Features Suggesting Preferential Conduction in Pulmonary Artery Ventricular Arrhythmia for Identification of Successful Ablation Sites

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Summary
Radiofrequency catheter ablation (RFCA) for pulmonary artery ventricular arrhythmia (PAVA) can be difficult because of the occasional existence of PAVA with preferential conduction.

This study described the characteristics of PAVA that demonstrate preferential conduction.

We analyzed electrocardiographic and electrophysiological data from 8 patients found to have PAVAs with preferential conduction out of 183 patients (4.4%) with right ventricular outflow tract (RVOT) arrhythmias who underwent RFCA at our hospitals. The PAVA with preferential conduction were classified into two types. In type 1 PAVA, successful ablation sites (success-sites) exhibited discrete prepotentials with an isoelectric line, in which the activation time (AT) was $\leq 50$ milliseconds. In type 2 PAVA, excellent pace mapping was achieved at two sites separated by $\geq 20$ mm: one in the RVOT free wall and the other at the success-site in the pulmonary artery. Type 1 and 2 PAVA features were considered signs of a short and long preferential conduction pathway, respectively.

There were four patients each with type 1 and 2 PAVA. Type 1 PAVA was distinguished by the isoelectric line at success-sites with the mean AT of $78 \pm 25.1$ milliseconds. In type 2 PAVAs, although the AT at RVOT sites was very short ($18.5 \pm 10.1$ milliseconds), the AT at success-sites was longer than that at the RVOT by $42.3 \pm 36.2$ milliseconds. Type 2 PAVAs displayed distinct electrocardiogram (ECG) features (R wave in lead I, RR’ in inferior leads, and transitional zone in V4) not found in typical PAVA ECGs.

PAVA with preferential conduction can manifest in distinct ways on the ECG and intracardiac mapping. Knowledge of these features may facilitate successful RFCA of such PAVA cases.

Key words: Discrete prepotential with an isoelectric line, Excellent pace-mapping sites

It is sometimes difficult to determine the optimal ablation site for pulmonary artery ventricular arrhythmias (PAVAs) due to the occasional existence of PAVAs with a preferential conduction pathway and atypical PAVA electrocardiogram (ECG) in some patients. We have found PAVA with preferential conduction that does not fit previously published features. For example, Sekiguchi, et al. reported that typical PAVA ECG characteristics were high R in inferior leads and a transitional zone (TZ) in V31 relative to right ventricular outflow tract (RVOT) ventricular arrhythmia (VA), but we found some patients with different PAVA ECG features. In addition, as another example, Maruyama, et al. reported a case in which a perfect pace-mapping site was found in the RVOT (exit site) 33 mm away from the pulmonary artery (PA). In that case, the PA was the successful ablation site, but pace mapping was not good at that site. Here we report another type of PAVA that is different from that reported earlier. We have found PAVAs characterized by excellent pace mapping at RVOT and PA sites separated by $\geq 20$ mm, of which the PA was the successful ablation site and the RVOT free wall was the exit site.

The objective of our study was to identify ECG and electrophysiological characteristics of PAVAs that demonstrate features of preferential conduction.

Methods

Study population: Of 183 patients with RVOT arrhythmias who underwent radiofrequency catheter ablation (RFCA) at our hospitals, 8 patients (4.4%) had PAVA with a preferential conduction pathway, and their electrocar-
diographic and electrophysiological data were characterized. We defined PAVA as an arrhythmia with an origin above the pulmonary valve. Conventional PAVA was defined as PAVA not showing preferential conduction pathway. There were 4 such patients, and they were not included in the current analysis. PA angiography and three-dimensional mapping were performed to confirm the location of the ablation catheter tip just before or after the successful ablation. We assumed the existence of a preferential conduction pathway when the electrophysiological features suggested conduction along a pathway that was not apparent on the endocardial surface of the ventricle. We speculated that the preferential conduction pathway was insulated between the origin and exit sites. We found there were two types of preferential conduction pathways. Type 1 PAVA was characterized by a discrete prepotential (DP) with an isoelectric line (DP-iso-line) up to the QRS onset ≥ 50 milliseconds (Figure 1A) and stimulus-QRS onset ≥ 40 milliseconds. These features were considered a sign of a short preferential conduction pathway. Type 2 PAVA was characterized by an excellent pace map at that site. In patients with type 1 PAVA, activation time (AT) at the successful ablation site was defined as the interval from the onset of the ventricular electrogram to the QRS onset. The pace-mapping score was defined as the median of scores given by three electrophysiologists. Pace mapping was defined as excellent for scores ≥ 11/12. We performed coronary angiography before ablation to ensure that the distance between the tip of the ablation catheter and the left coronary arteries was > 0.5-1 cm to avoid injuring them.13

**Electrophysiological study and ablation:** Antiarrhythmic drugs were discontinued for ≥ 1 week before the EP study. Studies were performed with patients in the fasting, non-sedated state. Conventional mapping catheters were introduced into the coronary sinus, the His bundle region, and the RVOT. The coronary sinus catheter was inserted into the coronary sinus as deeply as possible to map within the great cardiac vein and the anterior interventricular cardiac vein. A 7 F quadripolar deflectable catheter with a 4-mm-tip distal electrode was advanced to the aortic sinus cusp (ASC) for mapping at the ASC as needed. If a DP was recorded during mapping of the outflow tract, pace mapping was performed at that site. In patients with type 1 PAVA, activation time (AT) at the successful ablation site was defined as the interval from the onset of the DP to the QRS onset of the outflow tract (OT) VA. In patients with type 2 PAVA, AT was defined as the interval from the onset of the ventricular electrogram to the QRS onset. The pace-mapping score was defined as the median of scores given by three electrophysiologists. Pace mapping was defined as excellent for scores ≥ 11/12. We performed coronary angiography before ablation to ensure that the distance between the tip of the ablation catheter and the left coronary arteries was > 0.5-1 cm to avoid injuring them.13

**Statistical analysis:** All values are expressed as the mean ± SD. Between-group comparisons were made by unpaired t test using R version 4.0.0. Statistical significance was defined as P < 0.05.

**Results**

Age, gender, and VPC count per day are given for all
Figure 2. ECGs from the four patients with type 2 PAVA. Lead I displays an RR' wave in cases 5, 6, and 8 or Rsr in case 7; the RR' is seen especially in the inferior leads; and the transition zone is at V4 or later to be different from type 1 PAVA ECG (Lead I displays an S wave, tall R is recorded in the inferior leads, and the transitional zone is at approximately V3.).

Table I. Patient Characteristics

| Type   | 1     | 2     | Average ± SD |
|--------|-------|-------|--------------|
| Case   | 1     | 2     | 5     | 6     | 7     | 8     | 50.3 ± 21.5 |
| Age (years) | 77    | 47    | 48    | 78    | 46    | 15    | 31    | 60 |
| Gender | M     | F     | M     | F     | M     | F     | M     |    |
| VPC count | 32,000| 11,618| 34,530| 14,400| 26,341| 20,889| 34,599| 23,865| 24,780 ± 8,807 |

VPC count is per day. M indicates male; F, female; and VPC, ventricular premature contractions.

patients in Table I. Mean age was 50.3 years. Mean number of VPC per day was 24,780 ± 8,807. The successful RFCA site was in the PA in all 8 patients.

Ablation:

Type 1 PAVA (n = 4) Successful ablation sites exhibited DP-iso-line. The AT was ≥ 50 milliseconds (86, 58, 58, and 110 milliseconds), and all successful ablation sites were at the septal wall in patients with type 1 PAVA (Table II). A representative case of type 1 PAVA is demonstrated in Figure 1. In case 1, there was a distance of 8.7 mm between the two sites (PA and left ASC) where excellent pace maps with stimulus-QRS onset of 40 and 60 milliseconds, respectively, were obtained. In case 2, there was a distance of 4.0 mm between the two sites (PA and left ASC) where excellent pace maps were obtained, both with stimulus-QRS onset of 58 milliseconds. However, we did not attempt to locate excellent pace-mapping sites with stimulus-QRS onset of 0 milliseconds, i.e., exit sites, in either case. In case 4 only, the local potential of the successful ablation site showed two components during sinus rhythm, which reversed during PAVA, and the latter potential during sinus rhythm disappeared after the successful ablation.

Type 2 PAVA (n = 4) Excellent PM were obtained at two sites separated by ≥ 20 mm (Table III). One was at the successful ablation site in the PA; the second was in the RVOT free wall. The AT in the RVOT was ≤ 30 milliseconds. We interpreted the double excellent PM sites as signifying existence of a long preferential conduction pathway, with the VA origin in the PA and the exit site being in the RVOT free wall. The AT at successful ablation sites was longer than that at the RVOT free wall by 42.3 ± 36.2 milliseconds. Dividing distances by difference in AT gave a conduction velocity of 0.83 ± 0.5 m/second over the preferential conduction pathway. The successful ablation sites were either at the anterior or at the posterior lateral wall (Table II).

The successful ablation site was in the PA in all eight patients, requiring on average, 2.0 and 2.5 RF applications in type 1 and 2 PAVA, respectively (Table II). Indeed, in
two cases (cases 4 and 6), we were able to abolish the VA with a single RF application to the PAVA origin. In contrast, RF in other cases was applied to multiple sites in the RVOT and left-sided sites (Table II), but none succeeded in abolishing the VA.

**ECG features:** Twelve-lead ECG characteristics of type 1 and 2 PAVAs are shown in Figure 2. In type 1 PAVA ECGs, R wave amplitudes in the inferior leads were significantly higher than in the type 2 PAVA (Figure 3), and the TZ ranged between V2 and V3.5. In type 2 PAVA ECGs, lead I displayed an RR wave in cases 5, 6, and 8 and Rsr pattern in case 7; an RR’ pattern was recognized in at least one inferior lead (in all inferior leads in cases 6 and 8); and the TZ was at V4 or later. QRS duration was significantly wider in type 2 PAVA than in type 1 PAVA (Figure 3). Additionally, in cases 5 and 6 of type 2 PAVA, an S wave amplitude > 3.0 mV was seen in lead V2. Case 5 is shown in further detail in Figure 4.

**Follow-up data:** All patients remained free from arrhythmias and symptoms without antiarrhythmic drugs, and no chronic complications occurred during a follow-up period of 40 ± 27 months.

**Discussion**

Hasdemir, et al. explained why a PA could be a target of OTVA, namely, that the ventricular myocardial fibers could extend into the PA and aorta beyond the semi-lunar valves. However, it is sometimes difficult to determine the optimal ablation site for PAVAs because of the existence of PAVAs that belong to our type 1 and 2 PAVAs. These two groups have characteristics indicative of the presence of preferential conduction pathways.

Timmermans, et al. suggested that detailed mapping of the PA including the pulmonary valve should be performed when no early AT during ventricular tachycardia and no optimal pace-mapping sites can be found in the RVOT. Our study results provide expanded criteria indicating when one should seek PAVA ablation sites, and we have constructed a tentative flowchart for identifying PAVA with preferential conduction (Figure 5). Basically, our type 1 PAVA differs from conventional PAVA only in the presence of a DP-iso-line during PA mapping. Type 2 PAVA, however, has distinct electrocardiographic features (an R in lead I, RR’ in one or more inferior leads, and TZ in ≥ V4), which should prompt a search for a second excellent pace-mapping site in the PA, especially when AT at the RVOT excellent pace-mapping site is ≤ 30 milliseconds.

**PAVA with features suggesting preferential conduction:**

In our type 1 PAVAs, the exit sites were not detected, and in type 2 PAVAs, the successful ablation sites were characterized by a potential of unknown origin preceding the ventricular potential or existence of a second excellent pace-mapping site. Both features can only be explained by a preferential conduction pathway. Type 1 PAVA patients

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**Table II.** EP and Ablation Data in All Eight Patients

| Case | Type | Success-site in PA | Distance from success-site to PV (mm) | AT at success-site to PV (milliseconds) | S-QRS (milliseconds) | PM score at PA | PM score at best site in RVOT | RF count | Other |
|------|------|--------------------|--------------------------------------|----------------------------------------|---------------------|----------------|-------------------------------|---------|-------|
| 1    | 1    | Post-septum        | 10                                   | 86                                     | 40                  | 12             | 7                            | 2       | 3     |
| 2    | 1    | Post-septum        | 7                                    | 58                                     | 58                  | 12             | N/D                          | 1       | 0     |
| 3    | 1    | Ant-septum         | 12                                   | 58                                     | 58                  | 12             | 8                            | 4       | 8     |
| 4    | 1    | Septum             | 4                                    | 110                                    | 48                  | 12             | N/D                          | 1       | 0     |
| 5    | 2    | Post-lateral       | 5                                    | 54                                     | 54                  | 12             | 12                           | 5       | 9     |
| 6    | 2    | Ant-lateral        | 15                                   | 28                                     | 10                  | 12             | 12                           | 1       | 0     |
| 7    | 2    | Ant-lateral        | 12                                   | 120                                    | 48                  | 12             | 12                           | 3       | 3     |
| 8    | 2    | Anterior           | 11                                   | 41                                     | 41                  | 12             | 12                           | 1       | 3     |
| 5    |      |                    | 78 ± 25.1                            | 51 ± 8.7                               | 12 ± 0              | 2.0 ± 1.4       | 2.8 ± 3.8                    | 1.3 ± 1.5 |
| 6    |      |                    | 60.8 ± 40.9                          | 38.3 ± 19.6                           | 12 ± 0              | 2.5 ± 1.9       | 3.8 ± 3.8                    | 0       |       |

PA indicates pulmonary artery; post, posterior; ant, anterior; PV, pulmonary valve; AT, activation time; S-QRS, stimulus to QRS onset; PM, pace mapping; N/D, not done; LCC, left coronary cusp; RVOT, right ventricular outflow tract; and LVOT, left ventricular outflow tract. Average ± SD.

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**Table III.** Preferential Conduction Pathway Velocity in Patients with Type 2 PAVA

| Case | AT at success-site to PV (milliseconds) (1) | AT at RVOT with perfect PM (milliseconds) (2) | Difference between (1) and (2) (milliseconds) (3) | Distance between (1) and (2) (mm) (4) | Velocity: (4) / (3) (m/second) |
|------|------------------------------------------|---------------------------------------------|-----------------------------------------------|---------------------------------|-----------------------------|
| 5    | 54                                       | 30                                          | 24                                            | 20                             | 0.83                        |
| 6    | 28                                       | 10                                          | 18                                            | 26                             | 1.4                         |
| 7    | 120                                      | 24                                          | 96                                            | 25                             | 0.26                        |
| 8    | 41                                       | 10                                          | 31                                            | 25                             | 0.81                        |
| Average ± SD | 60.8 ± 40.9                          | 18.5 ± 10.1                                  | 42.3 ± 36.2                                   | 24 ± 2.7                       | 0.83 ± 0.5                  |

AT indicates activation time; RVOT, right ventricular outflow tract; PM, pace mapping; and SD, standard deviation.
Figure 3. Comparison of ECG findings between type 1 and 2 PAVAs. A–C: R wave amplitude in the inferior leads in type 2 PAVA was significantly lower than that in type 1 PAVA. D: QRS duration was significantly wider in type 2 PAVA than in type 1 PAVA. E: The transition zone in type 2 PAVA was at V4 or later, whereas it ranged between V2 and V3.5 in type 1 PAVA.

Figure 4. Detailed example of a patient with type 2 PAVA (case 5). A: Traces from the successful ablation site in the PA, and the transient successful ablation site and the successful ablation site in the three-dimensional mapping view. The distal ablation catheter shows an electrogram that precedes the QRS onset by 54 milliseconds as indicated by the red and blue arrows. It has high frequency components. The distance between the transient successful ablation site and the successful ablation site was 20 mm. ABL, ablation. B: 12-lead ECG from pace mappers. The left column displays the clinical VPC, the middle was from the transient successful ablation site, and the right column was from the successful ablation site. The stimulus latency was 34 milliseconds at the transient successful ablation site in the RVOT and 54 milliseconds at the successful ablation site in the PA as shown by the blue arrows. Success-site, successful ablation site.

were characterized by a DP-iso-line in which the AT was ≥ 50 milliseconds. We previously speculated that a DP-
Figure 5. Tentative flow chart for identifying the different types of PAVA. VA indicates ventricular arrhythmia; TZ, transitional zone; DP, discrete prepotential; PAVA, pulmonary artery ventricular arrhythmia; AT, activation time; and RVOT, right ventricular outflow tract.

Figure 6. Schematic diagrams. A: Schematic diagram of speculated short preferential conduction pathway in patients with type 1 PAVA (short axis view). The successful ablation site in these patients was the origin of the VPC (blue star), distant from the exit site. IVS indicates interventricular septum; AV, aortic valve; PV, pulmonary valve; LAD, left anterior descending artery; and LCX, left circumflex artery. B: Schematic diagram of speculated long preferential conduction pathway in patients with type 2 PAVA (long axis view). RA indicates right atrium; PA, pulmonary artery; RVOT, right ventricular outflow tract; and LV, left ventricle. The red star indicates the origin of the VPC; the blue arrow indicates the insulated preferential conduction pathway.

iso-line signifies preferential conduction. In Figure 6A, we present a schematic diagram of how we believe the preferential conduction pathway lies relative to anatomical structures based on electrocardiographic features. In a study that mirrors ours, but dealing with VA of ASC origin rather than PA origin, the authors found that 4 of 15 patients with VA of ASC origin had a pace map score close to perfect in sites in the RVOT. Those sites were considered exit sites, and the successful ablation site in the ASC was considered the origin of the VPC. Our cal-
calculation of the velocity of the preferential conduction tract in 4 of the 15 patients with VA of ASC origin gives 0.70 ± 0.6 m/second. Patients demonstrating type 1 PAVA may have a relatively short preferential conduction pathway from the PA to an exit site in the septum as described in previous reports.\(^\text{10}\) We did not attempt to identify exit sites in our patients with type 1 PAVA. Therefore, we were unable to measure the whole length of the preferential conduction pathway and calculate preferential conduction velocities for patients with type 1 PAVA. Nevertheless, we believe preferential conduction underlay their PAVA because of the DP-iso-line and because the successful ablation site was at the septum of the OT (Table II).\(^\text{3}\) Both features have been attributed to preferential conduction in a large study of VAs originating in the ASC.\(^\text{5}\)

**Consideration of type 2 PAVAs:** Because of the atypical electrophysiologic characteristics in type 2 PAVA, it was difficult to realize that the OTVA had a PA origin. Therefore, it led us to deliver an average of 3.8 RF to the RVOT that failed to abolish the VA. It is important to note that the successful ablation site was in the PA, but excellent pace-mapping sites were obtained at two sites: at the successful ablation site and at a second site in the RVOT free wall ≥ 20 mm (Table III) inferior to the first. Additionally, the stimulus latency was shorter at the RVOT than that at the successful ablation site. We speculate that the existence of a long preferential conduction pathway from the PA to the RVOT free wall. We interpret this to mean that the origin of the VPC was in the PA and the exit was in the RVOT free wall (Figure 6B).

Purkinje fiber conduction velocity is given in textbooks as 1.25-4.0 m/second\(^\text{3,10}\) and that of intrinsic muscle conduction velocity as 0.4-1.0 m/second.\(^\text{3,10}\) The average velocity of the preferential conduction pathway in our patients with type 2 PAVA was 0.83 m/second. “0.83 m/second” is within the range of the velocity of the myocardium and too slow to be that of the Purkinje fiber. Although the anatomical substrate for the preferential conduction pathway is unknown, the anterior limb of the trabecula septomarginals supporting the pulmonary valve\(^\text{11}\) has been suggested as a candidate.\(^\text{2}\) The continuous recording of distinct ventricular activation during VAs might indicate the presence of the preferential conduction pathway, but we did not attempt to map the distribution of the preferential conduction pathway in the current study. In one patient with type 2 PAVA, we paced a site midway between the successful ablation site and the exit site and obtained an excellent pace map (case 7).

**ECG findings:** Although the successful ablation sites were in the PA, it is noteworthy that two (first and third) out of the following three ECG findings: (1) R wave in lead I, (2) RR’ in inferior leads, and (3) TZ in V4 or later, similar to that reported for arrhythmias of RVOT free wall origin,\(^\text{12}\) were observed in all four of our patients with type 2 PAVA. Tada, et al. reported that S wave amplitude > 3.0 mV in lead V2 differentiated an RVOT free wall origin from an RVOT septal origin with 90% sensitivity and 80% specificity.\(^\text{12}\) In our study results, S wave amplitude > 3.0 mV in lead V2 was found in two of the four patients with type 2 PAVA. Wider QRS duration and a later TZ as seen in our patients with type 2 PAVA than those in patients with type 1 PAVA may also indicate RVOT free wall origin (Figure 3). In contrast, Sekiguchi, et al. reported that typical PAVA ECGs show high R in inferior leads (mean R wave amplitudes: 1.9 mV\(^\text{13}\)) and a TZ in V3\(^\text{13}\) relative to RVOT arrhythmias, just as we found in our patients with type 1 PAVA. In our study, R wave amplitude in inferior leads in type 1 PAVAs was also significantly higher than that in type 2 PAVAs (Figure 3).

It has been stated previously that ECG differentiation between arrhythmias originating from the RVOT and PA could be difficult because the RVOT could sometimes be the exit site of VAs arising from the PA.\(^\text{11}\) We feel, based on our current findings, that even in the presence of typical PAVA ECGs, knowledge of the existence of type 1 PAVAs should keep physicians alert to the possibility of finding DP in the septal PA area. We emphasize that ECG findings (R wave in lead I, RR’ in inferior leads, and TZ in ≥ V4) as in our patients with type 2 PAVA indicate an RVOT free wall origin rather than a PA origin. However, if in addition to such ECG findings the AT is ≤ 30 milliseconds, one should check that VA of PA origin is not overlooked (Figure 5).

**Limitations:** We calculated the velocity of the preferential conduction pathway assuming a straight path, but the conduction pathway is not necessarily straight. This would make our calculated velocity a lower limit. Our flowchart was constructed on the basis of our analysis of eight patients, limiting its validity.

Because we have tried to characterize type 1 and type 2 PAVA preferential conduction patterns based on only four patients each, there is a definite possibility that some patients will not fit neatly into the criteria we have defined for the flow chart. The relatively long length of the protected segment in patients with type 2 PAVA may mean that ECG findings in this group may not stay consistent as more patients are studied. However, we have deliberately selected criteria that not only were observed in our patients but also were consistent with a theoretical understanding of what causes the differences in ECG and mapping patterns and believed that keeping the general manifestations of our two atypical ECG types in mind instead of the exact details will assist the clinician in identifying these somewhat rare (4.4%) VAs when they arise.

**Conclusions**

We found two types of unconventional PAVA in 4.4% of our patients with RVOT arrhythmia that were best explained by assumption of existence of preferential conduction pathways. Detailed PA-RVOT mapping to find DP-iso-lines and scrutiny of ECG should facilitate identification of these unconventional PAVA origins and lead to more efficient RFCA.

**Disclosure**

**Conflicts of interest:** The authors have none to declare.
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