In patients with structural heart disease, radiofrequency catheter ablation for ventricular tachycardia (VT) has been shown to reduce arrhythmia burden without a clear benefit in cardiac mortality. To facilitate entrainment and activation mapping of hemodynamically unstable ventricular tachycardia (VT), there is limited data whether clinical outcomes are improved. We sought to retrospectively compare the outcomes of patients undergoing scar-related VT ablation with and without pLVAD support.

**Methods and Results**—The study population comprised 194 patients (109 pLVAD and 85 non-pLVAD). The pLVAD group more often had dilated cardiomyopathy (33% versus 13%; \(P=0.001\)), lower left ventricular ejection fractions (26±10% versus 39±16%; \(P<0.001\)), and electrical storm (49% versus 34%; \(P=0.04\)). Procedure times (422±112 versus 330±92 minutes; \(P<0.001\)), postablation VT inducibility (20% versus 7%; \(P=0.02\)), and length of subsequent hospitalization (median 6 versus 4 days; \(P=0.001\)) were all higher in the pLVAD group. During median follow-up of 215 days, the primary end point (recurrent VT, heart transplantation, or death) occurred in 36% of the pLVAD versus 26% of the non-pLVAD groups (\(P=0.14\)). After propensity matching for differences between groups, no differences were seen between groups for both acute procedural outcomes and the primary end point.

**Conclusions**—In this large single-center scar-related VT ablation experience, despite the worse clinical status of the patients selected for pLVAD support, clinical outcomes were better than expected and were similar to healthier patients not receiving hemodynamic support. Patients with dilated cardiomyopathy presenting with electrical storm, advanced heart failure, and severe left ventricular dysfunction most frequently received hemodynamic support during VT ablation. (Circ Arrhythm Electrophysiol. 2017;10:e004717. DOI: 10.1161/CIRCEP.116.004717.)

**Key Words:** catheter ablation • heart failure • percutaneous left ventricular assist device • stroke volume • ventricular tachycardia

In patients with structural heart disease, radiofrequency catheter ablation for ventricular tachycardia (VT) has been shown to reduce arrhythmia burden without a clear benefit in cardiac mortality. To facilitate entrainment and activation mapping of hemodynamically unstable VT and mitigate the effects of frequent induction and prolonged VT duration on end-organ perfusion, several studies have demonstrated the feasibility of percutaneous left ventricular assist devices (pLVADs) for hemodynamic support during ablation procedures. In these studies, pLVAD support resulted in increased mapping time during VT, less requirement for VT termination because of hemodynamic instability, and more VT terminations during ablation. However, there is limited data to ascertain whether this acute hemodynamic benefit translates into improved clinical outcomes. In this single-center retrospective study, we sought to determine whether pLVAD use during catheter ablation of scar-related VT improves clinical outcomes.

**Methods**

**Study Population**

Two-hundred and five consecutive patients who underwent catheter ablation for hemodynamically unstable scar-related VT at the Mount Sinai Medical Center were included in this retrospective study. Hemodynamically unstable VT was defined as that requiring internal/external cardioversion or antitachycardia pacing or associated with dizziness/syncope. The study was approved by the institutional review board.

**Procedural Details**

All procedures were performed under general anesthesia with endotracheal intubation. Hemodynamic monitoring was performed using radial or femoral arterial blood pressure monitoring, and bilateral
WHAT IS KNOWN
- Previous studies show that percutaneous left ventricular assist device support during catheter ablation of ventricular tachycardia (VT) allows for greater mapping time during VT and more VT terminations during ablation.
- However, there are limited data as to whether clinical outcomes are improved.

WHAT THE STUDY ADDS
- Although patients selected for percutaneous left ventricular assist device support had worse clinical status, clinical outcomes were better than expected and were similar to healthier patients not receiving support.
- Patients with dilated cardiomyopathy or who present with electric storm, advanced heart failure, or severe left ventricular dysfunction may benefit most from hemodynamic support during VT ablation.

Results

Characteristics of pLVAD and Non-pLVAD Groups
Of the 205 patients, ablation was not performed in 11 patients because of lack of inducible VT in addition to no identifiable scar (n=6), no appropriate site mapped for ablation (n=2), unmappable polymorphic VT (n=1), cardiac tamponade (n=1), and cardiac arrest (n=1) occurring before ablation. Among the remaining 194 patients, pLVAD was used in 109 (80 with Impella 2.5 and 29 with Impella CP) and not used in 85.

Baseline clinical characteristics and procedural details of the pLVAD group and the non-pLVAD group are shown in Table 1. Dilated cardiomyopathy was more common in the pLVAD group (33% versus 13%, P<0.001; Figure); however, arrhythmogenic right ventricular cardiomyopathy was less common (2% versus 11%, P=0.01). Patients in the pLVAD group had significantly lower LVEF (26±10% versus 39±16%, P<0.001), higher prevalence of New York Heart Association class ≥III heart failure (51% versus 25%, P<0.001), and more frequent electrical storm (49% versus 34%, P=0.04) on presentation. Use of pLVAD was associated with longer procedures (422±112 versus 330±92 minutes, P<0.001). There was a higher percentage of patients who underwent entrainment/
Table 1. Clinical and Procedural Characteristics of Patients Undergoing VT Ablation (n=194)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>pLVAD (n=109)</th>
<th>Non-pLVAD (n=85)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>64±11</td>
<td>61±15</td>
<td>0.16</td>
</tr>
<tr>
<td>Male</td>
<td>101 (93)</td>
<td>68 (80)</td>
<td>0.01</td>
</tr>
<tr>
<td>Nonischemic cardiomyopathy</td>
<td>48 (44)</td>
<td>36 (42)</td>
<td>0.81</td>
</tr>
<tr>
<td>DCM</td>
<td>36 (33)</td>
<td>11 (13)</td>
<td>0.001</td>
</tr>
<tr>
<td>Valvular heart disease</td>
<td>4 (4)</td>
<td>5 (6)</td>
<td>0.35</td>
</tr>
<tr>
<td>HCM</td>
<td>2 (2)</td>
<td>4 (5)</td>
<td>0.23</td>
</tr>
<tr>
<td>ARVC</td>
<td>2 (2)</td>
<td>9 (11)</td>
<td>0.01</td>
</tr>
<tr>
<td>Sarcoidiosis</td>
<td>4 (4)</td>
<td>4 (5)</td>
<td>0.50</td>
</tr>
<tr>
<td>Prior cardiac surgery</td>
<td>42 (39)</td>
<td>32 (38)</td>
<td>0.90</td>
</tr>
<tr>
<td>NYHA class ≥II</td>
<td>55 (51)</td>
<td>21 (25)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Electrical storm</td>
<td>53 (49)</td>
<td>29 (34)</td>
<td>0.04</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>26±10</td>
<td>39±16</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>25 (23)</td>
<td>19 (22)</td>
<td>0.92</td>
</tr>
<tr>
<td>CKD</td>
<td>43 (39)</td>
<td>23 (27)</td>
<td>0.07</td>
</tr>
<tr>
<td>Amiodarone</td>
<td>78 (72)</td>
<td>45 (53)</td>
<td>0.01</td>
</tr>
<tr>
<td>β-Blockers</td>
<td>101 (93)</td>
<td>73 (86)</td>
<td>0.12</td>
</tr>
<tr>
<td>Prior VT ablation</td>
<td>29 (27)</td>
<td>25 (29)</td>
<td>0.67</td>
</tr>
<tr>
<td>Inducibility of VT at baseline</td>
<td>106 (97)</td>
<td>75 (89)</td>
<td>0.02</td>
</tr>
<tr>
<td>VTs induced</td>
<td>3.3±2.1</td>
<td>2.4±2.1</td>
<td>0.004</td>
</tr>
<tr>
<td>≥1 hemodynamically mappable VT</td>
<td>85 (80)</td>
<td>51 (68)</td>
<td>0.06</td>
</tr>
<tr>
<td>Entrainment/activation mapping</td>
<td>75 (69)</td>
<td>49 (58)</td>
<td>0.11</td>
</tr>
<tr>
<td>VTs mapped during tachycardia</td>
<td>1.6±0.8</td>
<td>1.5±0.7</td>
<td>0.42</td>
</tr>
<tr>
<td>VTs terminated during ablation</td>
<td>1.4±0.8</td>
<td>1.4±0.7</td>
<td>0.96</td>
</tr>
<tr>
<td>Epicardial ablation</td>
<td>31 (28)</td>
<td>25 (29)</td>
<td>0.88</td>
</tr>
<tr>
<td>Ablation time, min</td>
<td>43±28</td>
<td>43±27</td>
<td>0.91</td>
</tr>
<tr>
<td>Procedure time, min</td>
<td>422±112</td>
<td>330±92</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data were presented as number (percentage) or mean±standard deviation. ARVC indicates arrhythmogenic right ventricular cardiomyopathy; CKD, chronic kidney disease; DCM, dilated cardiomyopathy; HCM, hypertrophic cardiomyopathy; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; pLVAD, percutaneous left ventricular assist device; and VT, ventricular tachycardia.

Discussion

This is the largest report of pLVAD use during catheter ablation of VT associated with structural heart disease. The main findings of this study are (1) patients selected for pLVAD support during VT ablation were more likely to have dilated VT induction was attempted in 85% of pLVAD patients and 81% of non-LVAD patients. Of these patients, VT inducibility was greater in the pLVAD group (20% versus 7%; P=0.02).

Procedure-related complications were similar between the pLVAD and non-pLVAD groups (17% versus 9%; P=0.15): pericardial effusion (7% versus 4%; P=0.26), vascular complications (7% versus 5%; P=0.45), and worsening heart failure (3% versus 1%; P=0.41). Acute kidney injury, defined as an absolute increase in serum creatinine elevation of ≥0.3 mg/dL or increase of ≥150% within 48 hours after the procedure, occurred in 24% of the pLVAD and 6% of non-pLVAD groups (P=0.001). It resolved in all individuals except in 2 patients who died because of electrical storm after ablation.

VT ablation facilitated with pLVAD was associated with a longer postprocedure hospitalization (median 6 [Q1, Q3: 4, 9] days versus 4 [Q1, Q3: 3, 7] days; P=0.001).

During a median follow-up of 215 (Q1, Q3: 21, 630) days after the index procedure, the primary end point (death, heart transplantation, and recurrent VT) occurred in 36% (39/109 patients) and 26% (22/85 patients) of patients in the pLVAD and non-pLVAD groups (P=0.14), respectively. Death occurred in 9 (8%) and 5 (6%) patients (P=0.53), heart transplantation in 4 (4%) and 0 (0%) patients (P=0.10), and recurrent VT in 35 (32%) and 18 (21%) patients (P=0.09) in the pLVAD and non-pLVAD groups, respectively.

pLVAD Versus Non-pLVAD VT: Matched Groups

Of the original sample of 194 patients, 76 (39%) met criteria for inclusion in the propensity score–matched analysis based on New York Heart Association heart failure class ≥III, electrical storm, and LVEF. The clinical and procedural characteristics of the matched cohort are shown in Table 2, in which average procedure time was found to be ≈66 minutes longer in the pLVAD group compared with the non-pLVAD group. However, there were no advantages demonstrated with pLVAD use with respect to acute procedural outcomes. At least 1 VT termination with ablation was seen in 93% of pLVAD and 100% of non-pLVAD patients (P=0.10) when an entrainment/activation mapping strategy was used. At procedure conclusion, VT inducibility was 14% and 10% in the p-LV AD and non-pLVAD groups (P=0.43), respectively, among those in whom induction was attempted. There were also no significant differences between the pLVAD and non-pLVAD groups with regard to procedure complications (11% versus 3%; P=0.18), reversible acute kidney injury (18% versus 5%; P=0.08), or postprocedure length of stay in the hospital (median 5 days for both groups; P=0.26).

The primary end point occurred in 32% and 29% of patients in the pLVAD and non-pLVAD groups (P=0.80). Rates of death were 5% and 8% (P=0.50), heart transplantation were 5% and 0% (P=0.25), and recurrent VT were 26% and 21% (P=0.29) in the pLVAD and non-pLVAD groups, respectively.
cardiomyopathy (33% versus 13%; \( P=0.001 \)) and present with electrical storm (49% versus 34%), have class III heart failure (51% versus 25%), and have significantly lower LVEFs (26% versus 39%) compared with those not receiving these devices, (2) procedures were longer with pLVADs and resulted in no significant differences in terms postablation VT inducibility or postprocedure length of hospitalization, (3) complication rates were similar in both groups; however, reversible acute kidney injury was more frequent in the pLVAD group, (4) despite being a higher risk group of patients, those who received pLVAD support experienced a similar combined rate of recurrent VT, heart transplantation, and death as the relatively healthier non-pLVAD group, (5) after propensity matching to account for the bias caused by confounders affecting pLVAD use, there was no discernable difference between groups in terms of either acute procedural outcomes or the primary end point.

pLVADs are being increasingly used in patients who are susceptible to hemodynamic compromise. They provide hemodynamic benefits because of their ability to reduce intracardiac filling pressures, intracardiac volumes, ventricular wall stress, and myocardial oxygen consumption. Additionally, they also maintain coronary artery and end-organ perfusion. They have been shown to be of potential benefit in select patients undergoing high-risk percutaneous coronary intervention, acute myocardial infarction, acute decompensated heart failure, and cardiogenic shock. Because robust clinical evidence is lacking, the Society for Cardiovascular Angiography and Interventions/American College of Cardiology/Heart Failure Society of America/Society of Thoracic Surgeons have provided a recent expert consensus statement in terms of patient populations that may derive benefit from these devices.

In a small single-center study of patients undergoing ablation for scar-related VT, we previously reported that pLVADs provided sufficient hemodynamic support to allow patients to be maintained in VT 2.5-fold longer, with fewer premature terminations required for hemodynamic instability, and allowed more patients to have termination of VT during ablation without any deleterious effects on end-organ perfusion.
In a prospective evaluation of pLVADs, patients were maintained in VT for nearly 1 hour. These findings suggest that those of other investigators. Common to these studies is the finding that pLVAD use provided no evidence of benefit in terms of postablation inducibility or freedom from recurrent VT compared with ablation without pLVAD support, although fewer comorbidities were present in cases without pLVAD support. Based on available data, the 2015 Society for Cardiovascular Angiography and Interventions/American College of Cardiology/Heart Failure Society of America/and Society of Thoracic Surgeons expert consensus statement has suggested that pLVADs may be considered in patients undergoing high-risk or complex ablation of VT without specifying which subgroup of patients are likely to benefit most.

In the present study, the patients who received pLVADs were sicker, and nearly half of the pLVAD group presented with electrical storm and class III/IV heart failure. The mean LVEF in this group was 26% compared with 39% in the non-pLVAD group (P<0.001). Despite the sicker status, outcomes with the pLVAD were similar to those of healthier non-pLVAD group. In the International VT Ablation Center Collaborative Group study of 2061 patients with structural heart disease who underwent VT ablation, lower ejection fraction, electrical storm, and heart failure were all independent predictors of VT recurrence and also the combined end point of cardiac transplantation and mortality. In that study, the use of hemodynamic support was associated with higher transplantation and mortality with no effect on VT recurrence. However, there were a variety of devices used, which provide varying degrees of hemodynamic support from minimal (intra-aortic balloon counterpulsation) to maximal (extracorporeal membrane oxygenation). Furthermore, it is unclear which of their patients were selected for pLVADs or how many patients received these devices, making comparison to our study difficult.

In the present study, only Impella pLVADs were used, which provides 2.5 to 3.5 L/min of hemodynamic support. The use of these devices in a sicker patient population resulted in better than expected outcomes, which may partially be because of reduction in postprocedure heart failure and acute hemodynamic decompensation, which is reported to occur in ≤11% of individuals undergoing ablation for scar-related VT. Santangeli et al demonstrated that those who experienced acute hemodynamic decompensation more often had class III/IV heart failure (55% versus 15%; P=0.001), had lower LVEFs (26±10% versus 36±16%; P=0.003), and were more likely to present with VT storm (77% versus 43%; P=0.002). At a mean follow-up of 21±7 months, mortality was significantly higher in those who experienced this complication (50% versus 11%; log-rank P<0.001). The characteristics of patients receiving pLVADs in our study are likely to have identified those who were prone to having acute hemodynamic decompensation. Yet, overall outcomes were better than expected in our study, likely in part because of the hemodynamic benefit provided by pLVADs.

Substrate-based ablation may be sufficient for successfully treating VT related to ischemic cardiomyopathy, It has been demonstrated that those who were prone to acute hemodynamic decompensation more often had class III/IV heart failure (55% versus 15%; P=0.001), had lower LVEFs (26±10% versus 36±16%; P=0.003), and were more likely to present with VT storm (77% versus 43%; P=0.002). At a mean follow-up of 21±7 months, mortality was significantly higher in those who experienced this complication (50% versus 11%; log-rank P<0.001). The characteristics of patients receiving pLVADs in our study are likely to have identified those who were prone to having acute hemodynamic decompensation. Yet, overall outcomes were better than expected in our study, likely in part because of the hemodynamic benefit provided by pLVADs.

Substrate-based ablation may be sufficient for successfully treating VT related to ischemic cardiomyopathy, However, this approach may have limited utility in patients with dilated cardiomyopathy, who often have a paucity of identifiable substrate (ie, small scars, few late potentials). In these patients, the ablation approach is often limited to pace mapping or entrainment/activation mapping. In dilated cardiomyopathy patients, pLVADs may provide sufficient hemodynamic support to allow activation mapping and ablation during otherwise unstable VTs. In the present study, more patients with dilated cardiomyopathy received pLVADs (33% versus 13%; P=0.001). Additionally, during electroanatomic mapping, the mean total area (endocardial and epicardial) with bipolar voltage <0.5 mV was significantly lower among dilated cardiomyopathy patients (10.3±15.9 cm²) than among ischemic cardiomyopathy patients (19.1±25.3 cm²; P=0.010). This relative lack of identifiable substrate in dilated cardiomyopathy patients likely made pLVADs particularly helpful for activation mapping.

The propensity matching analysis attempted to account for the bias caused by confounders affecting pLVAD use and demonstrated no benefit in terms of postablation inducibility or the combined primary end point. These findings may be because of the lack of power to detect differences in the smaller patient groups. For instance, based on an assumed rate for the primary
end point of 0.30 in the control non-PLVAD group, our post hoc power was 0.34 to detect a relative risk of 0.50 in the PLVAD group and 0.59 to detect a relative risk of 0.33. Or, there may be other confounding variables among the sicker patients that biased our estimates against the PLVAD group. Overall, the findings of this study do not support the wide use of pLVADs in all patients undergoing VT ablation. Instead, it seems most appropriate to use the pLVAD in patients with dilated cardiomyopathy or who present with electrical storm, New York Heart Association heart failure class ≥ III, or severe LV dysfunction. These factors suggest that sicker patients are more likely to benefit from use of pLVAD during ablation procedures.

Limitations
This is a single-center, nonrandomized, retrospective analysis from a tertiary referral center with a few experienced operators. Thus, the extrapolation of these findings to other patient populations and nontertiary centers should be done with caution. Only Impella pLVADs were used in this study, and the findings are not applicable to other forms of hemodynamic support, such as intra-aortic balloon counterpulsation, TandemHeart pLVAD, or extracorporeal membrane oxygenation. The majority of the pLVADs used in this study were the Impella 2.5 (73%), and it is possible that more favorable results may have been observed if the Impella CP, which provides an additional 1 L/min of support, was used in all cases.

Conclusions
In this single-center retrospective study of scar-related VT ablation, use of pLVAD hemodynamic support with the Impella device was associated with better than expected outcomes (ie, combined primary end point of recurrent VT, cardiac transplantation, and mortality) in the sickest patients, such as those presenting with electrical storm, low ejection fractions, and advanced heart failure. These data do not support the wide use of these devices in all patients undergoing scar-related VT ablation. Rather, pLVAD use would probably be most judicious in those patients most likely to benefit: those with dilated cardiomyopathy or who present with electrical storm, advanced heart failure, and severe LV dysfunction. Ideally, these results will be confirmed in prospective randomized controlled trials.

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Abiomed, Inc provided a research grant for the PERMIT 1 study (Percutaneous Hemodynamic Support With Impella 2.5 During Scar-Related Ventricular Tachycardia Ablation), which involved 20 patients who are included in this analysis.

Disclosures
Drs Dukkipati, Miller, d’Avila, and Reddy received honoraria from Abiomed, Inc. Dr Reddy received research grant from Abiomed, Inc for the PERMIT 1 study. The other authors report no conflicts.

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Outcomes of Ventricular Tachycardia Ablation Using Percutaneous Left Ventricular Assist Devices

Shigeki Kusa, Marc A. Miller, William Whang, Yoshinari Enomoto, Jorge G. Panizo, Jin Iwasawa, Subbarao Choudry, Sean Pinney, Anthony Gomes, Noelle Langan, Jacob S. Koruth, Andre d'Avila, Vivek Y. Reddy and Srinivas R. Dukkipati

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