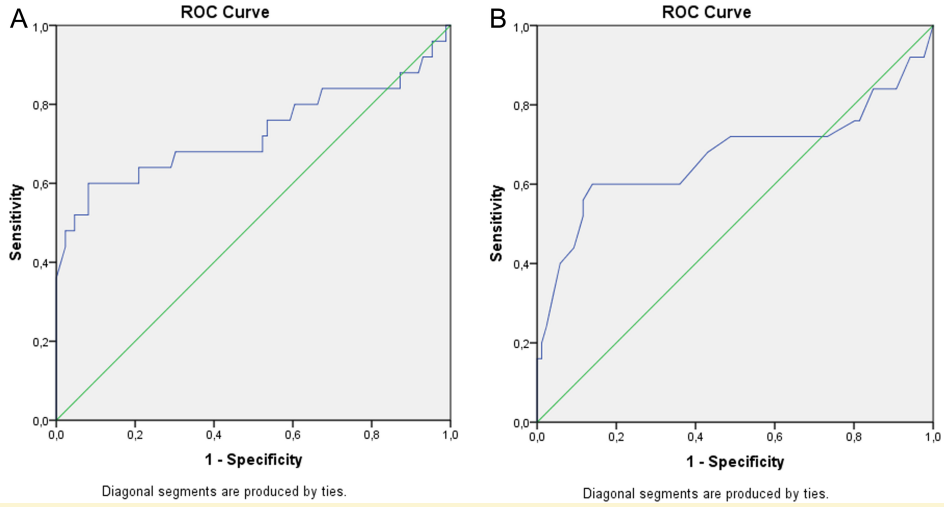

Figure 2. (A) PWDAR value of >830 ms/mV has 61.8% sensitivity and 88.4% specificity for the prediction of the AF recurrence (AUC, 0.727). (B). A PWPT value of >62.5 ms has 60% sensitivity and 86.1% specificity for the prediction of the AF recurrence (AUC, 0.671).

of the non-invasive tools, have been the focus of attention of researchers for predicting AF recurrence.

P-wave morphology represents atrial electrical activation. This activation depends on the distance and velocity of electrical currents on the myocardium. Atrial remodeling causes changes in the conduction pathway on the myocardial tissue of the atrium; these changes are divided into structural and electrical remodeling and most commonly occurs together. From the surface ECG, electrical and structural remodeling are seen as a prolonged PWD and PWPT, shortening of the refractory period with increased PWdisp and reduction of PWA.

Table 4. The Univariate and Multivariate Analysis for Predicting AF Recurrence

	Univariate		Multivariate	
	Odss Ratio (95% CI)	***P***	**Odss Ratio (95% CI)**	***P***
Age	1.01 (0.74-1.19)	.084		
Hypertension	0.98 (0.66-1.27)	.105		
Left atrium diameter	1.13 (0.82-1.33)	.062		
PWDAR^{EP}	2.08 (1.24-3.52)	<.001	3.47 (1.15-5.64)	<.001
PWDAR^{12-ECG}	1.27 (1.04-1.68)	.015	1.62 (1.06-2.81)	.001
PWPT^{EP}	1.19 (0.87-1.35)	.033	1.21 (1.02-1.75)	.018
PWPT^{12-ECG}	1.15 (0.79-1.23)	.057		
PWdisp^{EP}	1.08 (0.76-1.21)	.069		
PWdisp^{12-ECG}	0.99 (0.81-1.25)	.095		
CAD	0.83 (0.62-1.03)	.276		
RF ablation	0.79 (0.58-0.92)	.565		
Paroxysmal AF	0.87 (0.74-0.99)	.106		

AF, atrial fibrillation; PWDAR, p wave duration-to-amplitude ratio; PWPT, p wave peak time; PWdisp, p wave dispersion; ^{EP,} electrophysiology-based data; $^{12-ECG,}$ standard 12-lead ECG-based data; RF, radiofrequency.

P wave duration, PWdisp, PWPT, and PWA are ECG indexes related to P-wave, which may be linked to AF and its recurrence. Among the abovementioned indexes, PWdisp and PWD reflect discontinuous conduction and heterogeneity in the atrium. Numerous clinical studies were published on PWdisp in various fields. Related studies are available to show that PWdisp is one of the most sensitive muscle-specific factors in ECG prediction of AF,[16] and PWdisp also has a potential value in recurrence after AF ablation.[17] In our study, supporting the literature, PWdisp value was found to be higher in the AF recurrence (+) group than in the other group.

P wave peak time is an ECG parameter and represents the time for the conduction of the electrical activity from the sinus node to the maximal summation of positive deflection from both atria.[18] An increased PWPT has been shown as an independent predictor for PAF and its recurrence after ablation,[19] and also has been associated with acute ischaemic stroke.[20] In terms of predicting AF ablation recurrence, in our study, we showed increased PWPT values in the recurrence group.

In a recently published study, Karacop et al[21] investigated the role of P wave duration/P wave voltage, which is a novel index, in predicting new-onset AF. They screened a total of 640 consecutive patients who admitted to cardiology outpatient clinic with a complaint of palpitation. 24-hour Holter monitoring, echocardiography, and ECG recordings were reviewed to identify new-onset AF. They demonstrated that P wave duration/P wave voltage was found to be significant independent predictor of new-onset AF in a multivariate analysis, after adjusting for other risk parameters. This is a pioneering study showing that the newly introduced P wave duration/P wave voltage ratio among P wave indices has a high sensitivity in predicting an important public health problem such as AF. In our study, we investigated this novel index, which we

named PWDAR (P wave duration-to-amplitude ratio), to predict recurrence in AF patients who underwent PVI. We found that a PWDAR^{EP} value of >830 ms/mV has 61.8% sensitivity and 88.4% specificity for the prediction of the AF recurrence. Unlike their study, the P wave indices of the patients were calculated on both the standard surface 12-lead ECG and the EP system: P wave indices$^{12\text{-}ECG}$ and P wave indices^{EP}. Then, the correlation between these 2 measurement methods was examined. Positive significant linear correlations were observed between the 2 measurement methods. Also, in multivariate logistic regression analysis, PWDAR^{EP} was found to be independent predictor of AF recurrence.

Recently, the electrocardiographic risk score which is named morphology-voltage-P-wave duration (MVP) score was reported to be useful for predicting new-onset AF and recurrence of AF ablation. Yang et al[22] retrospectively evaluated the score's ability to predict arrhythmia recurrence after PVI procedure for PAF. The MVP ECG risk score is calculated in each patient being assigning 0-2 point for each of the following factors: PWD, IAB, and P-wave amplitude. They demonstrated that a score cut-off value of >3 showed the best predictive ability for AF recurrence within 1 year after PVI, with sensitivity (53.03%) and specificity (89.87%). However, although this ECG score is more easy-to-measure than other clinical scores, its sensitivity in predicting AF recurrence is relatively lower than in our study (53.03% vs. 61.8%).

Almost all of the mentioned P wave indices are based on measurements made over the P wave duration. The relationship between atrial remodeling and AF development/recurrence is known by the prolongation of the P wave duration and the changes in the calculated P wave indices. We think that with the addition of the P wave amplitude, which is an indicator of the electrical activity in the atrial tissue, in our study, this relationship is shown more comprehensively both structurally and electrically. When the results of the current study were evaluated, PWDAR, which reflects the duration and amplitude of the P wave combined, was found to be more sensitive in predicting AF recurrence compared to other P wave indices.

Our study has several limitations. It was a single-centered study with a limited number of patients (111) and has a retrospective design. Measurement of P wave indices with the CardioLab™ Electrophysiology Recording System is not easily accessible. Since the number of patients was small, AF subtypes were not analyzed separately in our study. PWDAR was not analyzed separately according to ablation techniques. Larger multicenter prospective studies are needed to investigate the effects of PWDAR in predicting AF recurrence and on clinical outcomes.

Conclusion

As far as to our knowledge, this is the first study demonstrating the predictive value of PWDAR for recurrence of AF after PVI. It may be considered PWDAR as an inclusive parameter that evaluates both temporal and electrical propagation of the P wave in the atria. This novel index may be used to give an idea about structural and electrical atrial remodeling and the possibility of AF recurrence before the procedure in patients who will undergo PVI.

Ethics Committee Approval: Dokuz Eylül University Faculty of Medicine Ethics Committee approved this study (decision number: 2021/13-27, date: April 19, 2021).

Informed Consent: All patients included in the study gave their informed consent to carry out the electrophysiological study and ablation.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.D., E.E.Ö.; Design – M.D., O.E.T., A.A.B.; Supervision – M.D., E.E.Ö.; Materials – A.A.B., U.D.İ.; Data Collection and/or Processing – A.A.B., O.E.T., M.D., U.Ö., R.Y.Y., U.D.İ.; Analysis and/or Interpretation – A.A.B., O.E.T., R.Y.Y., M.D.; Literature Review – M.D., U.Ö., O.E.T., R.Y.Y.; Writing – M.D., O.E.T., U.Ö.; Critical Review – M.D., E.E.Ö.

Declaration of Interests: The authors declare that they have no competing interest

Funding: This study received no funding.

References

1. Calkins H, Hindricks G, Cappato R, et al. 2017 HRS/EHRA/ECAS/APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation: executive summary. *Europace*. 2018;20(1):157-208. [CrossRef]
2. Cheniti G, Vlachos K, Pambrun T, et al. Atrial fibrillation mechanisms and implications for catheter ablation. *Front Physiol*. 2018;9:1458. [CrossRef]
3. Themistoclakis S, Schweikert RA, Saliba WI, et al. Clinical predictors and relationship between early and late atrial tachyarrhythmias after pulmonary vein antrum isolation. *Heart Rhythm*. 2008;5(5):679-685. [CrossRef]
4. Dilaveris PE, Gialafos EJ, Chrissos D, et al. Detection of hypertension patients at risk for paroxysmal atrial fibrillation during sinus rhythm by computer-assisted P wave analysis. *J Hypertens*. 1997;17:1463-1470.
5. Yazici M, Ozdemir K, Altunkeser BB, et al. The effect of diabetes mellitus on the P-wave dispersion. *Circ J*. 2007;71(6):880-883. [CrossRef]
6. Celik T, Iyisoy A, Kursaklioglu H, et al. Effects of primary percutaneous coronary intervention on P wave dispersion. *Ann Noninvasive Electrocardiol*. 2005;10(3):342-347. [CrossRef]
7. Park J, Kim TH, Lee JS, et al. Prolonged PR interval predicts clinical recurrence of atrial fibrillation after catheter ablation. *J Am Heart Assoc*. 2014;3(5):e001277. [CrossRef]
8. Salah A, Zhou S, Liu Q, Yan H. P wave indices to predict atrial fibrillation recurrences post pulmonary vein isolation. *Arq Bras Cardiol*. 2013;101(6):519-527. [CrossRef]
9. Hayıroğlu Mİ, Çınar T, Selçuk M, et al. The significance of the morphology-voltage-P-wave duration (MVP) ECG score for prediction of in-hospital and long-term atrial fibrillation in ischemic stroke. *J Electrocardiol*. 2021;69:44-50. [CrossRef]
10. Carmona Puerta R, Lorenzo Martínez E, Rabassa López-Calleja MA, et al. New parameter of the second half of the P-wave, P-wave duration, and atrial conduction times predict atrial fibrillation during electrophysiological studies. *Med Princ Pract*. 2021;30(5):462-469. [CrossRef]
11. Lang RM, Badano LP, Mor-Avi V, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging*. 2015;16(3):233-270. [CrossRef]

12. Tzou WS, Marchlinski FE, Zado ES, et al. Long-term outcome after successful catheter ablation of atrial fibrillation. *Circ Arrhythm Electrophysiol*. 2010;3(3):237-242. [CrossRef]
13. Letsas KP, Weber R, Bürkle G, et al. Preablative predictors of atrial fibrillation recurrence following pulmonary vein isolation: the potential role of inflammation. *Europace*. 2009;11(2):158-163. [CrossRef]
14. Shah AN, Mittal S, Sichrovsky TC, et al. Long-term outcome following successful pulmonary vein isolation: pattern and prediction of very late recurrence. *J Cardiovasc Electrophysiol*. 2008;19(7):661-667. [CrossRef]
15. Oakes RS, Badger TJ, Kholmovski EG, et al. Detection and quantification of left atrial structural remodeling with delayed enhancement magnetic resonance imaging in patients with atrial fibrillation. *Circulation*. 2009;119(13):1758-1767. [CrossRef]
16. Rosiak M, Bolinska H, Ruta J. P wave dispersion and P wave duration on SAECG in predicting atrial fibrillation in patients with acute myocardial infarction. *Ann Noninvasive Electrocardiol*. 2002;7(4):363-368. [CrossRef]
17. Dąbrowska-Kugacka A, Lewicka-Nowak E, Ruciński P, Zagożdżon P, Raczak G, Kutarski A. Relationship between P-wave duration and atrial electromechanical delay assessed by tissue Doppler echocardiography. *Pacing Clin Electrophysiol*. 2011;34(1):23-31. [CrossRef]
18. Acampa M, Guideri F, Tassi R, et al. P wave dispersion in cryptogenic stroke: a risk factor for cardioembolism? *Int J Cardiol*. 2015;190:202-204. [CrossRef]
19. Öz A, Aruğaslan E, Çınar T, et al. Long-term evaluation of electromechanical delay in patients with atrial septal defect after transcatheter closure. *Int J Cardiovasc Imaging*. 2019;35(1):33-39. [CrossRef]
20. Öz A, Cinar T, Kızılto Güler CK, et al. Novel electrocardiography parameter for paroxysmal atrial fibrillation in acute ischaemic stroke patients: P wave peak time. *Postgrad Med J*. 2020;96(1140):584-588. [CrossRef]
21. Karacop E, Enhos A, Bakhshaliyev N, Ozdemir R. P wave duration/P wave voltage ratio plays a promising role in the prediction of atrial fibrillation: a new player in the game. *Cardiol Res Pract*. 2021;2021:8876704. [CrossRef]
22. Yang N, Yan N, Cong G, Yang Z, Wang M, Jia S. Usefulness of Morphology-Voltage-P-wave duration (MVP) score as a predictor of atrial fibrillation recurrence after pulmonary vein isolation. *Ann Noninvasive Electrocardiol*. 2020;25(6):e12773. [CrossRef]