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The V_1–V_3 transition index as a novel electrocardiographic criterion for differentiating left from right ventricular outflow tract ventricular arrhythmias

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Abstract

Purpose The aim of this study was to develop a new electrocardiographic criterion for differentiating the origin of outflow tract ventricular arrhythmias (OT-VAs) with precordial transition in lead V_3.

Methods A total of 147 consecutive patients with OT-VAs displaying precordial transition in lead V_3 who underwent successful catheter ablation in the right ventricular outflow tract (RVOT) ($n = 118$) or left ventricular outflow tract (LVOT) ($n = 29$) were included in this study. The V_1–V_3 transition index was defined as the sum of S-wave amplitude in lead V_1 and V_2 during premature ventricular contractions (PVCs) divided by the S-wave amplitude during sinus rhythm (SR), respectively, minus the sum of R-wave amplitude in lead V_1, V_2, and V_3 during PVCs divided by the R-wave amplitude during SR, respectively, i.e., $[(S_{PVC}/S_{SR})V_1 + (S_{PVC}/S_{SR})V_2] - [(R_{PVC}/R_{SR})\ V_1 + (R_{PVC}/R_{SR})V_2 + (R_{PVC}/R_{SR})V_3]$.

Results The V_1–V_3 transition index was significantly higher for RVOT origins than for LVOT origins (1.25 ± 2.48 vs. -3.94 ± 3.11; $P < 0.001$). Receiver operating characteristic (ROC) analysis revealed an area under the curve (AUC) of 0.931 for the V_1–V_3 transition index, and a cutoff value of > -1.60 predicted a RVOT origin with a 93% sensitivity and 86% specificity. With respect to AUC and accuracy, the V_1–V_3 transition index was superior to any previously proposed ECG indices for differentiating left from right OT-VAs. In 37 prospective cases, the new index was able to predict the site of a RVOT origin with 95% accuracy (35 of 37 cases).

Conclusions The V_1–V_3 transition index is a useful novel ECG criterion for distinguishing left from right OT-VAs with precordial transition in lead V_3.

Keywords Catheter ablation · Electrocardiogram · Premature ventricular contraction · Ventricular outflow tract · Ventricular tachycardia

1 Introduction

Idiopathic outflow tract ventricular arrhythmias (OT-VAs) with a left bundle branch block and inferior axis QRS morphology includes premature ventricular contractions (PVCs) and ventricular tachycardias (VTs) originating from either the left ventricular outflow tract (LVOT) including the aortic cusps or the right ventricular outflow tract (RVOT)

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[1–3]. Predicting the anatomical origin of OT-VAs is important for mapping and catheter ablation procedures. Several electrocardiographic (ECG) algorithms have been proposed for differentiating LVOT from RVOT OT-VAs with precordial transition in lead V_3 [4–6]. However, their accuracy and usefulness are limited because the QRS morphology of OT-VAs can be affected by several factors such as lead position, cardiac anatomy, cardiac rotation, ventricular hypertrophy, breast size, body physique, gender, chest wall deformities, and preferential conduction across the ventricular outflow tract septum [7–9]. Moreover, some ECG algorithms can be used only in OT-VAs with a specific ECG pattern [5]. In this study, we aimed to develop a novel ECG criterion that could differentiate the origin of idiopathic OT-VAs with precordial transition zone in lead V_3. The accuracy, sensitivity, and specificity of the new criterion were compared with previously reported indices.

2 Methods

2.1 Patient selection

Consecutive patients with symptomatic OT-VAs and a precordial transition in lead V_3 (from R/S < 1 to R/S > 1) referred for catheter ablation between January 2009 and December 2018 were included in the present study. All antiarrhythmic drugs were discontinued for at least 5 half-lives before the study and no patient receiving amiodarone treatment. Exclusion criteria are patients with structural or ischemic heart disease, bundle branch block, paced rhythm, recorded R-wave amplitude in V_1 which was not 0 during sinus rhythm and OT-VAs, and unsuccessful ablation of OT-VAs.

2.2 Electrophysiological studies

Mapping and pacing were performed using an ablation catheter introduced from the right femoral vein (for the RVOT) or the right femoral artery (for the LVOT) (Prucka CardioLab recording system, GE Medical Systems, USA). When only a few PVCs were observed at the beginning of the electrophysiological study, induction of the OT-VAs was facilitated with isoproterenol infusion (2–4 μg/min). Intravenous heparin was administered to maintain an activated clotting time of > 250 s in LVOT procedures.

2.3 Mapping and radiofrequency catheter ablation

The 3-dimensional electroanatomic mapping system (CARTO, Biosense Webster, Diamond Bar, CA, USA) or the Ensite Array mapping system (Ensite, St. Jude Medical, MN, USA) was used in this study. The RVOT was initially mapped, and if no interesting bipolar and unipolar electrograms were recorded, LVOT mapping was then carried out. When OT-VAs were infrequent, pace mapping was performed during sinus rhythm (SR) at a pacing cycle length of 500 ms at an output just greater than the diastolic threshold as previously described [4]. The target site for the ablation was determined by the earliest bipolar electrogram preceding the QRS onset, the initial QS morphology for unipolar electrogram during OT-VAs and/or the excellent pace map (> 11/12 leads). When the earliest ventricular activation site was recorded at the LVOT, selective angiography of the coronary artery and aorta was performed to assess the anatomical relationships between these structures and the location of the ablation catheter. Irrigated radiofrequency ablation was delivered in a temperature control mode with a target temperature of 43 °C and maximum power of 35 W. When an acceleration or reduction in the incidence of the clinical OT-VAs was observed during the first 10 s of ablation, the radiofrequency delivery was continued for 120–180 s. Otherwise, the radiofrequency delivery was terminated, and the catheter was repositioned for new mapping. The endpoint of the catheter ablation was the elimination and non-inducibility of OT-VAs during an isoproterenol infusion (2–4 μg/min). Follow-up after the procedure included clinic visits with 24-h ambulatory (Holter) monitor. All patients who reported symptoms were given a 24-h Holter monitoring to document if the cause of the symptoms was due to OT-VAs. Successful catheter ablation was defined as (i) the absence of clinical OT-VAs with or without isoproterenol infusion at the end of the procedure and (ii) no recurrence of clinical OT-VAs during mora than 3 months of follow-up.

2.4 Electrocardiographic analysis

Surface 12-lead ECGs were recorded (Libang ECG recording, Libang Medical, Shenzhen, China) during SR and during the OT-VAs at a paper speed of 25 mm/s with limb and chest leads placed in a standard position. In particular, the electrodes of leads V_1 and V_2 were placed at the fourth intercostal space and the electrodes of lead V_3 was placed at the midway between leads V_2 and V_4 with careful attention because an incorrect electrode placement could markedly alter the QRS morphology of the OT-VAs. The QRS morphology during SR and OT-VAs was analyzed on the same 12-lead ECG using an electronic caliper. R-wave amplitudes in leads V_1–V_2 and S-wave amplitudes in leads V_1–V_3 measurements were performed manually and blinded to the PVC origin with 2 separate authors.

2.5 Definition of ECG indices for determining location of OT-VAs

The V_1–V_3 transition index was defined as the sum of S-wave amplitude in leads V_1 and V_2 during OT-VAs divided by the S-wave amplitude during SR, respectively, minus the sum of R-wave amplitude in leads V_1, V_2, and V_3 during OT-VAs divided by the R-wave amplitude during SR respectively, i.e., [(S_{PVC}/

$S_{SR})V_1 + (S_{PVC}/S_{SR})V_2] - [(R_{PVC}/R_{SR})V_1 + (R_{PVC}/R_{SR})V_2 + (R_{PVC}/R_{SR})V_3)]$. The $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index was calculated by computing lead V_2 the percentage R-wave during OT-VAs (R/R + S) divided by the percentage R-wave during SR (R/R + S) [5]. The PVC (S_{V2}/R_{V3}) transition index was defined as the S-wave amplitude in lead V_2 divided by the R-wave amplitude in lead V_3 during the OT-VAs [4].

2.6 Statistical analysis

The data were analyzed using SPSS (Version 23) and STATA (Version 13.0) statistical softwares. Continuous data are expressed as the mean ± SD or median as appropriate. Comparisons between groups were performed using the Mann–Whitney *U* test or independent samples *t* test as appropriate. A receiver operating characteristic analysis was used to calculate the sensitivity and specificity, and the AUC was used to compare the accuracy among the ECG criteria. We compared ROC curves using ROC chi-square test. A value of $P < 0.05$ was considered statistical significance.

3 Results

3.1 Clinical and electrophysiological data

Of 731 symptomatic patients without structural heart disease who underwent catheter ablation of drug-resistant OT-VAs between November 2011 and March 2019, 147 (20.1%) patients (78 men; mean age 52 ± 21 years; range 15–78 years) with OT-VAs displaying a precordial transition in lead V_3 were enrolled in this study. Based on mapping and successful ablation sites, 118 subjects exhibited a RVOT origin and 29 subjects a LVOT origin. All the OT-VAs in the RVOT group were successfully ablated at the septal wall, 20 cases of OT-VAs in the LVOT group were successfully ablated at the anterior part of the right coronary cusp, 7 cases of OT-VAs in the LVOT group were successfully ablated at the anterior part within the left coronary cusp, and 2 cases of OT-VAs in the LVOT group were successfully ablated at the anterior part under the left coronary cusp.

3.2 Development of the novel ECG criterion (V_1–V_3 transition index) and its predictive accuracy

The lead $(V_1(S_{PVC}/S_{SR}) + V_2(S_{PVC}/S_{SR}) + V_3(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$ exhibited an AUC of 0.842, the lead $(V_1(S_{PVC}/S_{SR}) + V_2(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}))$ 0.882, the lead $(V_1(S_{PVC}/S_{SR}) + V_2(S_{PVC}/S_{SR}) + V_3(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}))$ 0.783, the lead $V_1(S_{PVC}/S_{SR})/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$ 0.890, the lead $(V_2(S_{PVC}/S_{SR}) + V_3(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$ 0.771, and the lead $V_3(S_{PVC}/S_{SR})/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$ 0.569. Among the sum, subtraction, multiplication, and division of these 6 ECG measurements, the V_1–V_3 transition index exhibited the greatest AUC of 0.931 (Table 1) and was defined as the novel ECG criterion. The V_1–V_3 transition index was significantly higher for RVOT origins than for LVOT origins (1.25 ± 2.48 vs. − 3.94 ± 3.11; $P < 0.001$). The interobserver agreement in measurement of R- and S-wave amplitudes yielded an intra-class correlation coefficient of 0.953 (95% confidence interval 0.943 to 0.978, $P < 0.001$), and the kappa statistic for classification agreement was 0.894 ($P < 0.001$). In 37 prospective cases, the new index was able to predict the site of a RVOT origin with 95% accuracy (35 of 37 cases), the $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index was able to predict the site of a RVOT origin with 92% accuracy (34 of 37 cases), and PVC (S_{V2}/R_{V3}) transition index was able to predict the site of a RVOT origin with 86% accuracy (32 of 37 cases). The interobserver agreement in measurement of R- and S-wave amplitudes yielded an intra-class correlation coefficient of 0.932 (95% confidence interval 0.887 to 0.953, $P < 0.001$), and the kappa statistic for classification agreement was 0.835 ($P < 0.001$).

3.3 Comparison of the V_1–V_3 transition index with previously proposed indices

The V_1–V_3 transition index was compared with well-known ECG indices. The novel V_1–V_3 transition index displayed an AUC of 0.931, with a cutoff value of > − 1.60 predicting an RVOT origin with a 93% sensitivity and 86% specificity. The $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index had an AUC of 0.909, with a cutoff value of > 0.60 predicting an LVOT origins with a 98% sensitivity and 21% specificity. The PVC (S_{V2}/R_{V3}) transition index had an AUC of 0.872, with a cutoff value of < 1.5 predicting a LVOT origin with an 84% sensitivity and 76% specificity. Dot plot shows the distribution of V_1–V_3 transition index, $V_2(R/R+S)_{PVC}/V2(R/R+S)_{SR}$ transition index, and the PVC (S_{V2}/R_{V3}) transition index in the RVOT group and the LVOT group. Figure 2 shows precordial R/S > 1 in lead V_3 with prominent S-wave in lead V_1 is noted during PVCs than during SR, and the traditional index incorrectly predicted the origin of PVCs. Figure 3 shows examples where the traditional index and the V_1–V_3 transition index correctly predicted the origin of PVCs. The comparison of the ROC curves of V_1–V_3 transition index and the other ECG indices is depicted in Table 1.

3.4 Data regarding prospective population

The new ECG criterion was investigated prospectively in 37 cases of OT-VAs displaying transition zone in lead V_3. The new index was able to predict the site of a RVOT origin with 95% accuracy (35 of 37 cases) and a LVOT origin with 75% accuracy (3 of 4 cases). The index failed to determine the arrhythmia origin in two cases in the RVOT group because of OT-VA

Table 1 Comparison of the electrocardiographic indices for predicting the origin of outflow tract ventricular arrhythmias

ECG index	AUC	Lower CI	Upper CI	Error	Pr > Chi^2	Chi^2
V_1–V_3 transition index	0.931	0.885	0.997	0.023	–	–
$V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index	0.909	0.857	0.960	0.026	0.1942	1.6853
PVC (S_{V2}/R_{V3}) transition index	0.872	0.808	0.936	0.033	0.0917	2.8443
$(V_1(S_{PVC}/S_{SR}) + V_2(S_{PVC}/S_{SR}) + V_3(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$	0.842	0.755	0.929	0.004	0.0063	7.4549
$(V_1(S_{PVC}/S_{SR}) + V_2(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}))$	0.882	0.805	0.959	0.039	0.1273	2.3245
$(V_1(S_{PVC}/S_{SR}) + V_2(S_{PVC}/S_{SR}) + V_3(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}))$	0.783	0.688	0.879	0.049	0.0001	15.6330
$V_1(S_{PVC}/S_{SR})/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$	0.890	0.814	0.967	0.039	0.2153	1.5355
$(V_2(S_{PVC}/S_{SR}) + V_3(S_{PVC}/S_{SR}))/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$	0.771	0.676	0.866	0.048	0.00	17.8287
$V_3(S_{PVC}/S_{SR})/(V_1(R_{PVC}/R_{SR}) + V_2(R_{PVC}/R_{SR}) + V_3(R_{PVC}/R_{SR}))$	0.569	0.464	0.675	0.054	0.00	55.4352

CI, confidence interval. The reported Chi^2 and Pr > Chi^2 for each ECG marker were calculated comparing each marker with V_1–V_3 transition index

origin at the left–right coronary cusp commissure site with a precordial transition in lead V_3. The index failed to determine the arrhythmia origin in one case in the LVOT group because of originating from the RVOT exhibit preferential conduction to the right coronary cusps.

4 Discussion

This study describes the accuracy, sensitivity, and specificity of the novel V_1–V_3 transition index for differentiating left from right OT-VAs. Prediction of the origin of OT-VAs before the catheter ablation procedure has become increasingly essential because a different anatomical approach is required for mapping depending on the location [4]. Knowledge of the anatomic relation between the RVOT and LVOT including the aortic sinus cusps is essential for the accurate diagnosis of the origins of OT-VAs [10, 11]. Anatomically, the aortic sinus cusp (ASC) occupies a central location within the heart, and the location of RVOT is more anterior and leftward of the aortic root. The anteriorly situated RVOT passes slightly superior to and leftward of the ASC. The more distal posterior RVOT myocardium is immediately adjacent to the right coronary cusp (RCC) and part of the left coronary cusp (LCC) [12, 13]. The intimate nature of these two structures explains why OT-VAs from these two distinct locations can be morphologically similar on surface ECG, and ablation in the RVOT/LVOT can also lead to coronary artery occlusion, stenosis, or pseudoaneurysm [14–16]. With RCC origin, the transition was always at or before lead V_3 and frequently had an overall positive vector by lead V_2. However, the typical precordial transition for the RVOT has been shown to be at lead V_3 or later. Occasionally, the best location to map or ablate an OT-VAs in the RCC may be from the posterior RVOT or vice versa.

Several ECG markers have been proposed for differentiating an OT-VA of a LVOT from that of a RVOT origin. Ouyang et al. found that a greater R-wave duration and R/S-wave amplitude ratio in lead V_1 or V_2 reliably predicted an aortic sinus cusp compared with RVOT origin [17]. Cheng et al. reported R-wave deflection interval in lead $V_3 > 80$ ms combining with R-wave amplitude index in lead $V_1 > 0.30$ which can reliably distinguish LVOT from RVOT origin in idiopathic outflow tract OT-VAs in patients with transitional lead at V_3 [18]. Betensky et al. reported that the $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index > 0.60 predicted an LVOT origin with a sensitivity of 87% and specificity of 69% [5]. Yoshida et al. reported that the PVC (S_{V2}/R_{V3}) transition index with a cutoff value of < 1.5 predicted a LVOT origin with an 89% sensitivity and 94% specificity [4]. Herczku C et al. reported that the 10-ms isochronal map area and the longitudinal/perpendicular axis ratio accurately predict a left ventricular outflow tract origin of idiopathic ventricular tachycardia with V_3 transition and septal earliest activation [6]. Tanner H et al. reported that a stepwise endocardial and epicardial mapping through up to six anatomic approaches can lead to successful radiofrequency catheter ablation [19]. But these aforementioned ECG algorithms can be used only in OT-VAs with a specific ECG pattern, and the use of these mentioned indices may lead to incorrect prediction of the PVC origin.

In this study, we compared the predictive value of V_1–V_3 transition index with the two previously proposed ECG indices. Figure 1 shows dot plot for the distribution of V_1–V_3 transition index, $V_2(R/R+S)_{PVC}/V2(R/R+S)_{SR}$ transition index, and the PVC (S_{V2}/R_{V3}) transition index in the RVOT group and LVOT group. Figure 2 shows precordial R/S > 1 in lead V_3 with prominent S-wave in lead V_1 which is noted during PVCs than during sinus rhythm (SR). The calculated V_1–V_3 transition index was higher than the cutoff point (− 0.53 vs. − 1.60), suggesting a RVOT origin. On the contrary, the $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index was larger than its cutoff point (1.13 vs. 0.60), and the PVC (SV_2/RV_3) transition index was smaller than its cutoff point (0.96 vs. 1.94), suggesting a LVOT origin. The $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ and PVC (SV_2/RV_3) transition

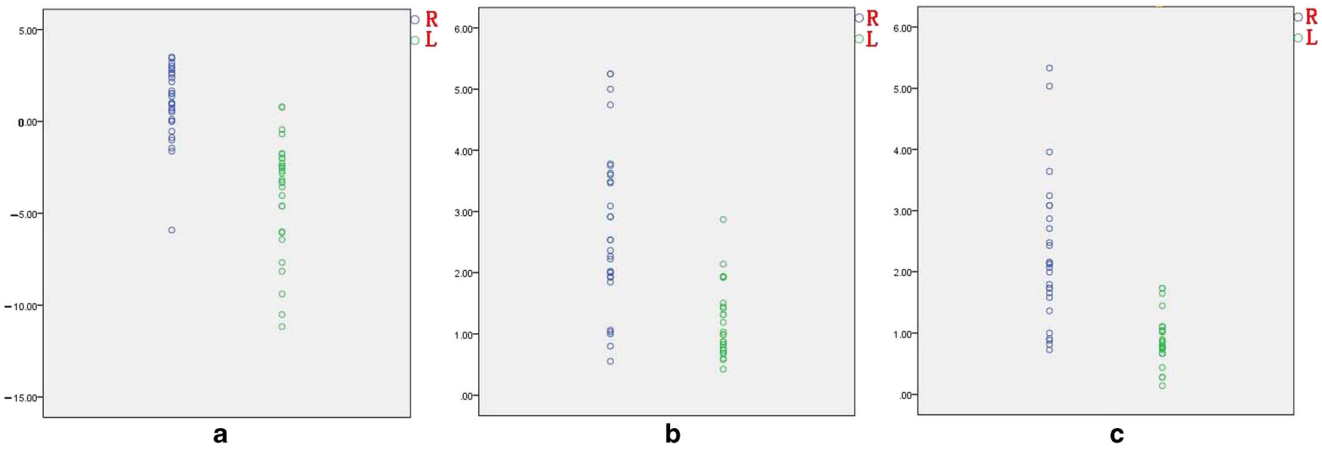

Fig. 1 Dot plot shows the distribution of V_1–V_3 transition index, $V_2(R/R+S)_{PVC}/V2(R/R+S)_{SR}$ transition index, and the PVC (S_{V2}/R_{V3}) transition index in the right ventricular outflow tract (RVOT) group and the left ventricular outflow tract (LVOT) group. **a** Dot plot of the distribution of V_1–V_3 transition index. **b** Dot plot of the distribution of $V_2(R/R+S)_{PVC}/V2(R/R+S)_{SR}$ transition index. **c** Dot plot of the distribution of PVC (S_{V2}/R_{V3}) transition index. R, RVOT group; L, LVOT group

indexes do not calculate the prominent S-wave in lead V_1 during PVC, which leads to incorrect prediction. Figure 3 shows examples where the two traditional indexes and the V_1–V_3 transition index correctly predicted the origin of PVCs. The main

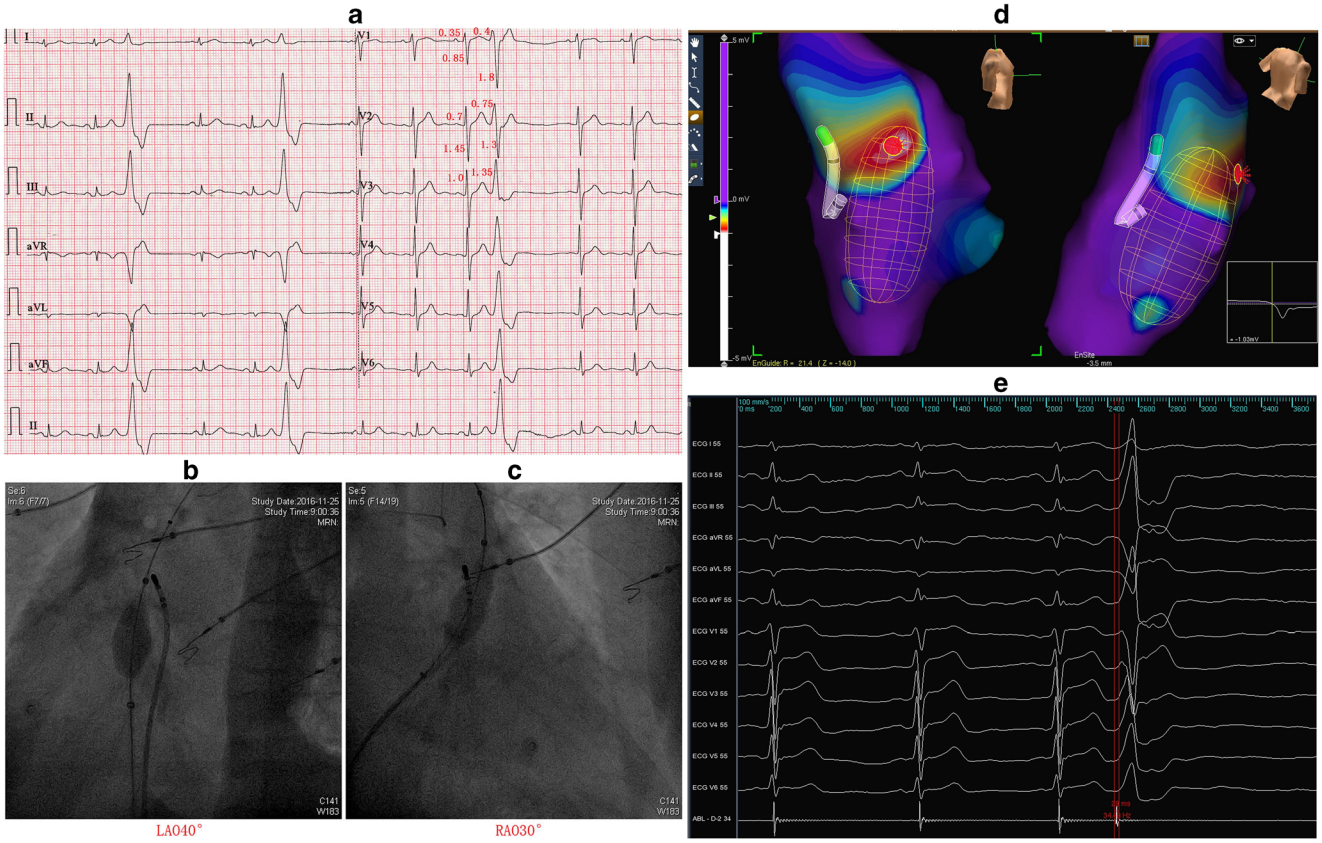

Fig. 2 Successful ablation of premature ventricular contraction (PVC) with a posterior RVOT origin but the two traditional indexes predicting instead a left origin. **a** Precordial R/S > 1 in lead V_3 with prominent S-wave in lead V_1 is noted during PVCs than during sinus rhythm (SR). The calculated V_1–V_3 transition index was higher than the cutoff point (− 0.55 vs. − 1.60) suggesting a RVOT origin. On the contrary, the $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index was larger than its cutoff point (1.13 vs. 0.60), and the PVC (SV_2/RV_3) transition index was smaller than its cutoff point (0.96 vs. 1.94), suggesting a LVOT origin. The $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ and PVC (SV_2/RV_3) transition indexes predicting instead a LVOT origin. **b** X-ray target LAO 40° projection. **c** X-ray target RAO 30° projection, the target is at the posterior RVOT. **d** Ensite Array mapping showing perfect propagation map and unipolar electrogram. **e** Bipolar target potential showing a V-QRS interval of 29 ms with a near-field potential. See the text for further details

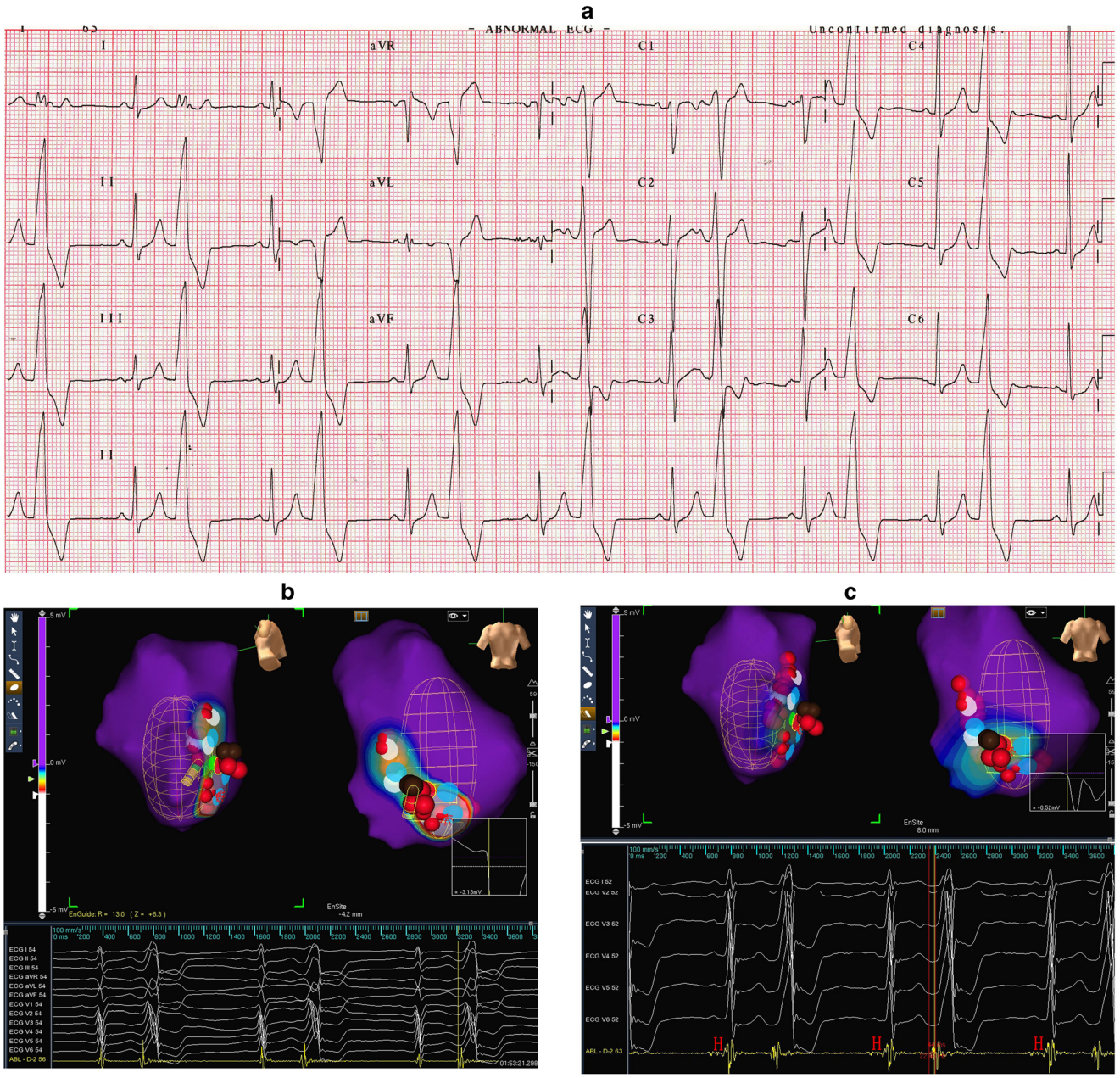

Fig. 3 **a** Successful ablation of a PVC originating from the right coronary cusp (RCC) and all the three indexes correctly predicted the origin. The V_1–V_3 transition index was smaller than the cutoff point (− 2.8 vs. − 1.60), the $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index was larger than the cutoff point (1.22 vs. 0.6), and the PVC (SV_2/RV_3) transition index was smaller than the cutoff point (1.32 vs. 1.5). **b** Ensite Array mapping at posterior RVOT, the unipolar electrogram with a small R-wave, the propagation map is not ideal; bipolar target recording with far-field potential at the start. **c** Bipolar target recording at RCC, V-QRS interval is 44 ms with perfect fragmented near-field potential, note that during SR, a far-field potential is recorded, the substrate giving rise to the PVC was successfully ablated

feature in the ECG is that the R-wave in leads V_1–V_3 was larger during PVC than during SR, and the S-wave in lead V_1–V_2 during PVC was slightly smaller than that during SR. All of these findings would predict a LVOT origin. In this study, the novel V_1–V_3 transition index showed the best predictive value; the highest AUC of 0.931 and a cutoff point of > − 1.60 predicted an RVOT origin with a sensitivity of 98% and specificity of 87%. The V_1–V_3 transition index comprehensively took into account the R-wave amplitude in leads V_1–V_3 and the S-wave amplitude in leads V_1 and V_2 during SR and OT-VAs. However, the $V_2(R/R+S)_{PVC}/V_2(R/R+S)_{SR}$ transition index derived data only from one lead during SR and OT-VAs, while the PVC (S_{V2}/R_{V3}) transition index took into account the S-wave amplitude in lead V_2 and the R-wave amplitude lead V_3 only during OT-VAs. Some PVCs originating from the RVOT only present with an especially prominent S-wave in lead V_1, and the use of the

previously mentioned indices may lead to incorrect prediction of the PVC origin. The V_1–V_3 transition index is a novel ECG criterion that accurately differentiates a LVOT from RVOT origin independent of the site of the precordial transition.

5 Limitations

The present study display limitation. First, a small number of patients with LVOT origin were initially validated to develop the V_1–V_3 transition index, and therefore, our data have to be interpreted with caution. Second, although our proposed criterion provided a higher predictive accuracy for OT-VAs with precordial transition in lead V_3 compared with previously proposed indices, further studies are warranted to compare all current criteria for localization of OT-VAs.

6 Conclusions

The novel V_1–V_3 transition index is an accurate ECG tool for the prediction of the OT-VAs origin in patients with idiopathic OT-VAs with transition zone in lead V_3. The use of this index may increase the safety and shorten the procedural time by avoiding unnecessary arterial or venous punctures.

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Compliance with ethical standards

This study was approved by the TEDA International Cardiovascular Hospital ethics committee for clinical research. All patients provided written informed consent.

Conflict of interest The authors declare that they have no conflict of interest.

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