Received: 5 August 2023 | Revised: 28 September 2023 | Accepted: 9 October 2023

DOI: 10.1002/joa3.12944

Journal of Arrhythmia Open Access WILEY

ORIGINAL ARTICLE

Characteristics of right pulmonary vein with an epicardial connection needing additional carina ablation for isolation

Takeshi Nehashi MD[1] | Takashi Kaneshiro MD[1] | Minoru Nodera MD[1] | Shinya Yamada MD[1,2] | Yasuchika Takeishi MD[1,2]

[1]Department of Cardiovascular Medicine, Fukushima Medical University, Fukushima, Japan

[2]Department of Arrhythmia and Cardiac Pacing, Fukushima Medical University, Fukushima, Japan

Correspondence
Takashi Kaneshiro, Department of Cardiovascular Medicine, Fukushima Medical University, 1 Hikarigaoka, Fukushima 960-1295, Japan.
Email: tk2435@fmu.ac.jp

Abstract

Background: This study thought to elucidate the anatomical features that can predict an epicardial connection (EC) between the right pulmonary vein (RPV) and right atrium.

Methods: We retrospectively analyzed 251 consecutive patients undergoing initial radiofrequency pulmonary vein isolation. We defined EC as present when RPV could not be isolated with circumferential ablation and additional ablation for the conduction gap if needed, and RPV isolation could be achieved by ablation for the earliest activation site >10 mm inside the initial ablation line. Using computed tomography data, we evaluated the RPV bifurcation angle, and the area occupation ratio of the carina region to the RPV antrum (ARC) for predicting EC. In subjects with EC undergoing RPV activation mapping after circumferential ablation, the correlation between conduction delay and bipolar/unipolar potential voltage in the carina region was investigated.

Results: There were ECs in 45 out of 251 patients (17.9%). The RPV bifurcation angle (47.7° vs. 38.8°, $p<.001$) and ARC (37.2% vs. 29.7%, $p<.001$) were significantly greater in the EC (+) group. Multivariate logistic regression analysis revealed that RPV bifurcation angle (odds ratio [OR]: 1.994, $p=.002$) and ARC (OR: 3.490, $p=.013$) were independent predictors of EC. In nine patients with EC undergoing carina region mapping, the unipolar potential voltage was correlated with conduction delay in RPV with EC ($R=-0.401$, $p<.001$).

Conclusion: Anatomical features suggesting a wider RPV carina region could predict the presence of EC, and potential with high voltage could be helpful for detecting EC connection sites.

KEYWORDS
atrial fibrillation, catheter ablation, epicardial connection

1 | INTRODUCTION

Advancement in catheter ablation systems, including an open-irrigated catheter and contact force monitoring, has contributed to the effective treatment of atrial fibrillation (AF).[1–4] Recently, a lesion quality marker has been widely used for pulmonary vein isolation (PVI).[5,6] Moreover, high-power short-duration ablation can achieve uniform, transmural lesions during the resistive heating phase, and reduce collateral tissue damage by shortening the conductive heating phase.[7,8] These technologies provide strong potential for the safety and efficacy of AF ablation.

Although we can make transmural lesions using these advanced modules, there are some cases in which additional carina region ablations are needed for isolation in addition to antral circumferential ablation, especially in the right pulmonary vein (RPV). An epicardial connection (EC) between the RPV and the right atrium (RA) is suggested to be the main cause of this phenomenon.[9,10] RPV carina breakthrough may be reflected by conduction through small fibers connecting epicardially between the RPV carina and the RA, and this can cause a need for additional carina ablation in the RPV with an EC.[10] The presence of patent foramen ovale and interatrial distance have been reported to be predictors of an EC; however, the anatomical features that can predict an EC have not yet been fully evaluated.[9,11]

2 | METHODS

2.1 | Study population

A total of 251 patients who had undergone their first radiofrequency ablation of drug-refractory AF at our institution from October 2018 to March 2021 were enrolled. Then, they were retrospectively evaluated to investigate the prevalence of ECs in RPVs and the characteristics of RPVs associated with ECs.

After this enrollment, we performed routinely high-density RPV mapping after circumferential ablation in patients with ECs in RPVs. Sixty-two patients had undergone the first radiofrequency ablation of AF, and high-density RPV mapping after circumferential ablation was performed in patients with ECs. In these patients, the association between bipolar/unipolar pulmonary vein (PV) potential voltage and relative conduction delay of mapped points in the RPV carina region was analyzed.

The study protocol was approved by the ethics committee of Fukushima Medical University. Written informed consent was obtained from all study subjects. The data that support the findings of this study are available from the corresponding author upon reasonable request.

2.2 | Catheter ablation for AF

AF was classified as paroxysmal AF or persistent AF according to the duration of AF; ≤7 days or >7 days, respectively. The detailed procedural protocol of PVI using radiofrequency catheter ablation at our institution was previously described.[12] All the PVI procedures were performed using a 3-dimensional (3D) electro-anatomical mapping system (CARTO system, Biosense Webster, Inc., Diamond Bar, CA, USA). ThermoCool SmartTouch SF (Biosense Webster) was used for radiofrequency energy delivery. PVI was performed via a point-to-point technique using an Ablation Index module (Biosense Webster).[5,6] Radiofrequency power output was set at 45–50 W, contact force was maintained between 10 and 15 g, and inter-lesion distance was set at 4 mm. The duration of radiofrequency application was determined by ablation index values, which were targeted around 380–450 in the RPV antrum.[12,13]

2.3 | Definition of epicardial connection

ECs were identified when the following criteria were met. (1) PVI cannot be achieved after circumferential ablation around RPV antrum. (2) No conduction gap was detected on the circumferential ablation line, or PVI could not be achieved by additional ablation for the detected gaps. The local potential with bipolar voltage >0.1 mV on the circumference should be considered as a conduction gap.[14] (3) The earliest activation site (EAS) showed centrifugal pattern and was located within the PV antrum >10 mm inside from the initial ablation line using high-density mapping technique with a 20-polar mapping catheter (Lasso or Pentaray, Biosense Webster).[15] (4) Focal ablation at the EAS was effective to achieve PVI.

We checked the timing of EC appearance, such as during circumferential ablation of RPV, after achieving RPV isolation by circumferential ablation, or during pharmacological provocation after RPV isolation using isoproterenol and/or adenosine triphosphate injection. Moreover, in the patients with ECs, we investigated the successful ablation site for achieving RPV isolation, which is known as the EC connection site. According to the presence or absence of EC, we divided the study subjects into two groups.

2.4 | Analysis of anatomical characteristics of RPV based on computed tomography data

An electrocardiogram (ECG)-gated computed tomography (CT) for image integration with the CARTO system was performed on all study subjects 1 day before PVI. The procedural protocol of CT was as previously described.[16] We analyzed these data using a computer workstation (Ziostation, Ziosoft Inc., Tokyo, Japan) and constructed a 3D geometry of each patient's left atrium (LA) to evaluate the following parameters that focus on the anatomy of the carina region in RPV. First, the bifurcation angle of the RPV in a cross-sectional plane (RPV bifurcation angle, Figure 1A) was calculated as the angle between the lines which run longitudinally through the center of superior and inferior RPVs in a cross-sectional plane. Second, the area occupation ratio of the carina region to the RPV antrum (ARC, Figure 1B) was calculated. The

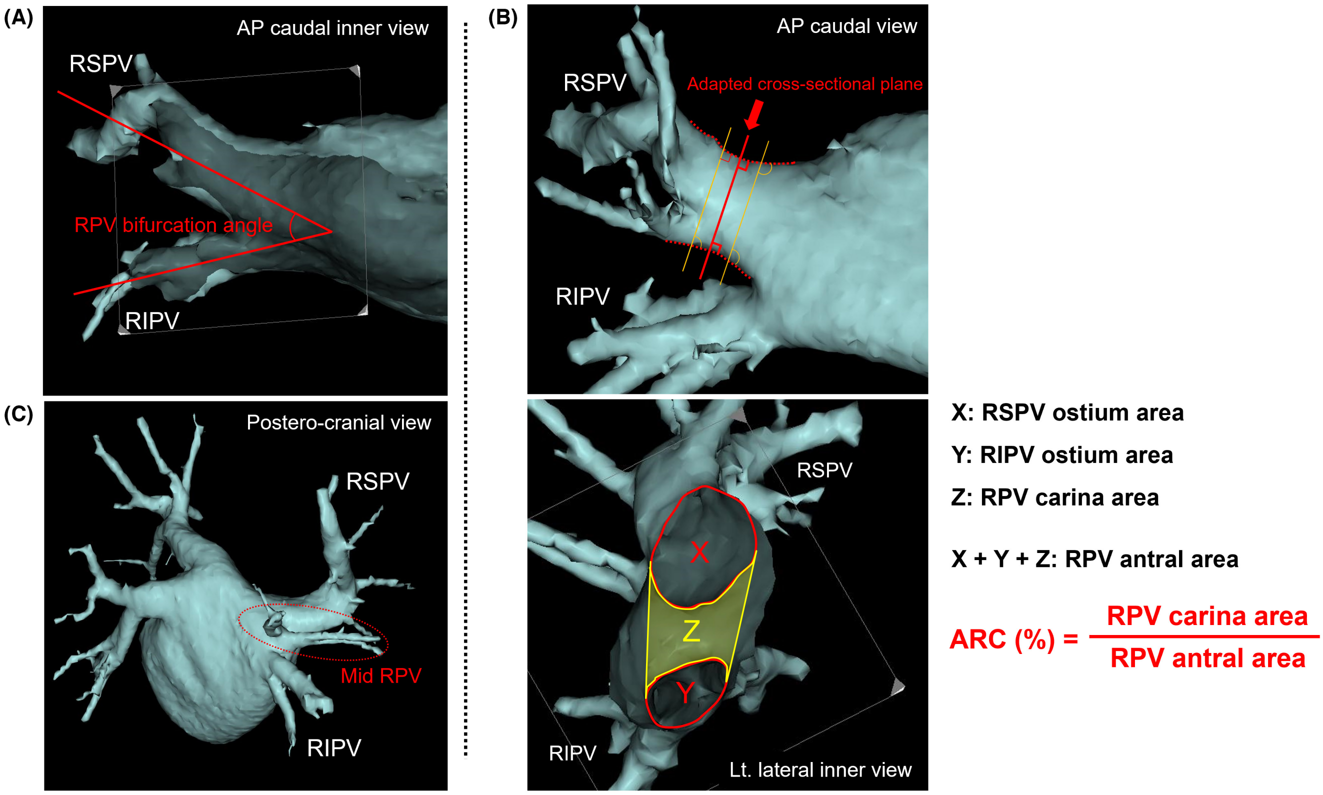

FIGURE 1 Analysis of anatomical characteristics of right pulmonary vein (RPV) based on computed tomography data. (Panel A) shows the RPV bifurcation angle, which was calculated as the angle between the lines which run longitudinally through the center of superior and inferior RPVs in a cross-sectional plane. (Panel B) shows the area occupation ratio of the carina region to the RPV antrum (ARC), which was calculated as the area ratio of the carina to the RPV antrum. (Panel C) shows the presence of mid RPV, which was defined as a pulmonary vein (PV) for which the ostium originates from the carina region, not from the trunk of each superior or inferior RPV.

cross-sectional areas of each superior and inferior RPV ostia were calculated, which were orthogonal to each pulmonary vein's roof and bottom as close to the LA side as possible. The area of the RPV antrum was defined as the area by connecting each cross-sectional area of the superior and inferior RPV. The carina area was defined as the area between each PV's cross-sectional area in RPV antrum, and was calculated using 3D surface area. Finally, ARC was calculated as the area ratio of the carina region to the RPV antrum. If mid-RPV was present, it's antral area was included in the carina area. These parameters were calculated by averaging the values evaluated by two investigators, who were blinded to the presence of EC in each study subject. Third, the presence of mid-RPV was evaluated (Figure 1C). This was defined as the pulmonary vein (PV) for which the ostium originates from the carina region, not from the trunk of each superior or inferior RPV.

2.5 | Follow-up

A follow-up study was performed in each patient at 1, 3, 6, and 12 months after the procedure. Antiarrhythmic drugs were administered for 3 months after PVI, depending on the operator's decision, and discontinued thereafter. At each visit, 12-lead ECG and 24-h Holter monitoring were performed. Recurrence was defined as documentation of atrial tachycardia (AT) or AF lasting >30 s recorded in 12-lead ECG or 24-h Holter monitoring.

2.6 | Association between PV potential voltage and relative conduction delay in RPV mapping after circumferential ablation in the patients with EC

In the second population with ECs undergoing detailed RPV mapping after achieving circumferential ablation, the correlation between relative conduction delay and bipolar/unipolar PV potential voltage of mapped points in the RPV carina region was investigated. We performed detailed activation and bipolar/unipolar voltage mapping in the RPV during RA pacing using a 20-polar mapping catheter (Pentaray, Biosense Webster) after achieving circumferential ablation. Mapping points were automatically collected using the CARTO confidence module with the following settings: cycle length filtering, ±30 ms; local activation time stability, <3 ms; position stability, <2 mm; and density, <1 mm. Relative conduction delay of each mapped point was calculated as the EAS which was set as 0 ms in each subject. Then, the correlation between relative conduction delay and bipolar/unipolar PV potential voltage of mapped points in the RPV was investigated.

2.7 | Statistical analysis

Normality of continuous variables was confirmed using the Shapiro–Wilk test. Normally distributed variables are presented as mean ± standard deviation, non-normally distributed variables are presented as median (25th percentile, 75th percentile), and categorical variables are expressed as counts and percentages. Normally and non-normally distributed variables were compared using an unpaired *t*-test and a Mann–Whitney *U*-test, respectively. A chi-square test was used for comparisons of categorical variables. All parameters with a significance of <0.10 in the univariate logistic regression analysis were entered into a multivariate logistic regression analysis. The correlation relationships were investigated by Spearman's rank correlation coefficient. A two-sided *p* value of <.05 was considered statistically significant. These analyses were performed using a statistical software package (SPSS ver. 21.0, IBM, Armonk, NY, USA).

3 | RESULTS

3.1 | Baseline characteristics, prevalence, and characteristics of EC

The clinical characteristics of the study subjects are summarized in Table 1. In all subjects, complete PVI was achieved in both sides of the PV.

The ECs were detected in 45 patients (17.9%) among the study subjects; during circumferential ablation of the RPV (before achieving RPV isolation) in 22 patients (49%), after achieving RPV isolation by circumferential ablation (most of them appeared after the completion of contralateral LPV ablation) in 19 patients (42%), and during the pharmacological provocation such as isoproterenol and/or adenosine triphosphate after ipsilateral PVI in four patients (9%). In the patients with ECs, the successful ablation sites for achieving RPV isolation, which represent the EC connection sites, were at the mid carina in 27 patients (60%), the anterior carina in 12 patients (27%), and the posterior carina in six patients (13%).

In comparisons between the groups according to the presence of EC, the prevalence of persistent AF, left atrial diameter, and left atrial volume index in echocardiography did not differ. The total amount of radiofrequency energy needed for RPV isolation was higher (39 198 [32 211–49 421] J vs. 25 982 [22 570–32 882] J, $p < .001$) in the EC (+) group compared to the EC (−) group. The total procedure time (213 [180–241] min vs. 182 [154–213] min, $p < .001$) and total fluoroscopic time (40.4 [29.5–49.3] min vs. 32.7 [23.2–45.5] min, $p = .009$) were also longer in the EC (+) group.

The distribution of gaps above or within 10 mm inside the line after first pass in each group is shown in Figure 2. Although the prevalence of gaps was different in the posterior–inferior area (1% in the group without EC versus 9% in the group with EC, $p = .010$), that was not different in the remaining areas between the groups.

3.2 | Anatomical characteristics of RPV predicting EC

Comparisons of anatomical characteristics of RPVs between the patients with and without ECs in study subjects are shown in Table 2. With the 3D analysis of CT data, the RPV bifurcation angle was significantly larger in the EC (+) group compared to the EC (−) group (47.7 [40.2–55.0] degrees vs. 38.8 [33.4–45.6] degrees, $p < .001$) (Figure 3). Moreover, ARC was significantly higher in the EC (+) group (37.2% [33.0%–41.9%] vs. 29.7% [25.4%–34.6%], $p < .001$) (Figure 4). The prevalence of mid-RPV was significantly higher in the EC (+) group than in the EC (−) group (17.7% vs. 6.3%, $p = .032$).

3.3 | Logistic regression analysis to predict EC

The detailed results of the logistic regression analysis for predicting EC in the total study subjects are shown in Table 3. Multivariate logistic regression analysis revealed that the RPV branching angle (odds ratio [OR]: 1.994, 95% confidential interval [95% CI]: 1.293–3.024,

TABLE 1 Baseline characteristics and comparison between the groups according to presence of epicardial connection.

	Total (*n* = 251)	EC (+) group (*n* = 45)	EC (−) group (*n* = 206)	*p* value
Age (years)	65 (57–70)	65 (55–69)	65 (57–71)	.292
Female (%)	66 (26%)	8 (18%)	58 (28%)	.153
Body mass index (kg/m^2)	24.1 (21.9–26.8)	23.9 (22.4–27.6)	24.1 (21.8–26.8)	.308
Persistent AF (%)	115 (46%)	22 (49%)	92 (45%)	.432
LAD (mm)	41 (37–46)	42 (39–46)	41 (37–46)	.306
LAVI (mL/m^2)	42.0 (35.0–51.0)	44.0 (37.5–54.5)	41.0 (34.0–51.0)	.140
Ejection fraction (%)	63.0 (60.0–66.0)	62.0 (59.5–66.5)	63.0 (60.0–66.0)	.881
Total radiofrequency energy for RPV isolation (J)	28 145 (23 339–34 959)	38 198 (32 211–49 421)	25 982 (22 570–32 882)	<.001
Procedure time (min)	189 (159–219)	213 (180–241)	182 (154–213)	<.001
Fluoroscopic time (min)	34.0 (24.2–46.7)	40.4 (29.5–49.3)	32.7 (23.2–45.5)	.009

Note: Data are shown as median (25th percentile, 75th percentile) or number of patients (%).

Abbreviations: AF, atrial fibrillation; LAD, left atrial diameter; LAVI, left atrial volume index.

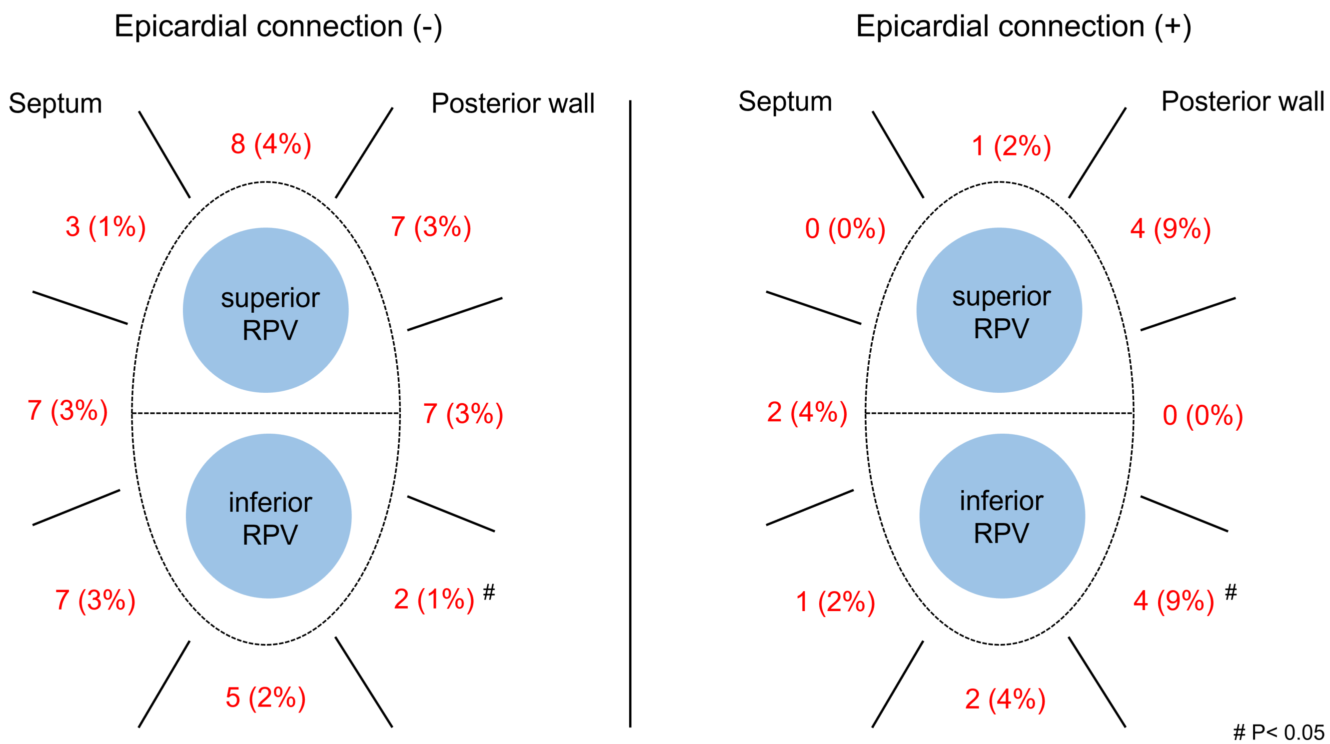

FIGURE 2 The distribution of gaps above or within 10 mm inside the line after first pass in the groups according to epicardial connection (EC). Although the prevalence of gaps was different in posterior–inferior area (1% in the group without EC vs. 9% in the group with EC, $p = .010$), that was not different in the remaining areas between the groups.

TABLE 2 Comparison of anatomical characteristics of RPV between the groups according to the presence of epicardial connection.

	Total ($n = 251$)	EC (+) group ($n = 45$)	EC (−) group ($n = 206$)	p value
RPV bifurcation angle (degrees)	39.9 (34.1–47.0)	47.7 (40.2–55.0)	38.8 (33.4–45.6)	<.001
RSPV ostium area (cm^2)	2.99 (2.10–3.59)	2.72 (2.00–3.61)	2.90 (2.11–3.59)	.741
RIPV ostium area (cm^2)	1.93 (1.40–2.40)	2.03 (1.59–2.33)	1.77 (1.37–2.41)	.357
RPV carina area (cm^2)	2.33 (1.66–2.86)	2.95 (2.50–3.26)	2.06 (1.53–2.60)	<.001
RPV antrum area (cm^2)	7.09 (5.77–8.52)	7.96 (6.73–8.98)	6.99 (5.53–8.35)	.003
ARC (%)	30.8 (26.2–36.7)	37.2 (33.0–41.9)	29.7 (25.4–34.6)	<.001
Presence of mid pulmonary vein	21 (8.4%)	8 (17.8%)	13 (6.3%)	.032

Note: Data are shown as median (25th percentile, 75th percentile) or number of patients (%).

Abbreviations: ARC, area occupation ratio of carina region to RPV antrum; RIPV, right inferior pulmonary vein; RPV, right pulmonary vein; RSPV, right superior pulmonary vein.

$p = .002$) and ARC (OR: 3.490, 95% CI: 1.295–9.388, $p = .013$) were independent predictors of EC in all study subjects.

3.4 | Prevalence of AT/AF recurrence and reconnection of RPV between the groups according to EC

With a 1 year follow-up, 25 patients (10%) experienced AT/AF recurrence. The Kaplan–Meier survival analysis revealed that 4 out of 45 patients (8.8%) experienced AT/AF recurrence in EC (+) group, and 20 out of 206 patients (9.7%) experienced AT/AF recurrence in EC (−) group (Log-Rank, $p = .899$) (Figure S1). Four patients with EC and 13 patients without EC received 2nd session, and there was no reconnection in the right PV in all patients.

3.5 | Correlation between PV potential voltage and relative conduction delay in RPVs with ECs

Nine out of 62 patients (14.5%) had ECs in their RPVs and underwent detailed carina region mapping after achieving circumferential ablation. Then, a total of 1324 mapped points (an average of 147 points per patient) were analyzed. The RPV was isolated by an additional

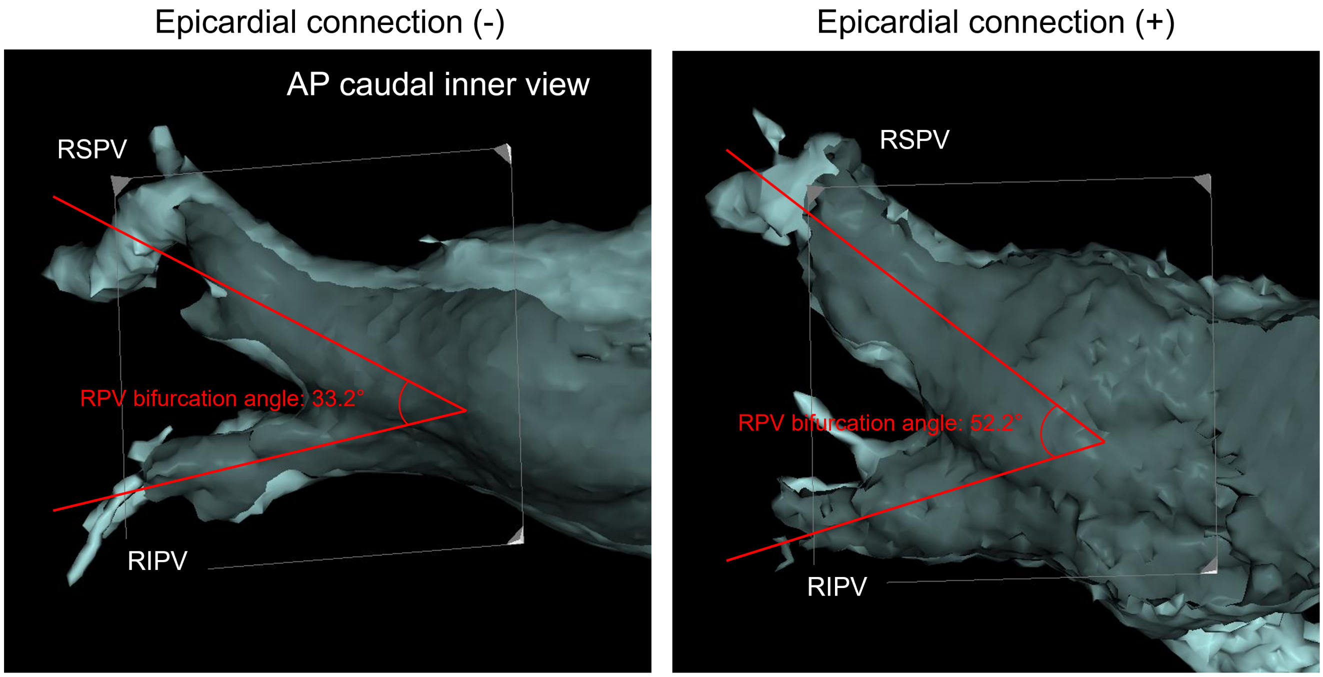

FIGURE 3 Representative cases with small and large right pulmonary vein (RPV) bifurcation angles. The left panel shows a case without epicardial connection (EC) and a small RPV bifurcation angle of 33.2°. The right panel shows a case with EC and a large RPV bifurcation angle of 52.2°.

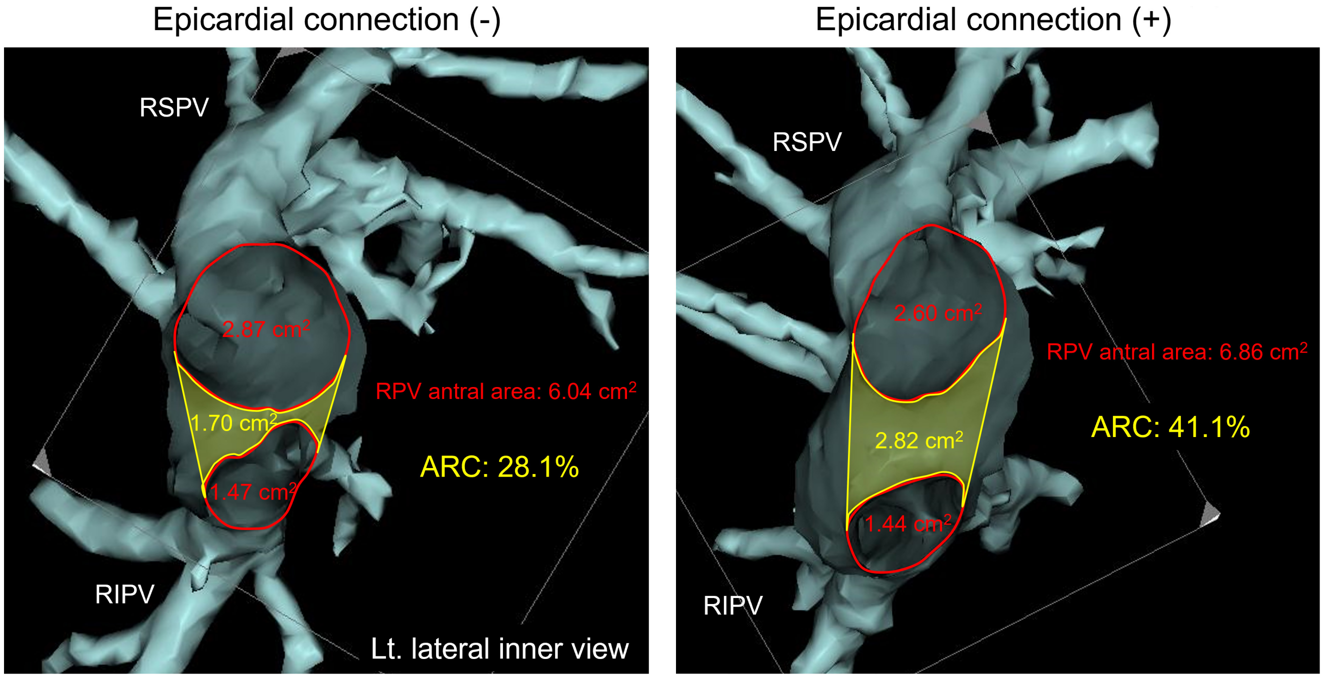

FIGURE 4 Representative cases with small and large area occupation ratios of the carina region to the right pulmonary vein antrum (ARC). The left panel shows a case without epicardial connection (EC) and a small ARC of 28.1%, and the right panel shows a case with EC and a large ARC of 41.1%.

ablation in the carina region after circumferential ablation in all patients. The mean values of bipolar and unipolar PV potential voltage of each mapped point were 0.84 and 1.26 mV, respectively. The bipolar PV potential voltage was negatively correlated with relative conduction delay among the mapped points in the carina region of the RPV ($R = -0.325$, 95% CI −0.372 to −0.276, $p < .001$). The unipolar PV potential voltage was also negatively correlated with relative conduction delay ($R = -0.401$, 95% CI −0.445 to −0.355, $p < .001$), the correlation of which was stronger than that of bipolar PV potential voltage (representative case in Figure 5).

TABLE 3 Results of the logistic regression analysis for predicting epicardial connection.

	Univariate		Multivariate	
	Odds ratio (95% CI)	*p* value	Odds ratio (95% CI)	*p* value
Age	0.986 (0.955–1.017)	.358		
Female	0.552 (0.242–1.256)	.156		
Body mass index	1.038 (0.960–1.121)	.351		
Persistent AF	0.772 (0.405–1.473)	.432		
LAD	1.019 (0.971–1.068)	.446		
LAVI	1.012 (0.992–1.033)	.236		
Ejection fraction	1.002 (0.962–1.045)	.912		
RPV bifurcation angle (+ 10-degree increase)	2.293 (1.613–3.247)	<.001	1.994 (1.293–3.024)	.002
RSPV ostium area	0.933 (0.685–1.270)	.659		
RIPV ostium area	1.108 (0.709–1.729)	.653		
RPV carina area	1.009 (1.006–1.013)	<.001	0.981 (0.957–1.005)	.114
RPV antrum area	1.222 (1.040–1.434)	.015	2.223 (0.962–5.134)	.061
ARC (+ 5% increase)	1.786 (1.436–2.230)	<.001	3.490 (1.295–9.388)	.013
Presence of mid-pulmonary vein	3.210 (1.243–8.287)	.016	0.728 (0.205–2.587)	.624

Abbreviations: AF, atrial fibrillation; ARC, area occupation ratio of carina region to RPV antrum; LAD, left atrial diameter; LAVI, left atrial volume index; RIPV, right inferior pulmonary vein; RPV, right pulmonary vein; RSPV, right superior pulmonary vein.

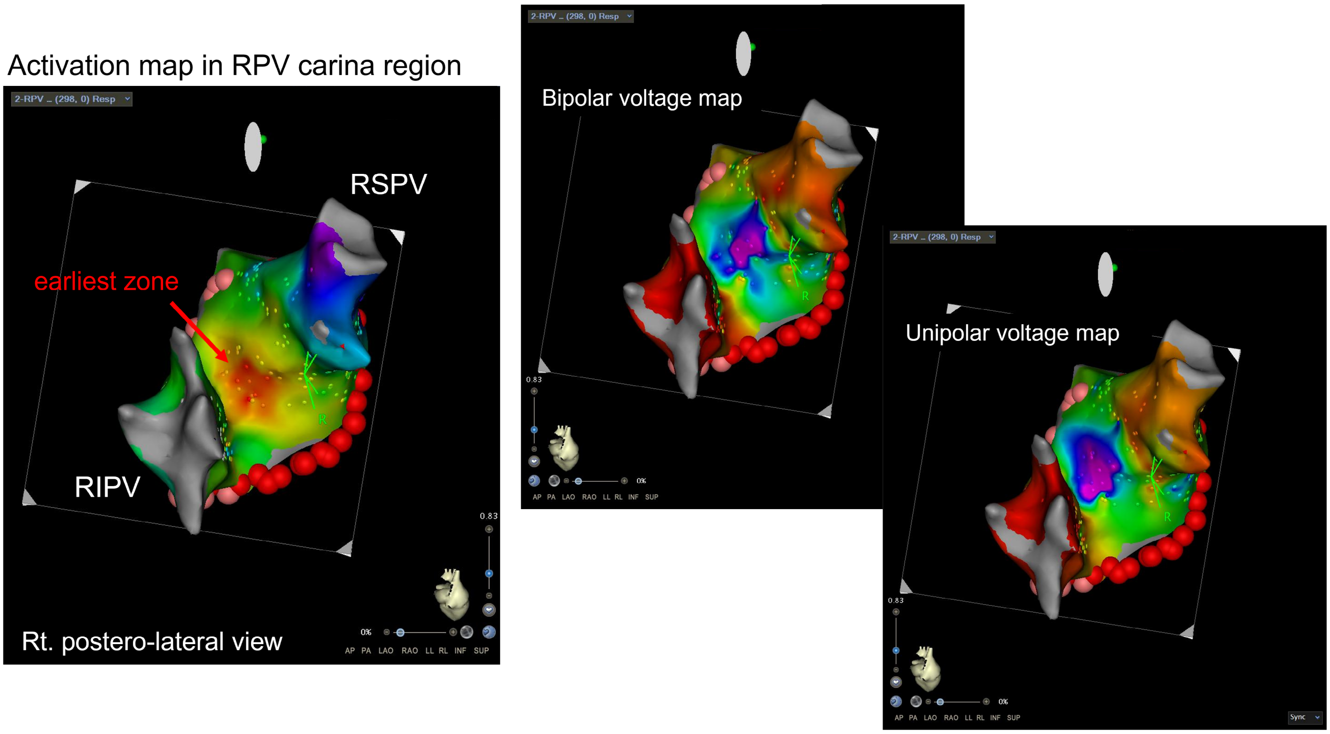

FIGURE 5 Results of the detailed right pulmonary vein carina mapping of the representative case with epicardial connection (EC). The left panel shows the activation map, which revealed the earliest activation zone in the carina region in a patient with EC. The center and right panels show the bipolar and unipolar voltage maps, which revealed the high-voltage zone in the carina region, which overlapped with the earliest activation zone.

4 | DISCUSSION

The major findings of the current study were as follows. First, the anatomical characteristics of the RPV, such as wide RPV bifurcation angle and high ARC, could predict the presence of an EC between the RPV and the RA. Moreover, the presence of mid-RPV was associated with the presence of an EC. Second, the timing of EC appearance could vary due to numerous factors, which increases the need for monitoring EC presence through the PVI procedure. Third, concerning the mapping for the EC connection site, PV potential with high voltage in the carina region after achieving RPV circumferential ablation could be helpful. These results may contribute to smoothly accomplishing RPV isolation.

4.1 | Usefulness of predicting factors of ECs

Previously, some factors which predict the presence of ECs have been reported. Persistent foramen ovale and interatrial distance were reported to predict the presence of an EC.[9,11] Similar to the present study, anatomical factors associated with the RPV carina region have been shown to predict ECs.[17,18] However, no predictor of ECs related to the detailed anatomical information of RPV carina regions has yet been revealed.

Since advancements in ablation technologies have given us a strong potential to make transmural lesions, we perform wide antral isolation using these technologies to improve the ablation outcomes.[19] However, longer distance between the ablation line and the PV ostia was found to be the major determinant for the need for carina ablation.[20] Therefore, a wider lesion set that does not cover the carina will find more ECs because they are not targeted.[17,20] Although activation mapping during sinus rhythm before ablation could be performed to detect an EC between the RPV and the RA, this maneuver is time-consuming for various reasons.[10,11] With these issues, a simple and visible factor predicting ECs would be efficient for smooth PVI procedures. Moreover, activation mapping in RPV for detecting ECs is impossible during AF rhythm and requires cardioversion. Based on the results of detailed RPV mapping after achieving circumferential ablation in the patients with ECs, the PV potential with high voltage could suggest an EAS, which might be the EC connection site. When we cannot achieve RPV isolation with circumferential ablation, it would be useful for achieving isolation to seek a PV potential with high voltage in the carina region in patients with wide RPV bifurcation angles, large ARC, or the presence of mid-RPV.

4.2 | Electrophysiological characteristics of EC between RPV and RA

Interestingly, the present study showed that the timing of EC appearance varies. Kumagai et al. reported that the dormant conductions induced by isoproterenol and adenosine triphosphate injection were frequently eliminated with ablations in carina regions.[21] The majority of these dormant conductions might be derived from ECs, and this suggests that ECs may be affected by some factors, such as changes in the autonomic nerve system. Therefore, it is possible that the timing of EC appearance could vary by time or pharmacological effects, and this suggests that the monitoring of EC presence should be noted through the PVI procedures.

Pulmonary vein triggers most commonly originate from the carina region of both right and left PVs, and this shows that the carina region has an electrophysiological instability resulting in arrhythmogenicities.[22] Indeed, PVs are complex structures under the influence of the autonomic system, which modulates firing from PVs.[23,24] Regarding anatomy, Ho et al. reported that the myocardial sleeves are thickest in the inferior walls of the superior veins and the superior walls of inferior veins; these areas are the carina region. Moreover, greater myocardial sleeves intermingling in the carina regions may be responsible for the origin of PV firing.[25] Therefore, the myocardial sleeves in the carina region might have anatomical and autonomic complexities, and may have a lot of arrhythmogenicity of AF. With the results of the present study, ECs were connected to the wide carina region. We suspect that ECs might be connected to these areas to compensate for the electrophysiological vulnerability. Yoshida et al. reported that arrhythmogenic substrates may overlie in the RPV and superior vena cava when these veins are connected by ECs.[26] Interatrial connections by ECs might act as a mediator of the arrhythmogenic substrate from the RPV carina to the RA, resulting in AF persistence and difficulty of AF suppression by ablation only in the LA. Although we could not clarify the pathophysiological reason for the existence of EC at wide-angle bifurcation in this study, the anatomical characteristics associated with EC presence might contribute to it's recognition and the smooth accomplishment of the PVI procedure.

4.3 | Clinical implications

The prevalence of ECs in the present study was relatively high at 17.9%, and all ECs in these patients were eliminated with additional ablations in the carina region. Because wide antral PVI is superior to ostial PVI with regard to AF suppression, we set the wider circumferential ablation line as possible.[19] This might lead us to encounter ECs frequently, resulting in the relative higher prevalence of ECs. Without recognizing the presence of ECs, excessive lesion formation should be expected in patients with ECs, resulting in complications such as cardiac tamponade and collateral tissue damage. Therefore, a simple predictor of ECs should be efficient for safe and smooth PVI procedures.

The predicting factors of ECs in the present study could be obtained by CT images, which are easy and noninvasive. We calculated and proposed the RPV bifurcation angle and the ARC; however, these parameters must be adapted with visual intuition, but without exact calculation of these parameters. Moreover, the presence of mid-RPV, which was associated with the presence of an EC, could be detected only by CT images, without 3D construction of CT images.

Based on the results of detailed RPV mapping in the patients with ECs, the PV potential with high voltage could suggest the connection sites of ECs. In patients with persisting AF, cardioversion and activation mapping during sinus rhythm, which are time-consuming procedures, are needed to detect the EC connection site. Therefore, this method may be more efficient if it is employed when searching for EC connection sites in patients with ongoing AF.

4.4 | Study limitations

There are several limitations in the present study. First, it was a single-center observational study, with findings that should be further evaluated in a multicenter, randomized control study. Second, because the present study was retrospective, the definition of EC was less strict compared to two previous studies that evaluated the breakthrough site in the RPV during sinus rhythm before circumferential ablation.[10,11] LA and RA mapping during RPV carina pacing would provide information about the atrial insertion of ECs in patients with EC. In case of EC insertion close to the RPV circle, it would be possible that the EC is just endocardial edema. Because we did not perform these mapping maneuvers, it could not be denied that ECs in the present study might include some endocardial edema. Moreover, we defined the EC according to the previous study, that showed the median distance from EC connection site to the initial ablation line was 10 mm.[15] However, we cannot deny the possibility that the definition of EC was not appropriate. Third, there are some types of ECs with bidirectional conduction between RA and PV, and unidirectional between RA and PV.[27,28] However, the definition of EC in the present study could detect only the ECs with unidirectional conduction from RA to RPV because of the retrospective study. Forth, there is a limitation in adapting the results of voltage mapping in the carina region for detecting EC connection sites during AF. During AF rhythm, PV potentials show both passive potential and firing potential. However, most PV firing activities become suppressed after circumferential ablation, and PV potentials become passive. In the passive state of PV after circumferential ablation, mapping for seeking PV potential with high voltage might be effective even during AF rhythm.

5 | CONCLUSIONS

Anatomical characteristics of the RPV, such as a wide RPV bifurcation angle and large ARC, could predict the presence of EC between the RPV and the RA. PV potential with high voltage in the carina region after achieving circumferential ablation could also be useful for detecting EC connection sites. Using these predictors might contribute to safely and smoothly accomplishing RPV isolation.

AUTHOR CONTRIBUTIONS

Takeshi Nehashi; Concept/design, Data analysis/interpretation, Drafting article, Statics, Data collection. *Takashi Kaneshiro*; Concept/design, Data analysis/interpretation, Drafting article, Statics, Data collection. *Minoru Nodera*; Approval of article, Data collection. *Shinya Yamada*; Approval of article, Data collection. *Yasuchika Takeishi*; Critical revision of article, Approval of article, Data collection.

CONFLICT OF INTEREST STATEMENT

Shinya Yamada belongs to the Department of Arrhythmia and Cardiac Pacing, which is supported by Abbott Medical Japan Co., Ltd., Biotronik Japan Inc, and Nihon Kohden Corp. These companies are not associated with the contents of this study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study protocol was approved by the ethics committee of Fukushima Medical University.

PATIENT CONSENT STATEMENT

Written informed consent was obtained from all study subjects.

ORCID

Takashi Kaneshiro https://orcid.org/0000-0002-5284-9538
Shinya Yamada https://orcid.org/0000-0001-5726-3926

REFERENCES

1. Calkins H, Kuck KH, Cappato R, Brugada J, Camm AJ, Chen SA, et al. 2012 HRS/EHRA/ECAS expert consensus statement on catheter and surgical ablation of atrial fibrillation: recommendations for patient selection, procedural techniques, patient management and follow-up, definitions, endpoints, and research trial design. Europace. 2012;14:528–606.
2. Wilber DJ, Pappone C, Neuzil P, De Paola A, Marchlinski F, Natale A, et al. Comparison of antiarrhythmic drug therapy and radiofrequency catheter ablation in patients with paroxysmal atrial fibrillation: a randomized controlled trial. JAMA. 2010;303:333–40.
3. Kautzner J, Neuzil P, Lambert H, Peichl P, Petru J, Cihak R, et al. EFFICAS II: optimization of catheter contact force improves outcome of pulmonary vein isolation for paroxysmal atrial fibrillation. Europace. 2015;17:1229–35.
4. Chikata A, Kato T, Sakagami S, Kato C, Saeki T, Kawai K, et al. Optimal force-time integral for pulmonary vein isolation according to anatomical wall thickness under the ablation line. J Am Heart Assoc. 2016;5:e003155.
5. Das M, Loveday JJ, Wynn GJ, Gomes S, Saeed Y, Bonnett LJ, et al. Ablation index, a novel marker of ablation lesion quality: prediction of pulmonary vein reconnection at repeat electrophysiology study and regional differences in target values. Europace. 2017;19:775–83.

6. Hussein A, Das M, Chaturvedi V, Asfour IK, Daryanani N, Morgan M, et al. Prospective use of ablation index targets improves clinical outcomes following ablation for atrial fibrillation. J Cardiovasc Electrophysiol. 2017;28:1037–47.
7. Castrejón-Castrejón S, Martínez Cossiani M, Ortega Molina M, Escobar C, Froilán Torres C, Gonzalo Bada N, et al. Feasibility and safety of pulmonary vein isolation by high-power short-duration radiofrequency application: short-term results of the POWER-FAST PILOT study. J Interv Card Electrophysiol. 2020;57:57–65.
8. Winkle RA, Mohanty S, Patrawala RA, Mead RH, Kong MH, Engel G, et al. Low complication rates using high power (45–50 W) for short duration for atrial fibrillation ablations. Heart Rhythm. 2019;16:165–9.
9. Barrio-Lopez MT, Sanchez-Quintana D, Garcia-Martinez J, Betancur A, Castellanos E, Arceluz M, et al. Epicardial connections involving pulmonary veins: the prevalence, predictors, and implications for ablation outcome. Circ Arrhythm Electrophysiol. 2020;13:e007544.
10. Yoshida K, Baba M, Shinoda Y, Harunari T, Tsumagari Y, Koda N, et al. Epicardial connection between the right-sided pulmonary venous carina and the right atrium in patients with atrial fibrillation: a possible mechanism for preclusion of pulmonary vein isolation without carina ablation. Heart Rhythm. 2019;16:671–8.
11. Hanaki Y, Yoshida K, Baba M, Hasebe H, Takeyasu N, Nogami A, et al. Interatrial distance predicts the necessity of additional carina ablation to isolate the right-sided pulmonary veins. Heart Rhythm O2. 2020;2:259–67.
12. Kaneshiro T, Kamioka M, Hijioka N, Yamada S, Yokokawa T, Misaka T, et al. Characteristics of esophageal injury in ablation of atrial fibrillation using a high-power short-duration setting. Circ Arrhythm Electrophysiol. 2020;13:e008602.
13. Hijioka N, Kaneshiro T, Nehashi T, Amami K, Nodera M, Yamada S, et al. Influence of power setting on superior vena cava potential during right pulmonary vein isolation. J Interv Card Electrophysiol. 2022;65:25–31.
14. Hocini M, Sanders P, Jaïs P, Hsu L, Weerasoriya R, Scavée C, et al. Prevalence of pulmonary vein disconnection after anatomical ablation for atrial fibrillation: consequences of wide atrial encircling of the pulmonary veins. Eur Heart J. 2005;26:696–704.
15. Sun X, Niu G, Lin J, Suo N, Guo T, Lu J, et al. The incidence and location of epicardial connections in the era of contact force guided ablation for pulmonary vein isolation. J Cardiovasc Electrophysiol. 2021;32:2381–90.
16. Kaneshiro T, Matsumoto Y, Nodera M, Kamioka M, Kamiyama Y, Yoshihisa A, et al. Anatomical predisposing factors of transmural thermal injury after pulmonary vein isolation. Europace. 2018;20:1122–8.
17. Mulder ML, Kemme MJB, Götte MJW, van de Ven PM, Hauer HA, Tahapary GJM, et al. Differences between gap-related persistent conduction and carina-related persistent conduction during radiofrequency pulmonary vein isolation. J Cardiovasc Electrophysiol. 2020;31:1616–27.
18. Shin DI, Koektuerk B, Waibler HP, List S, Bufe A, Seyfarth M, et al. Fast anatomical mapping of the carina and its implications for acute pulmonary vein isolation. J Arrhythm. 2021;37:1270–7.
19. Proietti R, Santangeli P, Di Biase L, Joza J, Bernier ML, Wang Y, et al. Comparative effectiveness of wide antral versus ostial pulmonary vein isolation. A systematic review and meta-analysis. Circ Arrhythm Electrophysiol. 2014;7:39–45.
20. Lin YJ, Tsao HM, Chang SL, Lo LW, Tuan TC, Hu YF, et al. The distance between the vein and lesions predicts the requirement of carina ablation in circumferential pulmonary vein isolation. Europace. 2011;13:376–82.
21. Kumagai K, Naito S, Nakamura K, Hayashi T, Fukazawa R, Sato C, et al. ATP-induced dormant pulmonary veins originating from the carina region after circumferential pulmonary vein isolation of atrial fibrillation. J Cardiovasc Electrophysiol. 2010;21:494–500.
22. Valles E, Fan R, Roux JF, Liu CF, Harding JD, Dhruvakumar S, et al. Localization of atrial fibrillation triggers in patients undergoing pulmonary vein isolation: importance of the carina region. J Am Coll Cardiol. 2008;52:1413–20.
23. Scherlag BJ, Yamanashi W, Patel U, Lazzara R, Jackman WM. Autonomically induced conversion of pulmonary vein focal firing into atrial fibrillation. J Am Coll Cardiol. 2005;45:1878–86.
24. Patterson E, Po SS, Scherlag BJ, Lazzara R. Triggered firing in pulmonary veins initiated by in vitro autonomic nerve stimulation. Heart Rhythm. 2005;2:624–31.
25. Ho SY, Cabrera JA, Tran VH, Farre J, Anderson RH, Sanchez-Quintana D. Architecture of the pulmonary veins: relevance to radiofrequency ablation. Heart. 2001;86:265–70.
26. Yoshida K, Hattori A, Tsuneoka H, Tsumagari Y, Yui Y, Kimata A, et al. Electrophysiological relation between the superior vena cava and right superior pulmonary vein in patients with paroxysmal atrial fibrillation. J Cardiovasc Electrophysiol. 2017;28:1117–26.
27. Niiyama D, Tsumagari Y, Uehara Y, Baba M, Hasebe H, Yoshida K. An epicardial connection with a unidirectional conduction property from the left atrium to pulmonary vein. JACC Case Rep. 2022;4:310–4.
28. Uemoto S, Takemoto M, Koga T, Tsuchihashi T. Detection of a unidirectional epicardial connection between the right-sided pulmonary venous carina and the right atrium by pacing from a high-density mapping catheter. Pacing Clin Electrophysiol. 2022;46:928–33. https://doi.org/10.1111/pace.14645

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Nehashi T, Kaneshiro T, Nodera M, Yamada S, Takeishi Y. Characteristics of right pulmonary vein with an epicardial connection needing additional carina ablation for isolation. J Arrhythmia. 2023;39:884–893. https://doi.org/10.1002/joa3.12944