Simple electrocardiographic index for A4-wave amplitude of the VDD leadless pacemaker

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BACKGROUND A4-wave amplitude (A4-amplitude) is a crucial factor determining the percentage of atrioventricular synchrony (%AVS) in a mechanical sensing–based VDD leadless pacemaker (VDD-LP). We hypothesized that 12-lead electrocardiographic (ECG) parameters related to right atrial (RA) excitation could predict A4-amplitude.

OBJECTIVES We aimed to investigate the relationship between A4-amplitude and 12-lead ECG parameters reflecting RA excitation and assess its predictive power for achieving an appropriate A4-amplitude associated with high %AVS.

METHODS This single-center, retrospective, observational study enrolled consecutive patients undergoing VDD-LP implantation. The relationship between A4-amplitude and the positive peak amplitude of the P wave in lead II (P2), the positive peak amplitude of the P wave in lead V_1 (V1P), and the sum of P2 and V1P (V1PP2) were assessed.

RESULTS Of the 67 patients undergoing VDD-LP implantation, 46 without atrial fibrillation bradycardia were enrolled. They had a data set of manual atrial mechanical sensing tests and 12-lead ECG. Among P2, V1P, and V1PP2, only V1PP2 was correlated with A4-amplitude (R^2=0.10; P=.029). In 30 patients in VDD pacing mode, the median %AVS was 67.8%. The A4-amplitude cutoff for %AVS $\geq$ 67.8% was 3.2 m/s^2 (area under the curve [AUC] 0.81; P=.002). For A4-amplitude $\geq$ 3.2 m/s^2, V1PP2 had moderate predictive power (AUC 0.72; P=.007). In 30 patients without sick sinus syndrome, the predictive power of V1PP2 for A4-amplitude $\geq$ 3.2 m/s^2 was increased (AUC 0.80; cutoff value 110 μV; sensitivity 83%; specificity 71%; P=.011).

CONCLUSION V1PP2, reflecting RA excitation, was related to A4-amplitude and had moderate predictive power. Notably, its predictive power increased when limited to patients without sick sinus syndrome. V1PP2 is a simple ECG predictor of A4-amplitude.

KEYWORDS Leadless pacemaker; Atrioventricular synchrony; P-wave; 12-Lead electrocardiogram; Atrioventricular block; Sick sinus syndrome

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Introduction

A recent VDD leadless pacemaker (LP) system, Micra AV (Medtronic, Minneapolis, MN), enables atrioventricular synchrony (AVS) via mechanical sensing of the P wave.[1–3] By automatically identifying the A4 wave following the P wave, which reflects the bloodstream acceleration created by right atrial (RA) contraction, VDD-LP can sense atrial contraction using a built-in accelerometer.[1] Therefore, A4-wave amplitude (A4-amplitude) is crucial for maintaining a high percentage of AVS (%AVS). Establishing a predictor of A4-amplitude could aid in selecting patients for VDD-LP implantation.

A P wave on a 12-lead electrocardiogram (ECG) indicates atrial contraction.[4–6] The inferior leads (II, III, and aVF) and lead V_1 are the easiest for identifying P waves among the 12 leads. Among the inferior leads, the first half of the P wave in lead II primarily indicates inferiorly leftward RA conduction on the coronal plane. Meanwhile, lead V_1 has a biphasic P wave that reflects the divergence of the right and left atrial (LA) activations on the horizontal plane,[7–9] with the first half primarily consisting of RA activation. Because the A4 wave is generated by RA contraction, we hypothesized that the P-wave positive peak amplitude in both leads II and V_1 would be related to A4-amplitude.

In this study, we aimed to investigate the relationship between A4-amplitude and the P-wave positive peak amplitude

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KEY FINDINGS

- V1PP2, the sum of the V_1 positive peak (V1PP) amplitude and positive P-wave amplitude in lead II (P2), was related to A4-wave amplitude (A4-amplitude) after VDD leadless pacemaker implantation.
- The A4-amplitude cutoff for percentage of atrioventricular synchrony $\geq$ 67.8% (median in our institute) was 3.2 m/s^2.
- V1PP2 $\geq$ 110 μV was associated with A4-amplitude $\geq$ 3.2 m/s^2 in patients with atrioventricular block.

in leads II and V_1 after LP implantation and to create a simple ECG predictor of A4-amplitude.

Methods

Study population

This was a single-center, retrospective, observational study. Of the 67 patients who underwent successful implantation of VDD-LP (Micra-AV) between December 2021 and December 2023 at Osaka University Hospital, 46 who underwent the manual atrial mechanical (MAM) sensing test and 12-lead ECG were retrospectively enrolled (Figure 1). Patients with persistent atrial fibrillation (AF) bradycardia were excluded. Forty-four patients underwent the MAM test and 12-lead ECG on the same day, and 2 underwent 12-lead ECG within 2 weeks before the MAM test. This study was conducted in accordance with the Declaration of Helsinki, and the study protocol was approved by the Institutional Review Board of Osaka University Hospital. Consent was obtained using an opt-out method.

Measurement of the P-wave amplitude

We recorded a standard 12-lead ECG with a paper speed of 25 mm/s and voltage calibration of 1.0 mV/10 mm. The P-wave amplitude was manually measured using an electric caliper (PRM-4000, PrimeVitaPlus system, Nihon Koden, Co., Tokyo, Japan). In the measurement of the P-wave positive peak amplitude, voltage calibration was adjusted from 1.0 mV/10 mm (Figure 2A) to 1.0 mV/40 mm (Figure 2B). We measured the P-wave positive peak amplitude (positive peak to isoelectric line) in leads II (P2) and V_1 (V1P) (Figure 2C). The absolute amplitudes (positive peak to negative peak) in leads aVL and V_1[10] and maximum deflection index (MDI) in lead II were also measured.[11] The *MDI* was defined as the duration from the onset to the peak of the P-wave amplitude deflection divided by the P-wave duration, as previously reported.

Transthoracic echocardiographic parameters

All patients underwent transthoracic echocardiography before the MAM test. Data on the left ventricular (LV) end-diastolic diameter, LV end-systolic diameter, LV ejection fraction (using the Teichholz method), and LA diameter were retrospectively collected.

VDD-LP implantation procedure

Experienced electrophysiologists performed VDD-LP implantation in the catheterization laboratory. After puncturing the femoral vein, a delivery catheter was advanced into the right ventricular chamber. The catheter tip was subsequently pushed against the intraventricular septum, guided by right and left anterior oblique views with contrast reagent. The target implantation site was on the mid–intraventricular septum in the longitudinal mid-portion, if possible. However, if the number of engaged tines was <2 or the pacing parameters were inappropriate (criteria: pacing threshold < 1.0 V/0.24 ms; pacing impedance 400–1000 Ω), the VDD-LP was recaptured and repositioned.

VDD-LP setting protocol and measurement of A4-amplitude

The MAM test was performed in the resting supine position (Online Supplemental Material 1).[12] A4-amplitude was measured for each vector (1 + 2, 1 + 3, 2 + 3, and 1 + 2 + 3). The highest A4-amplitude among the 4 vectors was adopted for analysis. A4-amplitude was measured on a programmer by an electrophysiologist and a medical engineer.

Statistical analyses

Categorical variables are presented as number and percentage. Normally distributed continuous variables are expressed as mean ± SD, whereas non-normally distributed

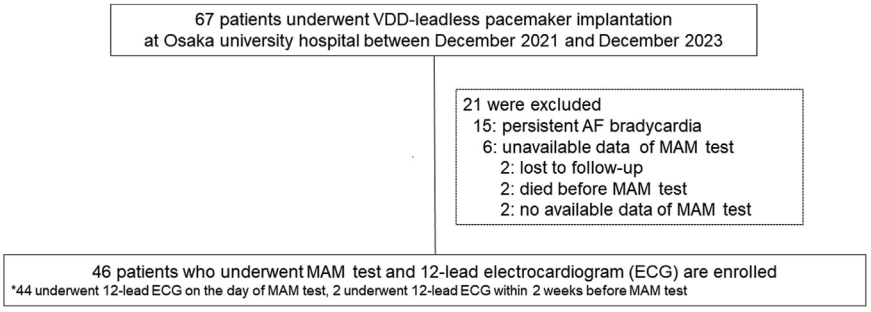

Figure 1 Study flowchart. Sixty-seven patients who undergo VDD leadless pacemaker implantation at Osaka University Hospital are retrospectively enrolled in this study. After excluding 21 patients, 46 are included. AF = atrial fibrillation; MAM = manual atrial mechanical.

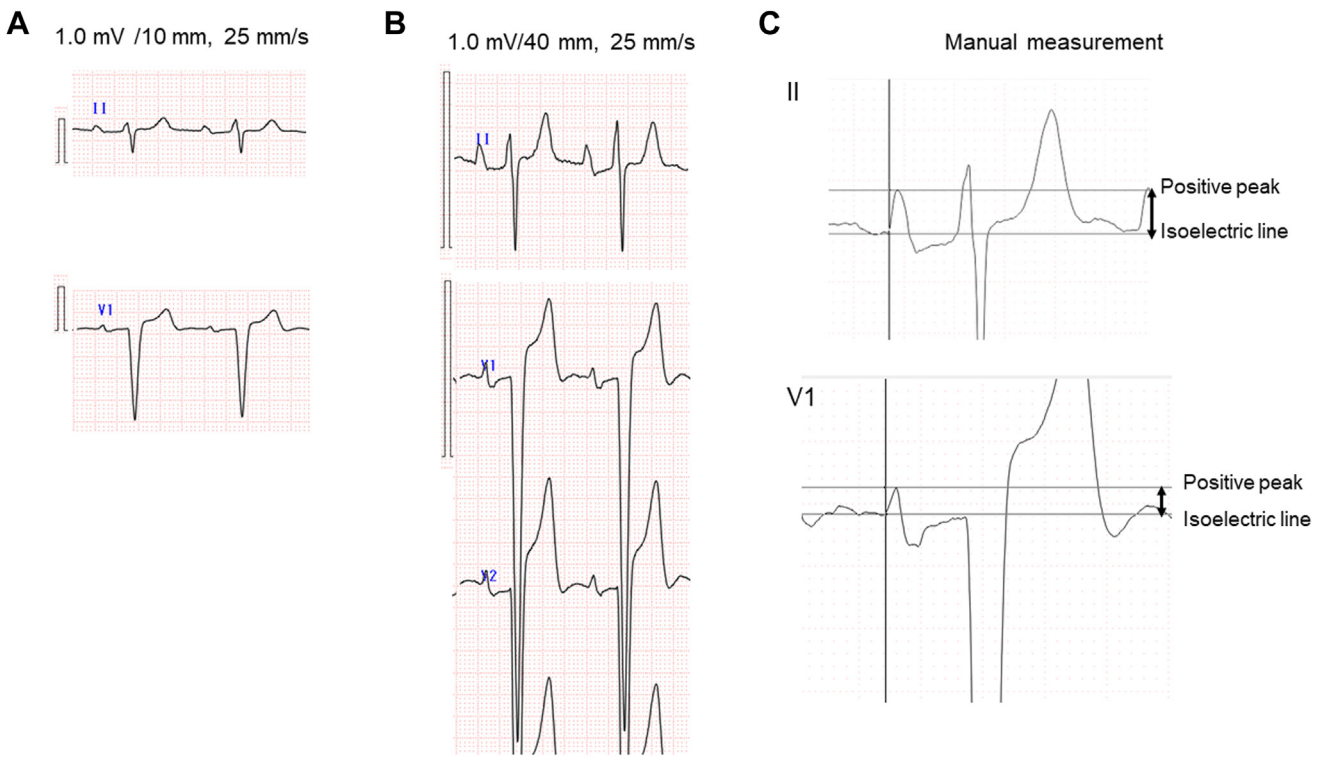

Figure 2 Measurement method of the P-wave positive amplitude in leads II and V_1. **A:** Standard 12-lead electrocardiogram with 1.0 mV/10 mm voltage calibration. **B:** Leads II and V_1 with 1.0 mV/40 mm voltage calibration. **C:** P-wave positive amplitude (positive peak to isoelectric line) is manually measured with an electric caliper.

variables are expressed as median and 25%–75% interquartile range. Normality was determined using the Shapiro-Wilk test. The relationship between 2 continuous variables was evaluated using the correlation coefficient (R). Receiver operating characteristic (ROC) analysis assessed the predictive power of each parameter for A4-amplitude. The optimal cutoff value was determined by considering the Youden index, and the area under the curve (AUC) was calculated. Statistical differences in non-normally distributed variables between the 2 groups were assessed using the Mann-Whitney U test. Categorical variables were analyzed using the χ^2 test. The interrater reliability (κ) was calculated. All reported P values are 2-sided, with a prespecified significance level of $P<.05$. Analyses were performed using MedCalc Software version 22.021 (MedCalc Software bvba, Ostend, Belgium).

Results

Baseline characteristics

Table 1 presents the baseline patient characteristics. The median age of the 46 patients was 78 (71–86) years, and 25 patients (54%) were female. The median body mass index was 21.5 (19.8–25.2) kg/m^2. Sixteen patients (35%) had transient sick sinus syndrome (SSS), and 30 patients (65%) had atrioventricular block (AVB). Among the patients with cardiac comorbidities, 43 patients (93%) had heart failure with preserved ejection fraction, 12 patients (26%) had paroxysmal AF, and 12 patients (26%) had a history of open heart surgery. The median LV ejection fraction was 69%. For the implantation procedure (Table 2), 34 patients (74%) was implanted in the mid-septum and 33 patients (72%) in the longitudinal mid-portion.

Relationship between the P-wave positive peak amplitude and A4-amplitude

The median A4-amplitude was 3.7 m/s^2 (Figure 3A). The median P2 and V1P were 92 and 53 μV, respectively (Figure 3B). The correlation between A4-amplitude and P2 and V1P was not significant (P2: $R^2=0.070$; $P=.076$ and V1P: $R^2=0.053$; $P=.12$) (Figures 3C and 3D). P2 did not correlate with V1P ($R^2=0.026$; $P=.28$) (Figure 3E). Some patients showed a discrepancy between P2 and V1P, that is, low P2/high V1P or high P2/low V1P. To adjust for the variations in P2 and V1P, we calculated the sum of P2 and V1P (V1PP2). The interrater reliability of V1PP2 was good (κ = 0.87 ± 0.02 [standard error]; 95% confidence interval 0.83–0.92) (Online Supplemental Material 2). The median V1PP2 was 153 μV (Figure 3B). V1PP2 was correlated with A4-amplitude ($R^2=0.104$; $P=.029$) (Figure 3F).

Best cutoff value for A4-amplitude based on %AVS

We assessed the A4-amplitude cutoff for optimal %AVS. Analyzing 21 patients with VDD pacing mode after the MAM test, we set the cutoff value for %AVS as

Table 1 Patient characteristics

Variable	Median or n	IQR or %
Age (y)	78	71–86
Female	25	54
Height (m)	1.56	1.50–1.66
Body weight (kg)	69	61–73
Body mass index (kg/m^2)	21.4	19.8–25.2
Predominant rhythm		
Sick sinus syndrome	16	35
Paroxysmal	16	35
Persistent	0	0
Atrioventricular block with normal sinus rhythm	30	65
Paroxysmal	11	24
Persistent	19	41
Comorbidity		
Hypertension	23	50
Dyslipidemia	16	35
Diabetes mellitus	10	22
Atrial fibrillation	12	26
Coronary heart disease	10	22
Chronic kidney disease	26	57
Stroke	2	4
Respiratory disease	3	7
Heart failure with preserved ejection fraction	43	93
Heart failure with mid-range ejection fraction	2	4
Heart failure with reduced ejection fraction	1	2
Adult congenital heart disease	1	2
Nonischemic cardiomyopathy	4	9
History of cardiac intervention		
Open heart surgery	12	26
Transcatheter aortic valve replacement	10	22
Surgical aortic valve replacement	7	15
Coronary aortic bypass graft	4	9
Catheter ablation	6	13
Percutaneous coronary intervention	4	9
Device extraction	4	9
Medication		
β-Blockers	11	24
ACE-I/ARB/ARNI	21	46
Mineral corticoid receptor antagonist	7	15
Sodium glucose transporter-2 inhibitor	2	4
Loop diuretics	11	24
Calcium channel blocker	15	33
Echocardiographic parameter		
LV end-diastolic diameter (cm)	4.4	4.1–4.9
LV end-systolic diameter (cm)	2.7	2.5–3.0
LV ejection fraction (%)	69	61–73
Left atrial diameter (cm)	4	3.7–4.6

ACEI = angiotensin-converting enzyme inhibitor; ARB = angiotensin receptor blocker; ARNI = angiotensin receptor blocker; IQR = interquartile range; LV = left ventricular.

Table 2 Parameters concerning leadless pacemaker implantation

Variable	Median or n	IQR or %
Electrical parameter at implantation		
Pacing threshold at 0.24 ms of pulse width (V)	0.63	0.5–1.0*
R-wave amplitude (mV)	8.2	5.8–10.8†
Impedance (Ω)	490	450–560
Device position		
Longitudinal axis		
Apical	11	24
Mid	33	72
Basal	2	4
Short axis		
High septum	3	7
Mid-septum	34	74
Low septum	9	20
Deployment attempts		
1	17	37
2	13	28
3	11	24
>4	5	11

IQR = interquartile range.
*Data from 3 patients are measured at 0.40 ms of pulse width.
†Two patients lacking own QRS complex are excluded.

≥67.8%, reflecting the median %AVS in our cohort. In the ROC analysis assessing the relationship between A4-amplitude and %AVS ≥ 67.8%, the best cutoff value for A4-amplitude was 3.2 m/s^2 (AUC 0.81; sensitivity 91%; specificity 70%; P=.002) (Figure 4A).

Predictive power of V1PP2 for sufficient A4-amplitude

V1PP2 demonstrated moderate predictive accuracy for A4-amplitude ≥ 3.2 m/s^2 (AUC 0.72; cutoff value 173 μV; sensitivity 54%; specificity 85%; P=.007) (Figure 4B). As shown in Online Supplemental Material 3 and 4, we assessed the predictive power of P2, V1P, and V1PP2 for various A4-amplitude cutoffs. V1PP2 demonstrated moderate predictive power for each A4-amplitude cutoff.

Predictive accuracy of V1PP2 in patients without SSS

AVS is important for patients with AVB rather than those with SSS. The P-wave amplitude was reportedly lower in patients with SSS than in those without.[13] We compared V1PP2 between patients with SSS (n=16) and those without SSS (n=30). V1PP2 appeared to be lower in patients with SSS (P=.56) (Figure 4C). In ROC analysis of patients without SSS (n=30), the predictive power for A4-amplitude cutoff ≥ 3.2 m/s^2 was higher than that in all patients (AUC 0.80; cutoff value 110 μV; sensitivity 83%; specificity 71%; P=.011) (Figure 4D). In 21 patients with VDD mode, the percentage of patients achieving %AVS ≥ 67.8% was 65% in those with V1PP2 ≥ 110 μV and 25% in those with V1PP2 < 110 μV (P=.16) (Online Supplemental Material 5).

Relationship between A4-amplitude and the reported P-wave index

We assessed the relationship between the reported P-wave index (MDI[11] and the sum of absolute amplitude in leads aVL and V_1[10]) and A4-amplitude. The MDI tended to be related to A4-amplitude (R^2=0.084; P=.057). The predictive power for A4-amplitude ≥ 3.2 m/s^2 was not significant (AUC

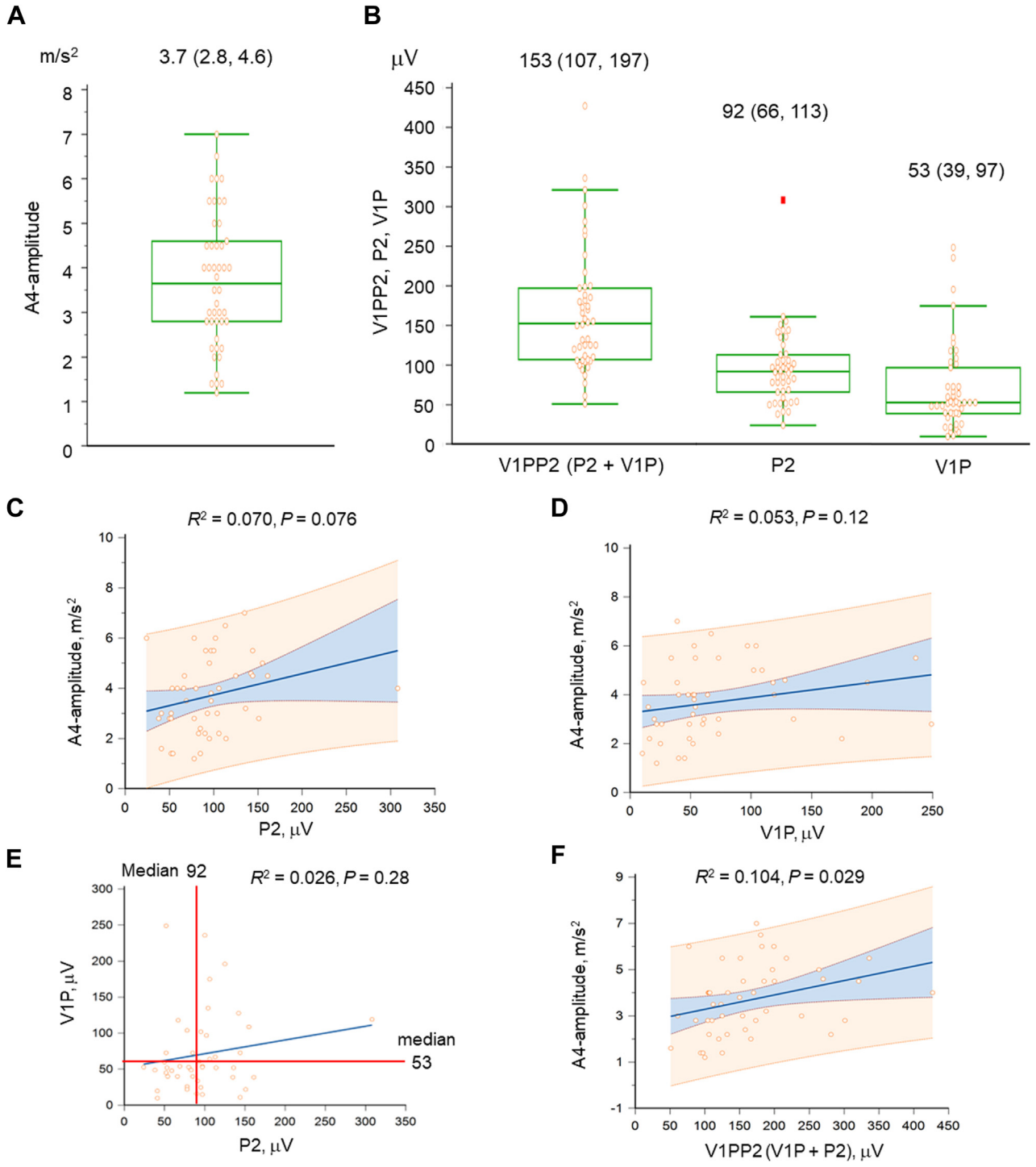

Figure 3 Distribution of A4-amplitude and P-wave positive peak amplitude in leads II and V_1. **A:** Distribution of A4-amplitude (m/s^2). **B:** Distributions of V1PP2, P2, and V1P. **C:** Correlation between P2 and A4-amplitude. **D:** Correlation between V1P and A4-amplitude. **E:** Correlation between P2 and V1P. **F:** Correlation between V1PP2 and A4-amplitude. The *blue line* represents the regression line; the *light blue curve* represents the 95% confidence interval; and the *orange curve* represents the 95% prediction interval. A4-amplitude = A4-wave amplitude; P2 = positive P-wave amplitude in lead II; V1P = positive P-wave peak amplitude in lead V_1; V1PP2 = positive P-wave amplitude in lead II plus positive P-wave peak amplitude in lead V_1.

0.61; P=.20) (Online Supplemental Material 6A–6C). The sum of absolute amplitude in leads aVL and V_1 was related to A4-amplitude (R^2=0.099; P=.034), and the predictive power for A4-amplitude $\geq$ 3.2 m/s^2 was moderate (AUC 0.67; P=.043) (Online Supplemental Material 6D–6F).

Discussion

We investigated the relationship between A4-amplitude and the positive peak amplitude of the P wave (P2, V1P, and V1PP2) and assessed the predictive power for A4-amplitude. The main findings were as follows:

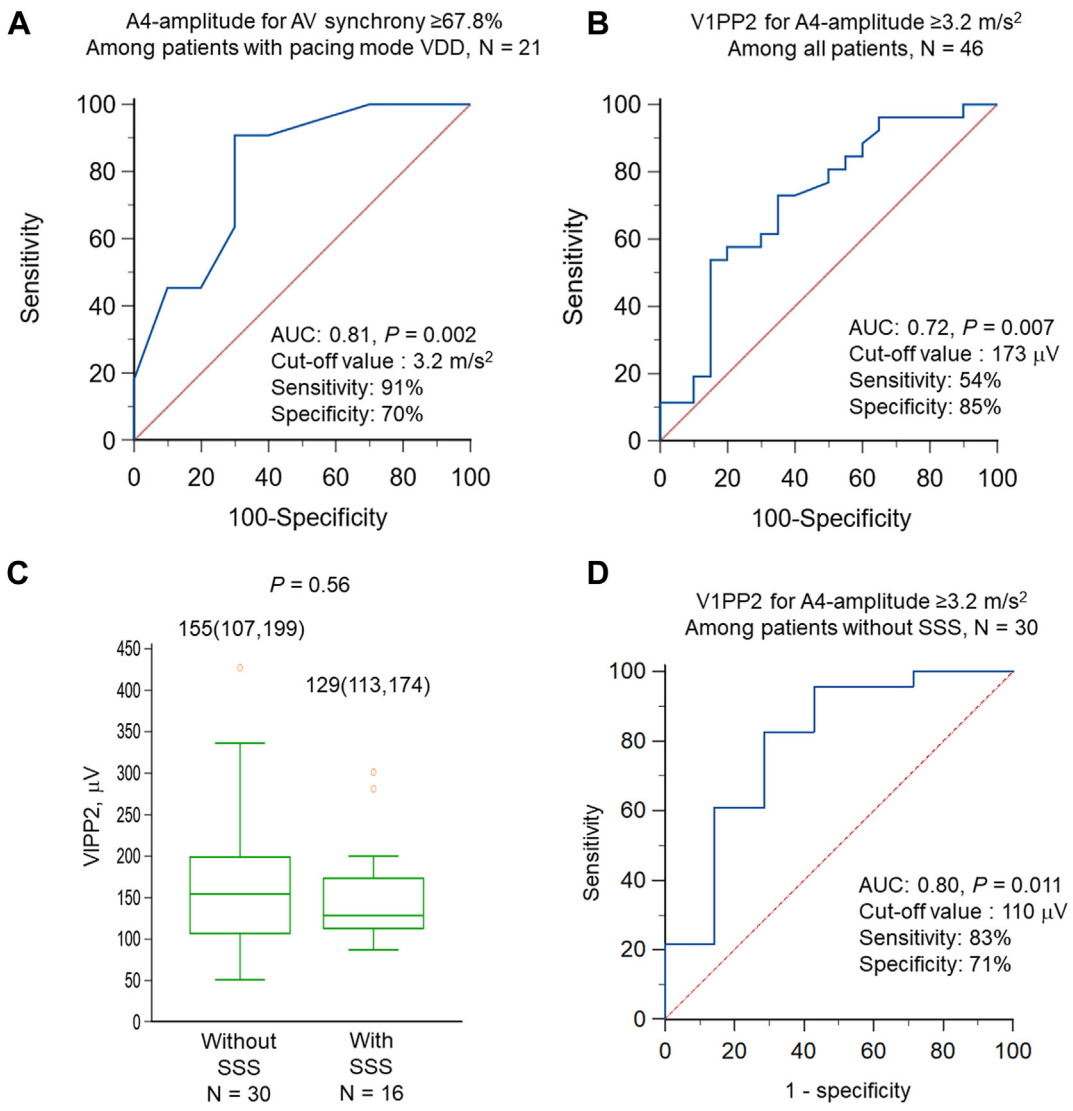

Figure 4 Predictive power of V1PP2 for A4-amplitude. **A:** ROC analysis (n = 21) of A4-amplitude for high %AVS ≥ 67.8%, which was the median %AVS in the 21 patients. **B:** ROC analysis of V1PP2 for A4-amplitude ≥ 3.2 m/s^2. **C:** Comparison of V1PP2 between patients with and without sick sinus syndrome. **D:** ROC curves of V1PP2 for 3.2 m/s^2 of A4-amplitude in patients without sick sinus syndrome (n = 21). A4-amplitude = A4-wave amplitude; AUC = area under the curve; %AVS = percentage of atrioventricular synchrony; P2 = positive P-wave amplitude in lead II; ROC = receiver operating characteristic; V1P = positive P-wave peak amplitude in lead V_1; V1PP2 = positive P-wave amplitude in lead II plus positive P-wave peak amplitude in lead V_1.

1. V1PP2 was a simple 12-lead ECG predictor of A4-amplitude.
2. The cutoff value for A4-amplitude for higher %AVS (≥67.8%) was 3.2 m/s^2, and V1PP2 was related to A4-amplitude ≥ 3.2 m/s^2 with a cutoff value of 173 μV in all patients.
3. In patients without SSS, the predictive accuracy of VIPP2 improved, with a cutoff value of 110 μV.

ECG parameters for RA activation

The introduction of a VDD-LP equipped with an accelerometer enabled AVS.[1] The Micra Atrial tRacking using a Ventricular accELerometer 2 study demonstrated that almost 90% of AVS cases were achieved in patients with AVB.[3] However, %AVS in real-world settings was lower than that in the Micra Atrial tRacking using a Ventricular accELerometer 2 study.[14,15] Factors influencing AVS include patient activity, body position, P-wave rate, and A4-amplitude, which reflect the acceleration of the bloodstream generated by the RA.[12] A sufficient A4-amplitude is desirable when setting the A4-amplitude threshold. Several echocardiographic predictors, such as atrial contraction excursion and LA strain, have been reported.[16] Recently, 2 groups reported ECG predictors of A4-amplitude,[10,11] including MDI and the absolute amplitude (peak-to-peak amplitude) of leads aVL plus V_1. The P-wave morphology, determined by the atrial voltage, conduction vector, and conduction time, could reflect A4-amplitude. Our group focused on the indicators of RA activation, P2, and V1P, because the acceleration of the bloodstream sensed by the accelerometer is generated by RA contraction. Dividing the P-wave duration in half, the first

half primarily reflects RA activation and the second half reflects LA activation.[17,18] P2 reflects the inferior and leftward vectors of atrial activation, with P2 consisting primarily of RA activation and partial LA activation. The P wave in lead V_1 showed a biphasic pattern, and V1P in the first half reflected RA activation.

V1PP2, a simple ECG predictor

First, we assessed the relationship of P2 and V1P with A4-amplitude. Contrary to our hypothesis, P2 and V1P did not show a correlation with A4-amplitude. The scatterplot showing the relationship between P2 and V1P revealed 4 variations: high P2/high V1P, low P2/low V1P, high P2/low V1P, and low P2/high V1P. Atrial morphology (eg, vertical heart and horizontal heart), sinus node location, and atrial scarring might cause this variation. To adjust for P2/V1P variation, we summed P2 and V1P (V1PP2), revealing a significant relationship with A4-amplitude. Next, we defined the A4-amplitude cutoff. The A4-amplitude cutoff used in the previous studies varied (eg, 2.5 m/s^2 of the median A4-amplitude in Kawatani et al[11] and 1.0 m/s^2 in Hofer et al[10]). As A4-amplitude might differ according to patient characteristics, examiners, body position, and sinus rate variety, defining a universal A4-amplitude cutoff might be difficult. In this study, we defined the A4-amplitude cutoff aiming for high %AVS. As the standard of high %AVS has not been established,[14,15,19] we defined it as the median value of 67.8%. By measuring parameters concerning AVS, a higher %AVS might be achievable.[12] Then, we calculated the A4-amplitude cutoff value for %AVS $\geq$ 67.8% as 3.2 m/s^2. The predictive power of V1PP2 for A4-amplitude $\geq$ 3.2 m/s^2 was moderate. We also tested the predictive power of V1PP2 for several A4-amplitude cutoffs. V1PP2 showed moderate predictive power for each A4-amplitude cutoff. Finally, we assessed the predictive accuracy of V1PP2 in patients without SSS. Progression of SSS decreased the P-wave amplitude in the inferior lead, suggesting that the pacemaker cells shifted downward and atrial fibrosis progressed, which may have caused an underestimation of RA contraction.[13,20] Furthermore, VDD mode is desirable for patients with AVB rather than those with SSS. After patients with SSS were excluded, the predictive power of V1PP2 improved. V1PP2 could facilitate real-world patient selection for VDD-LP.

Comparison of ECG predictors of A4-amplitude

Before our study, 2 prospective studies reported ECG parameters for A4-amplitude. Kawatani et al reported MDI, which reflects the RA conduction time relative to the whole atrial conduction time. Lower MDI indicates a larger dP/dt, resulting in a larger A4-amplitude. Hofer et al reported the absolute amplitude of leads aVL plus V_1, reflecting whole atrial activation including LA activation.[21,22] LA function was associated with A4-amplitude,[12,16] suggesting that LA contraction may surrogate RA contraction.

We summarized these studies together with our study in Table 3.[10,11] Several points should be considered when interpreting these results. First, patient characteristics (eg, age, sex, body mass index, race, comorbidity, and AF) could affect the stage of RA remodeling, which might determine A4-amplitude and ECG parameters. Because these were small-scale studies, the predictive power of each ECG parameter should be validated in a large-scale study. Second, the range of A4-amplitude differed. As a result, the A4-amplitude cutoff also differed. The predictive power of each ECG parameter could change according to the A4-amplitude cutoff. Kawatani et al adopted 2.5 m/s^2 of the median A4-amplitude, and Hofer et al adopted 1.0 m/s^2, which seemed quite low. To obtain the A4-amplitude cutoff applicable to clinical use, we defined the A4-amplitude cutoff on the basis of 67.8% of the median %AVS. The predictive power of V1PP2 should be validated in other populations. Since V1PP2 had moderate predictive power for 2.0—4.5 m/s^2 of the A4-amplitude cutoff, it might be applicable to a wide A4-amplitude range. Third, the inter-rater reliability could affect the predictive accuracy. For the accurate measurement, we measured P2 and V1P using 4-fold (1.0 mV/40 mm) calibration. P2 and V1P were easy to determine. We validated the effect of the 2 reported predictors. The measurement of MDI might require training of the examiner because the determination of P-wave onset and offset was difficult. Our MDI value was 15% larger than Kawatani's MDI (0.53 vs 0.46). Unfamiliar measurement might affect our result. Meanwhile, the peak amplitude might be easy to measure. Our absolute amplitude of aVL and V_1 value was equivalent to Hofer's (176 μV vs 180 μV). Considering these 3 studies, P-wave morphology should be considered when predicting A4-amplitude supporting high %AVS. We recommend V1PP2, which is a simple, reproducible, reasonable, and easy-to-remember predictor of A4-amplitude.

Study limitations

First, this was a single-center, retrospective, observational study that enrolled a small number of patients. There might have been bias in patient selection. Some of the analyses failed to show significant differences because of underpowering. Therefore, a large-scale study is needed to validate our results. Second, the timing of the MAM test was different for each patient because of its retrospective design. The MAM test and 12-lead ECG were performed a median of 208 days after implantation. Third, A4-amplitude changes dynamically with posture and hemodynamics. The MAM test was performed only in the resting supine position. AVS is not determined only by A4-amplitude. Fourth, the evaluation of true AVS was not validated using the Holter ECG. Fifth, although AVS optimization was performed as recommended by Medtronic, 67.8% of our median %AVS may not be high. The improvement in % AVS by the maximum configuration could have changed the results. Sixth, the manual measurement of the P-wave index could have included measurement bias as the values were small and delicate. To minimize bias, we used a

Table 3 Summary of the 3 studies investigating ECG parameters for A4-amplitude

Variable	Kawatani et al[11]	Hofer et al[10]	Present study
Study design	Prospective, single-center	Prospective, 2-centers	Retrospective, single-center
Patient number	50	61	46
Region	Asia, Japan	Europe, Switzerland	Asia, Japan
Age (y)	84 (median)	83 (77–87)	78 (71–86)
Female	18 (36%)	30 (49%)	25 (54%)
Body mass index (kg/m^2)	21 (median)	25.9 (22.9–33.6)	21.4 (19.8–25.2)
Comorbidity			
Hypertension	38 (76%)	46 (75%)	23 (50%)
Diabetes mellitus	17 (34%)	13 (21%)	10 (22%)
Chronic kidney disease	31 (62%)	35 (52%)	26 (57%)
Heart surgery	10 (20%)	31 (51%)	22 (48%)
Paroxysmal atrial fibrillation	13 (26%)	24 (39%)	12 (26%)
Pacemaker indication			
Permanent atrioventricular block	24 (48%)	26 (42%)	18 (39%)
Paroxysmal atrioventricular block	17 (34%)	19 (31%)	11 (24%)
Sick sinus syndrome	9 (18%)	7 (11%)	16 (35%)
Other	0 (0%)	9 (15%)	0 (0%)
Left ventricular ejection fraction (%)	60 (calculated from the Table 2)	n.a.	69 (61–73)
Mid-septal implantation	34 (68%)	31 (51%)	34 (74%)
ECG parameters			
Median A4-amplitude (m/s^2)	2.5	1.2	3.7
Absolute amplitude of lead V_1 (μV)	n.a.	110 (80–130)	102 (82–169)
Positive peak amplitude of lead II (μV)	130 (calculated from Table 3)	n.a.	92 (66–113)
Positive peak amplitude of lead V_1 (μV)	70 (calculated from Table 3)	n.a.	53 (39–97)
Maximum deflection index	0.46 (calculated from Table 3)	n.a.	0.53 ± 0.12
Absolute amplitude of leads aVL + V_1 (μV)	n.a.	180 (calculated from Table 2)	176 (133–249)

Values are presented as median (interquartile range) or absolute number (%).
A4-amplitude = A4-wave amplitude; ECG = electrocardiographic; n.a. = not applicable.

voltage calibration of 1.0 mV/40 mm. Seventh, we did not assess other factors affecting the P-wave amplitude (eg, body mass index and respiratory disease) because of the study design involving a small sample size. To assess the applicability of V1PP2, a large-scale study enrolling a diverse patient population is warranted. Eighth, we analyzed AVS after Micra AV1 implantation but the current Micra AV2 system is equipped with a new algorithm to adjust AVS. Using this new algorithm, the AVS of a diverse group of patients should be analyzed in a future study with a long follow-up period.

Conclusion

We retrospectively investigated the relationship between A4-amplitude and the P-wave positive peak amplitude in leads II and V_1 after VDD-LP implantation. V1PP2 was a simple ECG predictor of A4-amplitude to achieve optimal %AVS. The predictive power of V1PP2 was particularly improved in patients without SSS.

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Authorship: All authors attest they meet the current ICMJE criteria for authorship.

Patient Consent: Consent was obtained using an opt-out method.

Ethics Statement: This study was conducted in accordance with the Declaration of Helsinki, and the study protocol was approved by the Institutional Review Board of Osaka University Hospital.

Appendix

Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hroo.2025.01.006.

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