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.1–9 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.10–14 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.

The pLVAD catheter was maintained inside the LV at the maximum performance level (P8) unless electromagnetic interference occurred. To avoid EMI, a transseptal access was preferred in mapping the LV. Retrograde aortic approach was used in combination with transseptal approach where the endocardial mapping of the left ventricular outflow tract was difficult via the transseptal route or in the presence of a mechanical mitral valve. Appropriate positioning of the pLVAD was monitored and confirmed using fluoroscopy and intracardiac echocardiography (Acuson; Biosense Webster).

The composite primary end point included recurrent VT, heart transplant, and all-cause death. Monitoring for recurrent VT included continuous ECG monitoring during hospitalization, device interrogation, and review of outpatient medical records. Recurrent VT was defined as any sustained VT lasting ≥30 s or that required electric cardioversion or pacing therapy for termination.

Statistical Analysis
Clinical characteristics were compared between patients who underwent VT ablation with and without pLVAD support. Categorical variables were tested by χ² test or Fisher exact test. Continuous variables are expressed as mean±standard deviation for normally distributed variables or median with interquartile range for non-normally distributed variables (25%, 75% percentiles). For follow-up time in days, the date of the ablation procedure was considered time zero, and data were right-censored based on the earliest date of any component event in the primary end point or the date of last follow-up, whichever came first.

Categorical variables were compared between the non-pLVAD and pLVAD groups with χ² tests or Fisher’s exact tests. T-tests with assumption of unequal variances or Mann–Whitney U tests were used to compare continuous measures between groups. A one-to-one matching analysis was performed based on propensity scores to minimize the bias caused by confounding variables affecting pLVAD use.11 Propensity scores were estimated through a logistic regression model where the dependent variable consisted of pLVAD use, and independent variables included New York Heart Association class ≥III heart failure, electrical storm, and left ventricular ejection fraction (LVEF). Standardized differences (SD) of these covariates between the matched groups were calculated to assess the matching algorithm, and an absolute SD <10% represented meaningful balance between the matched groups. All statistical analyses were performed using SPSS 19.0 (SPSS Inc, Chicago, IL), and a 2-sided P value <0.05 was used to indicate statistical significance.

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/
activation mapping with the pLVAD, although this difference did not reach statistical significance (69% versus 58%; \(P=0.11\)). When an entrainment/activation mapping was used, at least 1 VT termination during ablation was seen in 91% of pLVAD and 98% of non-pLVAD patients (91% versus 98%; \(P=0.10\)). More overall number of VTs (3.3±2.1 versus 2.4±2.1; \(P=0.004\)) and percentage of patients with at least 1 hemodynamically mappable VT (80% versus 68%; \(P=0.06\)) were induced in the pLVAD group. After ablation, 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, \(^\text{11}\) 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] 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 postprocedural 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-LVAD groups, respectively.

**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...
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.\(^{19} \) 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.\(^{20-23} \)

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.\(^{19} \)

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.\(^{10} \)

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**Figure.** Patient with dilated cardiomyopathy undergoing ventricular tachycardia (VT) ablation. **A,** The bipolar voltage maps (left lateral projection) demonstrate a small endocardial (ENDO) and epicardial (EPI) scar at the lateral base of the left ventricle (LV). There were few late (black points) or fragmented (white) potentials. **B,** Hemodynamically unstable VT was induced with a cycle length of 350 ms. The mean femoral arterial blood pressure measured \( \approx 40 \text{ mm Hg} \) (arrow). **C,** Because of small scar and lack of significant substrate, a percutaneous left ventricular assist device (pLVAD) was inserted for hemodynamic support to enable activation/entrainment mapping. **D,** After insertion of the pLVAD, the mean arterial blood pressure was \( \approx 65 \text{ mm Hg} \) during the same VT. With the ablation catheter positioned near the exit site of the VT (arrow in **A** and circle in **C**), ablation resulted in termination of VT in 2.8 s.
In a prospective evaluation of pLVADs, patients were maintained in VT for nearly 1 hour. These findings are similar to 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/American 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. This relative lack of identifiable substrate in dilated cardiomyopathy patients likely made pLVADs particularly helpful for patients with dilated cardiomyopathy, who often have a paucity of identifiable substrate (ie, small scars, few late potentials).30 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 19.1±25.3 cm²; 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.

Table 2. Clinical and Procedural Characteristics of Matched Patients

<table>
<thead>
<tr>
<th></th>
<th>pLVAD (n=38)</th>
<th>Non-pLVAD (n=38)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>63±11</td>
<td>66±12</td>
<td>0.23</td>
</tr>
<tr>
<td>Male</td>
<td>34 (90)</td>
<td>30 (79)</td>
<td>0.21</td>
</tr>
<tr>
<td>Nonischemic cardiomyopathy</td>
<td>19 (50)</td>
<td>12 (32)</td>
<td>0.10</td>
</tr>
<tr>
<td>Prior cardiac surgery</td>
<td>15 (40)</td>
<td>18 (47)</td>
<td>0.49</td>
</tr>
<tr>
<td>NYHA class ≥III</td>
<td>14 (37)</td>
<td>14 (37)</td>
<td>1.00</td>
</tr>
<tr>
<td>Electrical storm</td>
<td>18 (47)</td>
<td>18 (47)</td>
<td>1.00</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>28±10</td>
<td>28±10</td>
<td>0.98</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>9 (24)</td>
<td>12 (32)</td>
<td>0.44</td>
</tr>
<tr>
<td>CKD</td>
<td>18 (47)</td>
<td>13 (34)</td>
<td>0.24</td>
</tr>
<tr>
<td>Prior VT ablation</td>
<td>10 (26)</td>
<td>10 (26)</td>
<td>1.00</td>
</tr>
<tr>
<td>Inducibility of VT at baseline</td>
<td>37 (97)</td>
<td>34 (90)</td>
<td>0.18</td>
</tr>
<tr>
<td>VTs induced</td>
<td>3.4±2.4</td>
<td>2.3±1.6</td>
<td>0.02</td>
</tr>
<tr>
<td>≥1 hemodynamically mappable VT</td>
<td>31 (n=37)</td>
<td>25 (n=34)</td>
<td>0.11</td>
</tr>
<tr>
<td>Entrainment/activation mapping</td>
<td>28 (74)</td>
<td>22 (58)</td>
<td>0.15</td>
</tr>
<tr>
<td>VTs mapped during tachycardia</td>
<td>1.6±0.8</td>
<td>1.3±0.5</td>
<td>0.12</td>
</tr>
<tr>
<td>VTs terminated during ablation</td>
<td>1.5±0.8</td>
<td>1.3±0.5</td>
<td>0.42</td>
</tr>
<tr>
<td>Epicardial ablation, n (%)</td>
<td>11 (29)</td>
<td>12 (32)</td>
<td>0.80</td>
</tr>
<tr>
<td>Procedure time, min</td>
<td>416±109</td>
<td>350±87</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Data were presented as number (percentage) or mean±standard deviation. CKD indicates chronic kidney disease; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association; pLVAD, percutaneous left ventricular assist device; and VT, ventricular tachycardia.
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 I 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 I study. The other authors report no conflicts.

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Outcomes of Ventricular Tachycardia Ablation Using Percutaneous Left Ventricular Assist Devices

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