Radiofrequency catheter ablation (RFCA) is a safe and effective treatment for outflow tract ventricular tachycardia/ventricular premature contractions (OT-VT/VPC), but in some patients the OT-VT was not able to be treated by ablation from the ventricular endocardium or coronary cusps. If an ECG parameter could predict spontaneous ventricular tachyarrhythmia, it would be useful. The aim of this study was to determine an ECG predictor of ablation success in difficult cases of OT-VT/VPC.

**Methods**

After written informed consent was given by all the patients in this study and antiarrhythmic drugs had been discontinued for at least 1 week, an electrophysiologic study was performed for each arrhythmia with the patients in a fasting, unsedated state. ECG analysis and RFCA were performed in 70 patients with OT-VT/VPC. Both the right and left outflow tracts, the coronary cusps, and the distal great cardiac vein (GCV) to the proximal anterior interventricular vein were precisely mapped to determine the ablation sites. A 7Fr quadripolar catheter with a 4-mm distal electrode, 2.5-mm interelectrode spacing, and a deflectable tip (Boston Scientific; Natick, MA, USA) was used for mapping and ablation. RF energy was applied at the site where both the earliest ventricular activation and the best pace mapping were attained. For the patients with an endocardial left OT-VT/VPC, a 7Fr quadripolar catheter with a 4-mm distal electrode, 2.5-2-mm interelectrode spacing, and a deflectable tip (Biosense Webster, Diamond Bar, CA, USA; EP Technologies, San Jose, CA, USA) was used. For the patients in whom the successful ablation site was the distal GCV, a 5Fr quadripolar catheter with a 5-mm distal electrode and a deflectable tip (Ablaze Fantasista, Japan Lifeline Co, Ltd, Tokyo, Japan) was used because of its small size.

The peak deflection index (PDI) was determined in the inferior lead presenting the tallest R wave by dividing the time from QRS onset to peak QRS deflection by total QRS duration (Figure 1). The ECG was recorded at a paper speed of 50–100 mm/s for precise measurement of the PDI.

**Statistical Analysis**

Continuous variables are expressed as mean±standard deviation.
ECG Predictor of Difficult Ablation

Results

In 10 (14%) of the 70 patients with OT-VT/VPC, RFCA was delivered at a septal or epicardial site after precise mapping, but was unsuccessful (group 1); RFCA was successful in the remaining 60 patients (group 2). We compared the clinical characteristics of the 2 patient groups and found no significant differences in age, sex, number of VPCs or left ventricular (LV) ejection fraction (Table 1). The best mapping sites, activation times, and ECG data for group 1 patients are shown in Table 2. The best mapping sites were either in the septal right ventricular outflow tract (RVOT) or at an epicardial site. Although the best mapping site by both activation mapping and pace mapping was in the septal RVOT, RFCA was unsuccessful in cases 2, 6, 7, 9, and 10 (Table 2). We defined the OT-VT/VPC in these cases to be of intramural origin. The average QRS duration was 141 ms, and the average PDI was 0.62 in group 1. There was no significant difference between group 1 and group 2 in QRS duration (141 ± 19 ms vs 137 ± 19 ms, P=0.6), voltage in the inferior lead (2.1 ± 0.6 mV vs 1.8 ± 0.5 mV, P=0.2), and activation time (−35 ± 15 ms vs −40 ± 12 ms, P=0.3).

The receiver-operating characteristic curve identified with a sensitivity of 80% and a specificity of 90% the use of a PDI >0.6 as the optimal cut-off point for an unsuccessful result of OT-VT/VPC ablation (Table 3).

In group 1, although detailed mapping was performed and the best mapping sites were the left coronary cusp (LCC), the distal GCV or the septal RVOT, the PDI of each patients was >0.6, and RFCA was unsuccessful (Figure 2). In group

![Figure 1.](image-url)
Figure 1. Calculation of peak deflection index (PDI) is determined from the 12-lead ECG in the inferior lead that presents the tallest R wave by dividing the time from QRS onset to the earliest peak deflection by total QRS duration. PDI=A/QRS, where PDI is peak deflection index, A is the duration from QRS onset to earliest peak of R wave in the inferior lead that presents the tallest R wave (lead III in this case) and QRS is QRS duration (paper speed, 100 mm/s).

### Table 1. Comparison of Clinical Characteristics of Groups 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Sex (F/M)</th>
<th>No. of VPCs/day (beats)</th>
<th>LVEF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>57±17</td>
<td>5/5</td>
<td>21,254±10,987</td>
<td>65±13</td>
</tr>
<tr>
<td>Group 2</td>
<td>47±13</td>
<td>36/24</td>
<td>17,757±14,313</td>
<td>64±8</td>
</tr>
<tr>
<td>P value</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

VPC, ventricular premature contraction; LVEF, left ventricular ejection fraction; NS, not significant.

### Table 2. Best Mapping Site, AT, and ECG Data in Group 1

<table>
<thead>
<tr>
<th>Case</th>
<th>Best mapping site</th>
<th>AT (ms)</th>
<th>QRS (ms)</th>
<th>A (ms)</th>
<th>PDI</th>
<th>Voltage in inferior lead (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RCC (epi)</td>
<td>−15</td>
<td>150</td>
<td>92</td>
<td>0.61</td>
<td>II=2.0</td>
</tr>
<tr>
<td>2</td>
<td>Septal RVOT</td>
<td>−30</td>
<td>160</td>
<td>108</td>
<td>0.675</td>
<td>II=2.1</td>
</tr>
<tr>
<td>3</td>
<td>Epicardial site (at the distal GCV)</td>
<td>−40</td>
<td>164</td>
<td>100</td>
<td>0.61</td>
<td>II=3.5</td>
</tr>
<tr>
<td>4</td>
<td>Epicardial site (at the distal GCV)</td>
<td>−70</td>
<td>160</td>
<td>101</td>
<td>0.63</td>
<td>III=1.5</td>
</tr>
<tr>
<td>5</td>
<td>Epicardial site (at the distal GCV)</td>
<td>−35</td>
<td>120</td>
<td>80</td>
<td>0.67</td>
<td>III=2.3</td>
</tr>
<tr>
<td>6</td>
<td>Septal RVOT</td>
<td>−36</td>
<td>120</td>
<td>84</td>
<td>0.7</td>
<td>III=1.9</td>
</tr>
<tr>
<td>7</td>
<td>Septal RVOT</td>
<td>−38</td>
<td>158</td>
<td>76</td>
<td>0.48</td>
<td>II=2.0</td>
</tr>
<tr>
<td>8</td>
<td>LCC (epi)</td>
<td>−25</td>
<td>120</td>
<td>76</td>
<td>0.63</td>
<td>III=1.6</td>
</tr>
<tr>
<td>9</td>
<td>Septal RVOT</td>
<td>−38</td>
<td>120</td>
<td>79</td>
<td>0.66</td>
<td>III=2.1</td>
</tr>
<tr>
<td>10</td>
<td>Septal RVOT</td>
<td>−25</td>
<td>140</td>
<td>80</td>
<td>0.57</td>
<td>II=1.8</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>−35±15</td>
<td>141±19</td>
<td>88±12</td>
<td>0.62±0.06</td>
<td>2.1±0.6</td>
<td></td>
</tr>
</tbody>
</table>

AT, activation time; A, the time from QRS onset to the earliest peak deflection in the inferior lead that presents the tallest R wave; PDI, peak deflection index in inferior lead; RCC, right coronary cusp; epi, epicardial; RVOT, right ventricular outflow tract; GCV, great cardiac vein; LCC, left coronary cusp; SD, standard deviation.
2, however, the successful ablation site was located in the RVOT area, with each PDI ≤0.6 (Figure 2).

The best mapping site where pace mapping matched the VPC in the 2 unsuccessful group 1 cases was epicardial (Table 2); that is, at the distal GCV (Figure 3). Ventricular activation at the site preceded onset of the VPC QRS by 40 ms in case 3 and by 70 ms in case 4. The PDI was 0.61 in case 3 and 0.63 in case 4 (Figure 3). In 3 cases in group 1 (3–5, of which 2 are shown in Figure 3), the impedance at the best mapping site at the distal GCV was too high (>130 Ω) to perform RFCA.

Comparison of the PDI distribution between groups 1 and 2 is shown in Figure 4. The PDI value in group 1 was significantly higher than that in group 2 (0.62±0.06 vs 0.55±0.06, P=0.002).

In 2 cases in group 1 the optimal ablation site was the septal RVOT, whereas in the 6 cases in group 2, the successful ablation site was on the LCC in 3 cases, at the anteroseptal RVOT in 1 case and in the distal GCV in the 2 remaining cases (Table 3). The distance from the successful ablation site in the distal GCV to the LCC in the case in which it could be measured was 1.4 cm. A PDI >0.6 identified an intra-

### Table 3. Sensitivity and Specificity of PDI as a Predictor of Difficult Cases of OTVT/VPC Ablation

<table>
<thead>
<tr>
<th>Group 1 unsuccessful†</th>
<th>Group 2 successful†</th>
<th>Intramural or epicardial‡</th>
<th>Endocardial‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDI &gt;0.6</td>
<td>8</td>
<td>6*</td>
<td>14</td>
</tr>
<tr>
<td>PDI ≤0.6</td>
<td>2†</td>
<td>54</td>
<td>3**</td>
</tr>
</tbody>
</table>

*Successful ablation site was on the left coronary cusp in 3 cases, at the anteroseptal RVOT in 1 case, and in the distal GCV in the 2 remaining cases.
†Sensitivity: 80%; Specificity: 90%.
‡Sensitivity: 82%; Specificity: 100%.
§Optimal ablation site was the septal RVOT.
**Successful ablation site was on the right coronary cusp in the 1 of the 3 cases.

PDI, peak deflection index; OTVT/VPC, outflow tract ventricular tachycardia/ventricular premature contraction; RVOT, right ventricular outflow tract.

Figure 2. In group 1 (Left panel), the best mapping sites were the left coronary cusp (LCC), the distal great cardiac vein (GCV), and the septal right ventricular outflow tract (RVOT). However, the peak deflection index (PDI) >0.6, and radiofrequency catheter ablation was unsuccessful. In group 2 (Right panel), the successful ablation site was located in the RVOT with PDI ≤0.6.
Figure 3. PM from cases 3 and 4 in Table 2, which showed the best PM site, activation time, and ECG data in group 1. The site where PM matched the VPC in both of these group 1 cases was epicardial (ie, the distal great cardiac vein). Ventricular activation recorded at the site preceded the onset of the VPC QRS by 40 ms in case 3 and by 70 ms in case 4. The peak deflection index (PDI) was 0.61 in case 3 and 0.63 in case 4. VPC, ventricular premature contraction; PM, pace mapping (paper speed, 25 mm/s).

Figure 4. Comparison of peak deflection index (PDI) distribution in groups 1 and 2. ■ 2 cases in which the optimal ablation site was the septal right ventricular outflow tract (RVOT) (see Table 3); ● 6 cases in which the successful ablation site was on the left coronary cusp, at the anteroseptal RVOT or in the distal great cardiac vein (see Table 3). Dashed lines indicate the mean PDI in each group.
mural or epicardial site of OT-VT/VPC ablation with a sensitivity of 82% and a specificity of 100% in the patients with OT-VT/VPC. In the 1 case in the intramural or epicardial group, the successful ablation site was on the right coronary cusp (Table 3).

There were no differences in background or electrophysiologic parameters between the patients with PDI >0.6 and an unsuccessful ablation result and those with PDI >0.6 and a successful result.

Discussion

Main Findings

Ablation outcome can be improved if the origin of the OT-VT/VPC can be determined from the ECG morphology. Moreover, if we can position a small mapping catheter in the distal GCV at the site of the proximal anterior interventricular vein, we can determine whether the origin of the OT-VT/VPC is the left side, including the coronary cusps and the distal GCV. However, we cannot differentiate whether the origin of the OT-VT/VPC is endocardial or epicardial or deep within the ventricular septum solely by activation mapping from the catheter located in the distal GCV. Therefore, we need an ECG marker that can identify the origin of the OT-VT/VPC, because it is difficult to attain successful ablation when the OT-VT/VPC origin is located epicardially or deep within the ventricular septum. In our study, a PDI >0.6 was more likely to be associated with ablation failure, suggesting that this ECG finding may reflect either a deeper site or an epicardial site of origin (Figure 2).

In the present study, we found that a PDI >0.6 measured from the ECG identified an unsuccessful ablation outcome for OT-VT/VPC with a sensitivity of 80% and a specificity of 90%. Some sites of origin that may be difficult to reach from an endocardial approach may be successfully ablated from an epicardial (GCV) or aortic cusp approach, as was the case in 5 of the 6 patients in group 2 with a PDI >0.6. This may have contributed to the relatively low sensitivity of 80%.

Reasons for Ablation Failure in Group 1

We believe that the reason why the impedance at the best mapping site at the distal GCV was too high (>130 Ω) to perform RFCA in 3 cases in group 1 (3-5, of which 2 representative cases are shown in Figure 3) was because the diameter of the distal GCV in those patients was small. In the case of the right coronary cusp (no. 1) and LCC (no. 8), transpericardial RFCA may have been required. In the other 5 cases of septal RVOT, we believe that the focus was in the intramural region because the endocardial and epicardial sites we could reach were precisely mapped, but successful RFCA could not be attained. To date, transpericardial RFCA has never been performed by us.

ECG Morphology

The reason we use an inferior lead rather than a thoracic lead to determine the PDI is because the deflection of the QRS can be seen quickly. Daniels et al previously reported on the electrophysiologic characteristics, catheter ablation, and identification from the 12-lead ECG of epicardial LV tachycardia originating remote from the sinus of Valsalva. Although they calculated the MDI (maximum deflection index) using a precordial lead, the QRS morphology from the precordial leads is too variable among patients, making it difficult to quickly identify a high MDI. Tada et al reported that the R-wave amplitude in the inferior leads would be greater in VTs originating from the LV epicardium than in other VTs with an endocardial origin. Therefore, we thought that determination of the PDI from an inferior lead would be clearer and simpler than from a thoracic lead.

Yang et al observed that endocardially ablated RVOT sites had an earlier QRS peak in leads III and aVF than did aortic cusp (non-endocardial) sites (93 vs 110 ms), which supports our results. However, the initial peak/nadir in the inferior leads in the group 1 patients in this study was greater than 93 ms in only 3 of 10 (Table 2), so we believe that the initial peak/nadir may not be the best indicator of epicardial or intramural origin.

Additionally, we believe that it is not necessary to differentiate coronary cusp VT/VPC from epicardial VT/VPC by ECG. Because VT/VPC were not easily ablated safely in either of these sites in the present study, we also recognized that the VT/VPC were probably of epicardial origin. Furthermore, we want to simplify the means of distinguishing group 1 from group 2 patients. In fact, Pak et al reported that it was difficult to differentiate VT originating from the aortic cusp from VT originating from the anterior interventricular epicardium based on the ECG morphology. Of course, we need to differentiate the site where successful ablation can be attained in the coronary cusp from that in the distal GCV; however, we can do this with intracardiac mapping, not with the ECG. We believe that a PDI >0.6 may indicate that the origin of the OT-VT/VPC exists deep within the ventricular septum or at an epicardial site.

Clinical Implications

Our observations would suggest that if the patient has a PDI >0.6 and endocardial mapping/ablation has been unsuccessful, it may be helpful to place a small-diameter catheter in the distal GCV for mapping purposes. In 3 cases (2 of which are shown in Figure 3) in group 1, the impedance at the best mapping site at the distal GCV was too high to perform RFCA. We measured the diameter of the distal GCV during the venous phase of coronary angiography in those patients, and the diameter was <3 mm. However, the diameter at the successful ablation site in the distal GCV was >4 mm in the 2 patients with epicardial OT-VT/VPC in group 2. Therefore, the diameter of the distal GCV should be measured when the ECG of OT-VT/VPC shows a PDI >0.6. In addition, an 8-mm-tip ablation catheter should be used to create a deeper lesion when the endocardial site is approached, because the origin of the OT-VT/VPC exists deep within the ventricular septum.

Which Factors Increase the PDI?

In the present study, a PDI >0.6 identified an intramural or epicardial site of OT-VT/VPC ablation with a sensitivity of 82% and a specificity of 100% (Table 3). These high values for sensitivity and specificity may mean that a PDI >0.6 indicates an intramural or epicardial origin of the OT-VT/VPC. When the origin of the OT-VT/VPC exists deep within the ventricular septum or at an epicardial site, and especially at these locations, conduction time through the entire ventricle is prolonged, because of the time it takes to conduct the impulse from the OT-VT/VPC origin deep within the ventricular septum or the epicardial site to the His-Purkinje system in the endocardium before the rest of the ventricle can be excited. In addition, a high precordial maximum deflection index, which reflects delayed initial activation of the left ventricle, has been described as being related to slower spread of activation from a focus on the epicardial
surface relative to the endocardium and to delayed global ventricular activation resulting from later engagement of the His–Purkinje network.\textsuperscript{5,13} We think the mechanism causing the high PDI seen with intramural septal RVOT-VT/VPC is the same as that for epicardial OT-VT/VPC.

**Study Limitations**

Given the small measurement involved, a precise PDI cannot be calculated from the standard 12-lead ECG recorded at 25 mm/s paper speed; the ECG must be recorded at 50–100 mm/s for PDI measurement. If the patient is taking certain antiarrhythmic agents, the QRS duration will be prolonged, and the PDI may be altered. Thus, it may be difficult to diagnose the origin of the VT/VPC by ECG analysis alone. Irrigated ablation catheters, which are not yet approved for use in Japan, create deeper lesions than do conventional ablation catheters.\textsuperscript{14} Had we had access to such catheters, ablation might have been successful in some patients in group 1. Another important limitation is that RFCA cannot be performed many times on the coronary cusps or in the distal GCV. Complications of RFCA involving the aortic cusps, such as occlusion of the left main trunk\textsuperscript{15} or aortic regurgitation, can be critical, and sometimes the impedance is too high to perform RFCA at the optimal ablation site in the distal GCV. We believe that RFCA on the aortic cusps should not be performed more than 3 times if these complications are to be avoided.

**Conclusions**

For outflow tract arrhythmias, a measured PDI >0.6 is associated with a higher rate of ablation failure than is a PDI ≤0.6. A PDI >0.6 measured from the tallest inferior lead may indicate a non-endocardial (intramural or epicardial) site of origin.

**Acknowledgment**

We thank George B. Powell for his review of this manuscript.

**References**