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THREE-DIMENSIONAL ELECTROANATOMIC MAPPING-GUIDED COMPLETE ZERO-FLUOROSCOPY ABLATION OF PREMATURE VENTRICULAR COMPLEXES: FEASIBILITY AND PATIENT SELECTION CHARACTERISTICS

Nguyen Thi Thu Ha[1,2], Phan Dinh Phong[2], Hoang Trung Kien[1], Do Duc Thinh[1], Nguyen Manh Hung[1], Ninh Thi Nhu Quynh[1], Nguyen Dai Nghia[3], Vu Van Ba[3]*

[1]Cardiovascular Center, E Hospital
[2]Hanoi Medical University
[3]University of Medicine and Pharmacy, Vietnam National University, Hanoi

ABSTRACT

Background: Complete zero-fluoroscopy ablation of premature ventricular complexes (PVCs) guided by three-dimensional electroanatomic mapping may eliminate radiation exposure. However, its feasibility depends on appropriate patient selection, particularly in settings where intracardiac echocardiography is not routinely available.

Objective: To evaluate the feasibility of complete zero-fluoroscopy PVC ablation and to identify electrocardiographic characteristics associated with successful completion of the procedure without fluoroscopy.

Methods: This descriptive observational study included patients undergoing catheter ablation for PVCs at the Cardiovascular Center, E Hospital, from January 2025 to May 2026. Clinical characteristics, 12-lead electrocardiographic findings, Holter data, anatomical sites of origin, and procedural outcomes were analyzed according to whether the procedure was completed entirely without fluoroscopy.

Results: A total of 60 patients were included. Forty patients were initially selected for a complete zero-fluoroscopy strategy, of whom 37 completed the procedure without fluoroscopic guidance, yielding a feasibility rate of 92.5%. Three patients crossed over to fluoroscopic support; the final sites of origin were the right coronary cusp in one patient and suspected intramural origins in two patients. Compared with the fluoroscopy-used group, the complete zero-fluoroscopy group had a lower R/RS ratio in lead V2 during PVCs (0.13 ± 0.10 vs. 0.42 ± 0.34, $p < 0.001$), a later PVC precordial transition index (2.94 ± 1.10 vs. 2.00 ± 0.60, $p < 0.001$), and a lower V2 transition ratio (0.41 ± 0.31 vs. 1.94 ± 2.90, $p < 0.001$). In the complete zero-fluoroscopy group, acute procedural success was achieved in 97.3% of patients; mean procedural time was 60.1 ± 29.2 minutes and mean ablation time was 346.5 ± 196.4 seconds. No major complications occurred.

Conclusion: Three-dimensional electroanatomic mapping-guided complete zero-fluoroscopy ablation of PVCs is highly feasible in appropriately selected patients. Electrocardiographic features suggesting late precordial transition may support patient selection for this strategy.

Keywords: *Premature ventricular complexes; zero fluoroscopy; three-dimensional electroanatomic mapping; electrocardiography.*

1. INTRODUCTION

Premature ventricular complexes (PVCs) are common cardiac arrhythmias that may cause symptoms, impair quality of life, and, in patients with a high PVC burden, contribute to left ventricular dysfunction. According to the 2022 European Society of Cardiology guidelines, catheter ablation represents an important therapeutic option for symptomatic idiopathic PVCs, particularly for arrhythmias originating from the right ventricular outflow tract (RVOT) and for cases of suspected PVC-induced cardiomyopathy[1].

Three-dimensional electroanatomic mapping systems enable real-time catheter localization, reconstruction of intracardiac anatomy, and identification of the earliest activation site with minimal reliance on fluoroscopy. Recent evidence suggests that zero-fluoroscopy ablation of ventricular arrhythmias is feasible and may eliminate radiation exposure without compromising acute procedural efficacy[2,3]. Nevertheless, the feasibility of completing PVC ablation entirely without fluoroscopy is influenced by several factors, including the presumed site of origin, anatomical complexity, intraprocedural PVC frequency, catheter stability, and operator experience.

In many centers, including those in Vietnam, intracardiac echocardiography is not routinely available for ventricular arrhythmia ablation. In this setting, preprocedural 12-lead electrocardiography becomes particularly important for estimating the PVC site of origin and selecting appropriate candidates for a zero-fluoroscopy strategy. Electrocardiographic features such as QRS morphology in lead V1, frontal plane axis, precordial transition, and the R/RS ratio in lead V2 may help distinguish RVOT from left ventricular outflow tract origins[4,5]. In clinical practice, PVCs with late precordial transition, especially from V3 onward, are more suggestive of a right-sided chamber or RVOT origin and may therefore be more suitable for a complete zero-fluoroscopy approach.

This strategy was informed by previous experience with zero-fluoroscopy ablation of ventricular arrhythmias originating from the RVOT. In the study by Vu Van Ba et al., patients were selected based on electrocardiographic features consistent with RVOT origin, including left bundle branch block morphology, inferior axis, and precordial transition from V3 onward. The study demonstrated that three-dimensional electroanatomic mapping-guided zero-fluoroscopy ablation achieved efficacy and safety comparable to conventional fluoroscopy-guided ablation[6]. Building on this approach, the present study aimed to evaluate the feasibility, patient selection characteristics, and acute procedural outcomes of complete zero-fluoroscopy PVC ablation guided by three-dimensional electroanatomic mapping.

2. METHODS

2.1. Study design and population

• This descriptive observational study included patients undergoing catheter ablation for premature ventricular complexes (PVCs) at the Cardiovascular Center, E Hospital, from January 2025 to May 2026.

• Patients were eligible if they had an indication for catheter ablation according to current recommendations[1], available preprocedural 12-lead electrocardiograms documenting PVC morphology, and provided

[1]Cardiovascular Center, E Hospital
[2]Hanoi Medical University
[3]University of Medicine and Pharmacy, Vietnam National University, Hanoi
*Corresponding author: Vu Van Ba
Email: drbavuvan@gmail.com - Tel: 0977142107
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consent to participate.

• Patients were excluded if the electrocardiogram was of insufficient quality for analysis, if PVCs were absent during the procedure, if they declined participation, or if key clinical or procedural data were missing.

2.2. Procedural strategy and grouping

Before the procedure, all patients underwent 12-lead electrocardiographic analysis to estimate the likely PVC site of origin. A complete zero-fluoroscopy strategy was preferentially selected when the preprocedural ECG suggested a right ventricular outflow tract or right-sided origin. This selection approach was adapted from the criteria used by Vu Van Ba et al., including a left bundle branch block morphology during ventricular ectopy, an inferior frontal-plane axis, and precordial transition at V3 or later. These criteria were used to guide patient selection rather than as absolute diagnostic criteria for the anatomical site of origin[6].

Patients were classified into two groups: the initial zero-fluoroscopy group and the planed fluoroscopy group. The initial zero-fluoroscopy group included patients in whom the entire procedure was completed without fluoroscopic guidance. The planed fluoroscopy group included patients in whom fluoroscopy was planned from the outset and those initially selected for a zero-fluoroscopy strategy who crossed over to fluoroscopic support during the procedure for technical or safety reasons.

2.3. Procedural workflow

All procedures were performed using a three-dimensional electroanatomic mapping system (EnSite Precision, Abbott) from the beginning. In the initial zero-fluoroscopy group, catheter navigation was guided entirely by the three-dimensional map, intracardiac electrograms, and electroanatomic landmarks (Figure 1). In the planned fluoroscopy group, fluoroscopy was used as an adjunct to support catheter localization, confirm anatomical orientation, guide access when required, or maintain procedural safety in complex cases. The zero-fluoroscopy strategy was not mandatory once selected. Operators were instructed to convert to fluoroscopic support whenever anatomical uncertainty, catheter instability, suspected left-sided or intramural origin, or any safety concern was encountered.

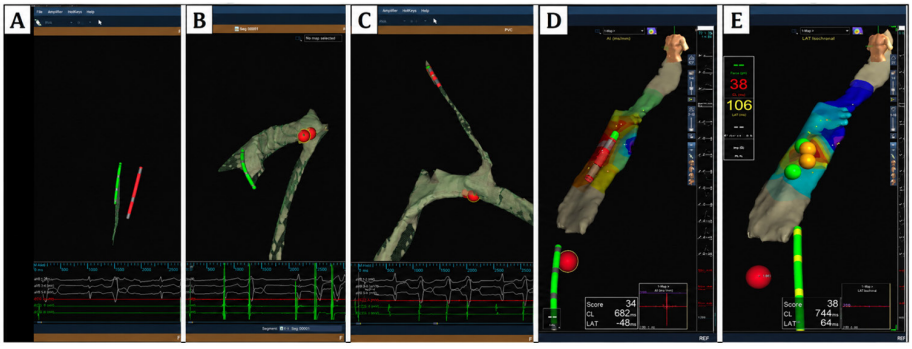

Figure 1. Stepwise workflow of right ventricular–oriented complete zero-fluoroscopy PVC ablation using three-dimensional electroanatomic mapping

(A) Following femoral venous access, a quadripolar diagnostic catheter was introduced for initial non-fluoroscopic navigation; (B) The diagnostic catheter was advanced into the heart and used to delineate key electroanatomic landmarks; (C) The ablation catheter was subsequently advanced along the previously established catheter trajectory under three-dimensional mapping guidance; (D) Activation mapping was performed to localize the earliest site of the clinical premature ventricular complex; (E) Radiofrequency energy was delivered at the mapped PVC origin.

2.4. Study outcomes

The primary outcome was the feasibility of the complete zero-fluoroscopy strategy, defined as the proportion of patients who completed the procedure entirely without fluoroscopy among those initially selected for this approach. Acute procedural success was defined as elimination of the clinical PVC without recurrence during a 15-minute post-ablation observation period and a residual PVC count of <1000 beats/24 hours on 24-hour Holter monitoring performed the following day. Major complications were defined as events requiring invasive treatment, causing hemodynamic compromise, prolonging hospitalization, or resulting in permanent sequelae. Minor complications were defined as transient or conservatively managed events without long-term consequences.

2.5. Statistical analysis

Data were managed using REDCap and analyzed with SPSS version 27. Continuous variables were expressed as mean ± standard deviation, and categorical variables as frequencies and percentages. Between-group comparisons were performed using the independent samples t test or Mann–Whitney U test for continuous variables, and the Chi-square test or Fisher exact test for categorical variables, as appropriate. A two-sided p value <0.05 was considered statistically significant.

2.6. Ethical considerations

The study protocol was approved by the Protocol Review Board of Hanoi Medical University (approval No. 5324). All patient data were de-identified before analysis and managed using coded study identifiers. No direct personal identifiers were included in the analytic dataset, and all procedural images were reviewed to remove potentially identifiable information before manuscript submission.

3. RESULTS

3.1. Study population

A total of 60 patients undergoing catheter ablation for PVCs were included. The mean age was 53.44 ± 16.43 years, and 46 patients (75.0%) were women. Palpitations were the most common presenting symptom, reported in 54 patients (90.0%). Hypertension was the most frequent comorbidity, whereas 33 patients (55.5%) had no documented underlying disease (Table 1).

3.2. Feasibility of the complete zero-fluoroscopy strategy

Among the 60 patients, 40 were initially selected for three-dimensional electroanatomic mapping-guided complete zero-fluoroscopy ablation. Of these, 37 completed the procedure without fluoroscopic guidance, yielding a feasibility rate of 92.5%. Three patients crossed over to fluoroscopic support during the procedure; the final sites of origin were the right coronary cusp in one patient and suspected intramural origins in two patients. The remaining 20 patients were assigned to fluoroscopy-supported ablation from the outset because of suspected left-sided or anatomically complex origins. Therefore, we had 2 group: Zero fluoroscopy (37 patients) and Fluoroscopy (23 patients).

Echocardiographic parameters were comparable between the complete zero-fluoroscopy and fluoroscopy-used groups. Mean left ventricular ejection fraction was preserved in both groups. PVC count and PVC burden tended to be higher in the fluoroscopy-used group, but these differences were not statistically significant (Table 2).

Table 1. Characteristics of the study population

Characteristics	Value	(n=60)
Age (years)	Mean	53.44 ±16.43
	Minimum	15
	Maximum	85
Female sex (n, %)		46 (75%)
BMI (kg/m²)		21.96±2.02
Comorbidities	Hypertension (n, %)	15(25%)
	Diabetes mellitus (n, %)	3 (5%)
	Coronary artery disease (n, %)	1 (1.7%)
	Valvular heart disease (n, %)	1 (1.7%)
	Thyroid disease (n, %)	3.3 (2.6%)
	No underlying disease (n, %)	33 (55.0%)
Symptoms	Chest pain (n, %)	32 (53.3%)
	Dyspnea (n, %)	10 (16.7%)
	Palpitations (n, %)	54 (90%)
	Presyncope (n, %)	1 (1.7%)
	Syncope (n, %)	0 (0%)

Table 2. Echocardiographic and Holter electrocardiographic characteristics by procedural group

Characteristic			
Overall group (n=60)	**Zero fluoroscopy (n=37)**	**Fluoroscopy (n=23)**	**p**
LVEDd, mm			
46.95 ± 5.44	46.08 ± 5.11	48.34 ± 5.77	0.208
LVEDs, mm			
29.76 ± 5.37	29.18 ± 5.36	30.69 ± 5.37	0.286
LVEF, %			
62.28 ± 8.83	63.02 ± 9,01	62.65 ± 8,74	0.632
LVEF <50%, n (%)			
3 (5.0)	2 (5.4)	1 (4.3)	1.00
PVC count/24 hours			
22636 ± 18723	21431 ± 21962	24574 ± 12020	0.070
PVC burden, %			
22.8± 17.5	22.17 ± 20,68	23.82 ± 11.03	0.094
Couplets/triplets, n (%)			
25 (41.7)	14 (37.8)	11 (47.8)	0.783
Non-sustained VT, n (%)			
26 (43.3)	15 (40.5)	11 (47.8)	0.603

3.3. Anatomical distribution of PVC sites of origin

PVC sites of origin differed substantially between the two procedural groups. In the complete zero-fluoroscopy group, most PVCs originated from the right ventricular outflow tract, while selected non-RVOT right-sided sites were also successfully approached without fluoroscopy, including the para-Hisian region, pulmonary valve region, and ventricular myocardial sites. By contrast, the fluoroscopy-used group consisted predominantly of left-sided or anatomically complex substrates, including the left coronary cusp, right coronary cusp, papillary muscle, mitral annulus, aortic root, superior mitral annulus, and suspected intramural origins (Figure 2).

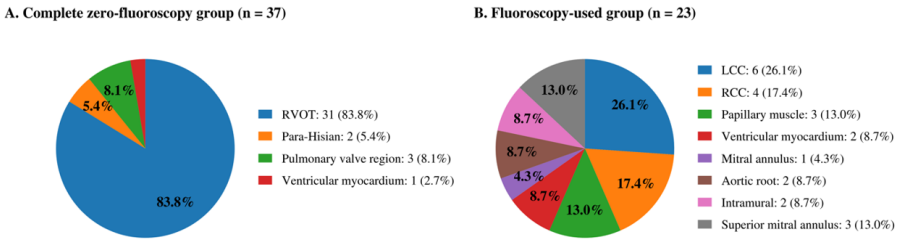

Figure 2. Distribution of PVC sites of origin according to procedural strategy

3.4. Electrocardiographic characteristics

The complete zero-fluoroscopy group showed ECG features consistent with later precordial transition. Compared with the fluoroscopy-used group, patients in the complete zero-fluoroscopy group had a significantly lower R/RS ratio in lead V2 during PVCs (0.13 ± 0.10 vs. 0.42 ± 0.34, $p < 0.001$), a later PVC transition index (2.94 ± 1.10 vs. 2.00 ± 0.60, $p < 0.001$), and a lower V2 transition ratio (0.41 ± 0.31 vs. 1.94 ± 2.90, $p < 0.001$) (Table 3).

3.5. Acute procedural outcomes and safety

Procedural time was shorter in the complete zero-fluoroscopy group than in the fluoroscopy-used group (60.1 ± 29.2 vs. 110.09 ± 46.32 minutes, $p < 0.001$). Ablation time tended to be shorter in the complete zero-fluoroscopy group (346.5 ± 196.4 vs. 485.57 ± 365.21 seconds), although the difference did not reach statistical significance ($p = 0.054$). The overall acute procedural success rate was 95.0%, with no significant difference between the complete zero-fluoroscopy and fluoroscopy-used groups (97.3% vs. 91.3%, $p = 0.325$). No major complications occurred. Minor complications included transient right bundle branch block in two patients and one conservatively managed access-site vascular complication (Table 4).

Table 3. Electrocardiographic characteristics by procedural group

Characteristic	Overall (n=60)	Zero fluoroscopy (n=37)	Fluoroscopy (n=23)	p
PVC QRS duration, ms	155.4 ± 17.4	155.89 ± 17.34	154 ± 17.9	0.733
Coupling interval, ms	473 ± 77.6	464 ± 78.8	489 ± 74.69	0.241
Positive QRS in lead I, n (%)	18 (30)	15 (40.5)	3(13)	0.057
RR' pattern in lead III, n (%)	17 (28.3)	12 (32.4)	5 (21.7)	0.012
R-wave ratio in lead III/II	0.96 ± 0.49	0.85 ± 0.29	1.14 ± 0.68	0.053
Q-wave ratio in aVL/aVR	0.81 ± 0.58	0.79 ± 0.63	0.83 ± 0.49	0.487
R/RS in V2 during sinus rhythm	0.36 ± 0.21	0.37 ± 0.21	0.33 ± 0.22	0.423
R/RS in V2 during PVCs	0.24 ± 0.26	0.13 ± 0.1	0.42 ± 0.34	<0.001
PVC transition index	2.59 ± 1.06	2.94 ± 1.1	2 ± 0.6	<0.001
Sinus rhythm transition index	2.0 ± 0.89	1.84 ± 0.96	2.26 ± 0.68	0.328
PVC transition later than sinus rhythm. n (%)	27 (45)	24 (64.9)	3 (13)	0.405
PVC transition equal to sinus rhythm. n (%)	20 (33.3)	10 (27)	10 (43.5)	

Characteristic	Overall (n=60)	Zero fluoroscopy (n=37)	Fluoroscopy (n=23)	p
PVC transition earlier than sinus rhythm. n (%)	13 (21.7)	3 (8.1)	10 (43.5)	
V2 transition ratio	0.97 ± 1.89	0.41 ± 0.31	1.94 ± 2.9	< 0.001

Table 4. Acute procedural outcomes by procedural group

Characteristic	Overall (n=60)	Zero fluoroscopy (n=37)	Fluoroscopy (n=23)	p
Procedural (time. min)	79.25 ± 40.2	60.1 ± 29.2	110.09 ± 46.32	< 0.001
Ablation time (s)	399.78 ± 279.14	346.5 ± 196.4	485.57 ± 365.21	0.054
Mean temperature (°C)	51.61 ± 5.81	53 ± 2.03	49.27 ± 8.78	0.669
Mean power (W)	31.22 ± 3.34	31.11 ± 3.29	31.71 ± 3.5	0.621
Mean impedance (Ω)	105.14 ± 12.37	107.11 ± 13.09	101.82 ± 10.5	0.160
Earliest activation time relative to QRS (ms)	25.64 ± 4.58	26.32 ± 4.0	24.5 ± 5.32	0.110
Pace mapping score/12	11.6 ± 0.49	11.64 ± 0.48	11.52 ± 0.51	0.333
Acute success. n (%)	57 (95.0)	36 (97.3)	21 (91.3)	0.325
Transient RBBB. n (%)	2 (3.3)	1 (2.7)	1 (4.3)	0.624
Vascular complication. n (%)	1 (1.67)	1 (2.7)	0 (0)	0.617
Major complications, n (%)	0 (0)	0 (0)	0 (0)	0

4. DISCUSSION

The anatomical distribution of PVC origins further supports the selection-based nature of this strategy. Most PVCs completed without fluoroscopy arose from the RVOT, but selected non-RVOT right-sided sites, including para-Hisian, pulmonary valve, and ventricular myocardial locations, were also successfully approached. In contrast, the fluoroscopy-used group consisted mainly of left-sided or complex substrates. This pattern suggests that the high feasibility rate was not attributable to indiscriminate fluoroscopy avoidance, but rather to preprocedural selection of anatomically favorable cases.

This study demonstrates that complete zero-fluoroscopy ablation of premature ventricular complexes (PVCs) guided by three-dimensional electroanatomic mapping is feasible in carefully selected patients. There were 37 patients completed the procedure without any fluoroscopic guidance, yielding a feasibility rate of 92.5%; only 03 patients required conversion to fluoroscopic support because final sites of origin at the RCC in one patient and suspected intramural origins in two patients. These findings support the growing evidence that, with appropriate mapping technology and operator experience, fluoroscopy can be avoided in a substantial proportion of ventricular arrhythmia ablation procedures. In a meta-analysis by Irnizarifka et al. including 9 cohort studies and 1,408 patients with ventricular arrhythmias, zero-fluoroscopy ablation achieved an acute success rate comparable to fluoroscopy-guided ablation, with a risk ratio of 1.01 (95% CI, 0.95–1.07; p = 0.69)[3].

Procedural time was significantly longer in the fluoroscopy-used group than in the complete zero-fluoroscopy group. However, this difference should be interpreted cautiously and

should not be regarded as evidence that the zero-fluoroscopy strategy intrinsically shortens the procedure. Patients requiring fluoroscopy generally had more anatomically complex substrates, including left-sided, coronary cusp, mitral annular, papillary muscle, aortic root, or suspected intramural origins. Therefore, the longer procedural duration in this group most likely reflects anatomical complexity and the need for additional catheter manipulation rather than the effect of fluoroscopy itself.

The three crossover cases also support the safety-oriented nature of our procedural strategy. These patients were initially selected for complete zero-fluoroscopy ablation but required conversion to fluoroscopic support during mapping. The final sites of origin were the right coronary cusp in one patient and suspected intramural origins in two patients. Thus, crossover to fluoroscopy was not considered a failure of the zero-fluoroscopy approach, but rather a predefined safety measure when mapping findings suggested a more complex or less favorable anatomical substrate.

The feasibility rate observed in our study appears favorable when compared with reports involving more anatomically complex ventricular arrhythmias. Rodkiewicz et al. evaluated 53 patients with idiopathic left ventricular arrhythmias and achieved a completely zero-fluoroscopy procedure in 44 patients, corresponding to 83.0%.7 In that study, fluoroscopy was required mainly because of proximity to the coronary arteries requiring coronary angiography in 4 cases (7.55%) and difficulty advancing the catheter through the arterial system in 5 cases (9.43%)[7]. The higher feasibility rate in our study may be explained by a preprocedural selection strategy that prioritized patients with electrocardiographic features suggestive of a right-sided origin or sites expected to be accessible using electroanatomic mapping alone.

Our acute procedural outcomes were also consistent with multicenter data on zero- or near-zero-fluoroscopy PVC ablation. Mugnai et al. reported 131 patients undergoing PVC ablation with a zero/near-zero fluoroscopy approach; the right ventricular outflow tract was the most common site of origin, accounting for 55.0% of cases, and acute PVC suppression was achieved in 127 patients (96.9%), with no major complications[8]. In the our study, the overall acute success rate was 95.0%, which is comparable to that report. No major complications were observed. Minor events included transient right bundle branch block and one vascular access complication, neither of which required specific intervention. These results suggest that complete fluoroscopy avoidance, when applied to suitable cases, does not appear to compromise acute procedural efficacy or safety.

A central finding of this study is the potential role of preprocedural electrocardiographic characteristics in selecting candidates for complete zero-fluoroscopy ablation. Patients who completed the procedure without fluoroscopy had a significantly lower R/RS ratio in lead V2 during PVCs than those who required fluoroscopy (0.13 ± 0.10 vs. 0.42 ± 0.34; $p < 0.001$). They also had a later PVC precordial transition index (2.94 ± 1.10 vs. 2.00 ± 0.60; $p < 0.001$) and a lower V2 transition ratio (0.41 ± 0.31 vs. 1.94 ± 2.90; $p < 0.001$). These findings are consistent with established principles of ECG localization, whereby earlier precordial transition and greater R-wave amplitude in the right precordial leads tend to indicate a left ventricular or left ventricular outflow tract origin, whereas later transition is more suggestive of a right ventricular or right ventricular outflow tract origin[4,5].

The importance of surface ECG in procedural planning has been reinforced by recent studies. Qiu et al. proposed the V2S angle for differentiating right from left ventricular outflow tract arrhythmias and reported an area under the curve of 0.888, with sensitivity of 85.7%, specificity of 95.2%, and accuracy of 93.8% in a prospective cohort[4]. More recently, a network

meta-analysis of 22 studies including 3,483 patients and evaluating 21 ECG algorithms confirmed that ECG-based criteria provide clinically useful discrimination between right and left outflow tract origins; the weighted hybrid score showed a pooled sensitivity of 0.83 and a pooled specificity of 0.92[9]. These data support the rationale of our approach: preprocedural ECG may be useful not only for estimating the site of origin but also for identifying patients in whom a complete zero-fluoroscopy strategy is more likely to be feasible.

Several limitations should be acknowledged. First, this was a single-center observational study with a limited sample size. Second, selection of the zero-fluoroscopy or fluoroscopy-used strategy was based on operator assessment, which introduces selection bias. Third, only three patients required conversion to fluoroscopy, limiting the ability to build a reliable prediction model for conversion. Fourth, although several precordial transition indices were analyzed, other ECG markers such as the R-wave duration index and R/S amplitude index were not fully incorporated into the current analysis. Finally, this study focused on feasibility and acute procedural outcomes; long-term arrhythmia recurrence and sustained clinical efficacy require further follow-up.

5. CONCLUSION

Three-dimensional electroanatomic mapping-guided complete zero-fluoroscopy ablation of premature ventricular complexes is highly feasible in appropriately selected patients, with a procedure completion rate without fluoroscopy of 92.5%. Electrocardiographic features suggesting late precordial transition, particularly a low R/RS ratio in V2, a low V2 transition ratio, and a later PVC transition index, may support patient selection for this strategy.

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