EMERGING TECHNIQUES

Intra-aortic Balloon Pump Counterpulsation and Percutaneous Ventricular Assist Devices for Hemodynamic Support During Ventricular Tachycardia Ablation

KARTIKYA AHUJA, MD, ANTHONY AIZER, MD, MSc, DANIEL K. O’NEILL, MD and LARRY A. CHINITZ, MD

1Division of Cardiology, New York University Langone Medical Center, New York University School of Medicine, New York, NY
2Department of Anesthesiology, New York University Langone Medical Center, New York University School of Medicine, New York, NY

KEYWORDS. Impella™, intra-aortic balloon pump counterpulsation, percutaneous left ventricular assist device, Tandem Heart™, ventricular tachycardia ablation.

Introduction

The cornerstone of therapy for ventricular arrhythmias in the setting of structural heart disease is the implantable cardioverter-defibrillator (ICD). In patients who continue to have symptomatic ventricular tachycardia (VT) following ICD therapy, adjunctive treatments include antiarrhythmic drugs and catheter ablation. Pharmacologic therapy for VT is limited by high failure rates and the potential for proarrhythmia or toxicity. For these patients, catheter ablation may improve symptoms by decreasing the incidence of ICD therapy. Integral to a comprehensive catheter-based VT ablation procedure is activation and entrainment mapping, which occurs during prolonged periods of ventricular tachycardia. In almost 70% of patients, these periods of VT are not tolerated hemodynamically (requiring direct current cardioversion or pace termination), which limits detailed activation and entrainment mapping. This has prompted an interest in using cardiac assist devices, such as intra-aortic balloon pumps (IABPs) or percutaneous left ventricular assist devices (pVADs), so that VT can be sustained long enough for sufficient mapping information to be collected. This review will discuss the available cardiac assist devices and recent publications that describe hemodynamic support during VT ablation.

IABP counterpulsation

IABP counterpulsation was first introduced in the 1960s and is currently the most widely used circulatory assist device. It is composed of two principal parts: A) a flexible catheter with a lumen that allows for continuous blood pressure monitoring and B) a closed balloon with helium gas. The external mobile console contains the system for helium transfer, as well as a computer to control the inflation-deflation cycle. The catheter is most commonly inserted through an 8.5-French sheath in the common femoral artery, and the distal end is advanced under fluoroscopic guidance to 1-3 cm distal to the origin of the left subclavian artery. Pumping is initiated and controlled by the console using input from both the aortic pressure monitor and the electrocardiogram.
**Figure 1:** The Tandem Heart™ is a percutaneous left atrial-to-femoral arterial ventricular assist device. Figure provided by Cardiac Assist Inc., Pittsburgh, PA.
Figure 2: The Tandem Heart™. A 21-French inflow venous cannula is inserted into the left atrium by trans-septal puncture, and a 17-French arterial cannula is inserted via the common femoral artery into the iliac artery for the return of blood from an extracorporeal pump. Figure provided by Cardiac Assist Inc., Pittsburgh, PA.
Figure 3: The Impella™ 2.5 percutaneous ventricular assist device catheter. Figure provided by ABIOMED Inc., Danvers, MA.
Inflation occurs immediately after aortic valve closure, and deflation is just before aortic valve opening. The IABP has two major roles: 1) blood is displaced to the proximal aorta by inflation during diastole and 2) afterload reduction during systole through a vacuum effect created by rapid balloon deflation. In patients with cardiogenic shock, expected hemodynamic changes include a 20% decrease in systolic pressure, a 30% increase in aortic diastolic pressure, and an increase in mean arterial pressure (MAP) via an increase in cardiac output by 20%. It has a long history in clinical practice, is inserted easily and rapidly, is the least expensive of all the devices, and it does not require constant monitoring by technical support personnel. Contraindications include moderate or severe aortic regurgitation, significant abdominal aortic aneurysm or aortic dissection, and severe peripheral arterial disease. The total complication rate is approximately 7%, but the rate of major complications (acute limb or visceral ischemia, severe vascular bleeding, and death related directly to the IABP) occurs at 2.6%, with mortality directly related to the IABP at 0.5%. Minor complications include thrombocytopenia, hemolysis, seroma, groin infection, and neuropathy.

Although the IABP is the most often used device to prevent patients in cardiogenic shock from experiencing acute myocardial infarction or progressive heart failure, its supportive use during a VT ablation has not been widely reported in the literature. In fact, there are several factors of VT ablations (tachycardia and severe hypotension) that could make the use of an IABP challenging.

**Figure 4:** The Impella™ 2.5. A 12-French catheter with a 6-French pigtail distal end is passed retrograde through the aortic valve and draws blood out of the left ventricle ejecting into the ascending aorta. Figure provided by ABIOMED Inc., Danvers, MA.
Tachycardia greater than 120 beats per minute (bpm) results in a significant decline in the hemodynamic improvements provided by an IABP, mainly due to inadequate time to allow for complete balloon inflation and deflation. Heart rates from 80–110 bpm seem to provide optimal IABP hemodynamic effects, but the heart rates of most patients during a VT ablation procedure preclude the benefits of this device. In addition, IABPs are known to be ineffective in patients with systolic aortic pressures less than 60–70 mm Hg. Animal studies have demonstrated markedly decreased diastolic augmentation during IABP counterpulsation at mean aortic pressure less than 40 mm Hg, mainly due to increased arterial compliance. Given that tachycardia and severe hypotension are common during activation and entrainment mapping during VT, the beneficial effects of an IABP may be limited during this procedure. Conversely, a VAD does not appear to be limited by these factors and could better facilitate VT ablation.

**Tandem Heart™**

The Tandem Heart™ (Cardiac Assist Inc., Pittsburgh, PA) is a percutaneous left atrial-to-femoral arterial VAD (Figure 1). Briefly, a 21-French inflow venous cannula is inserted into the left atrium by trans-septal puncture, and a 17-French arterial cannula is inserted via the common femoral artery into the iliac artery for blood return from an extracorporeal pump (Figure 2). Insertion of the device takes an average of 30 min, and it can provide flows up to 4 L/min. The disposables for the Tandem Heart™ now cost $15,000 per case. There is also an initial capital investment for the console. The role of this device has been mainly for short-term stabilization during cardiogenic shock during myocardial infarction. Compared with an IABP, the Tandem Heart™ has been shown to significantly reduce preload and augment cardiac output. In a report of 18 patients with cardiogenic shock due to myocardial infarction, the cardiac index improved from 1.7 to 2.4 L/min/m², mean blood pressure increased from 63 to 80 mm Hg, and mean flow of the VAD was 3.2 L/min. Pulmonary capillary wedge pressure, central venous pressure, and pulmonary artery pressure were also all reduced.

Friedman et al published the first report of using the Tandem Heart™ to support a VT ablation in 2007. They described a 55-year-old male with non-ischemic cardiomyopathy who experienced 9 ICD shocks within 2 months despite triple antiarrhythmic drug therapy. During an electrophysiology study, VT induction resulted in a systolic blood pressure of 30 mm Hg. Insertion of the VAD achieved flow rates over 4 L/min, resulting in a mean blood pressure of 95 mm Hg while the patient was in VT. The patient was able to tolerate VT for 105 min with VAD support, allowing for both endocardial and epicardial activation mapping and subsequent ablation. Periprocedural complications included the need for 2 units of packed red cells and a left femoral arteriovenous fistula that did not require surgical intervention. The patient had not experienced any further VT at the 7-month follow-up.

In 2011, Bunch et al compared the outcomes of 13 consecutive patients who underwent Tandem Heart™-supported VT ablation with 18 matched patients who had undergone a substrate-based VT ablation. In the patients supported with a VAD, more VTs were induced (3.2 versus 1.6) and ablated (2.2 versus 1.5), however 1-year freedom from ICD shocks for sustained VT was similar between the groups at 9 ± 3-months follow-up. Long-term complications were similar between the two groups.

**Impella™ Platform**

The Impella 2.5 (ABIOMED Inc., Danvers, MA) is a percutaneous VAD that provides up to 2.5 L/min forward flow from the left ventricle into systemic circulation.
Briefly, a 12-French catheter with a 6-French pigtail distal end is inserted through a 13-French sheath into the common femoral artery (Figures 3–4). The catheter is then passed retrograde through the aortic valve until the pigtail and inlet are across the aortic valve in the left ventricle, and the outlet and motor are in the ascending aorta (Figures 5A and 5B). The axial flow pump then revolves at high speeds and draws blood out of the left ventricle ejecting into the ascending aorta. The role of this device has been mainly for hemodynamic support during high-risk percutaneous coronary interventions. The cost is $25,000 per case. In June 2008, it received FDA clearance for temporarily supporting systemic circulation.

In 2010, Abuissa et al described the first use of the Impella™ 2.5 in three patients with hemodynamically unstable VT that allowed successful completion of VT ablation procedures.12 In all three patients, multiple VTs were induced, and periprocedural MAPs of 40–70 mm Hg were maintained. The average time spent in VT was 180 min, and an average of 2 VTs were ablated per patient. There were no significant complications, and no patient had experienced recurrent VT/VF or ICD shock therapy at 9-month follow-up.

A larger non-randomized case control trial comparing the Impella™ 2.5 (n=10) versus IABP (n=6) or no mechanical support (n=7) reported on the periprocedural and short-term outcomes of VT ablation.13 Compared to the non-VAD group, the VAD group was maintained in VT significantly longer (66.7 versus 27.5 min) and required fewer early terminations of sustained VT for hemodynamic instability (1 versus 4). However, there was no significant difference in recurrent VT/VF or ICD shock therapy at 3-month follow-up. One patient in each group experienced a pericardial bleed that required intervention, but there were no other significant complications.

Table 1: Baseline Demographics and Modality Used

<table>
<thead>
<tr>
<th>Modality</th>
<th>Demographic Data</th>
<th>Case Data</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Patients (n)</td>
<td>Age (yr)</td>
</tr>
<tr>
<td>Miller et al</td>
<td>13 Impella™ 2.5</td>
<td>10</td>
</tr>
<tr>
<td>Friedman et al</td>
<td>10 Impella™ 2.5</td>
<td>1</td>
</tr>
<tr>
<td>Bunch et al</td>
<td>Tandem Heart™</td>
<td>13</td>
</tr>
<tr>
<td>Abuissa et al</td>
<td>Impella™ 2.5</td>
<td>3</td>
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Table 2: Electrophysiology Characteristics

<table>
<thead>
<tr>
<th>Modality</th>
<th>Case Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peri-procedural MAP (mm Hg)</td>
</tr>
<tr>
<td>Miller et al</td>
<td>13 Impella™ 2.5</td>
</tr>
<tr>
<td>Friedman et al</td>
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<tr>
<td>Bunch et al</td>
<td>Tandem Heart™</td>
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<tr>
<td>Abuissa et al</td>
<td>Impella™ 2.5</td>
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Abbreviations: DCCV: direct current cardioversion; IABP: intra-aortic balloon pump; MAP: mean arterial pressure; VT: ventricular tachycardia.

Discussion

Despite the use of antiarrhythmic drugs, recurrent ICD shocks for VT remains an issue of significant morbidity in patients with structural heart disease. The success rates of VT ablation procedures in recent large series range from 61% in non-ischemic cardiomyopathy to 71% in ischemic cardiomyopathy.2 Freedom from VT at nearly 1 year is 54%.14 However, a major limitation of this procedure is severe hypotension due to hemodynamically intolerant VT that limits detailed activation and entrainment mapping. Even in patients with hemodynamically stable VT, anesthesia from the procedure can cause hypotension and limit mapping. Mapping in tachycardia allows identification of regions critical to the tachycardia circuit. Substrate mapping, the most frequently used technique, allows modification of the arrhythmogenic substrate but has limitations. Because the critical isthmus of clinical VT is often not known, a broad ablative approach is required to homogenize scar borders, find and treat all late potentials within scar boundaries, or perform extensive linear ablation of critical regions between scar borders and electrically inert structures. This approach may miss small VT circuits. Furthermore, if VT is induced without support, hemodynamic instability may result in acute heart failure and complicate periprocedural outcomes.

From the available literature, it seems that hemodynamic support with a mechanical assist device likely allows for spending more time in VT, thus targeting more VT morphologies in any given patient (Tables 1 and 2). It also seems it can be performed safely, but whether this
results in improved long-term outcomes is unclear (Table 3). Among the different modalities of mechanical support, it appears that IABP counterpulsation efficacy declines during tachycardia and severe hypotension, thus limiting its use for VT ablation procedures. The growing use of percutaneous VAD support provides hemodynamic stability to adequately perform activation and entrainment mapping, and it also enhances post-operative patient care by potentially reducing the incidence of acute heart failure from the administered fluid volume of irrigated catheters. Hazards of VAD include increased procedural time; higher cost, greater fluid volume of irrigated catheters. Hazards of VAD support, it appears that IABP counterpulsation efficacy declines during tachycardia and severe hypotension, thus limiting its use for VT ablation procedures. The two available percutaneous VADs, the Tandem Heart TM provides higher cardiac output compared to the Impella TM Platform; however it is more invasive and requires trans-septal puncture. Insufficient literature exists for further comparison between the two devices in the setting of VT ablation.

Conclusion

Although the number of cases is limited, these series of case reports and an observational study suggest a promising future for the use of pVADs for supporting patients with hemodynamically unstable ventricular arrhythmias. It is clear that VADs allow patients to better tolerate VT and provide the electrophysiologist more time for detailed activation and entrainment mapping. This seems to improve the ability to ablate more VT morphologies. Although the literature does not allow us to make a conclusion about long-term outcomes, it appears that VAD support is safe during VT ablation. Further studies should include a randomized control trial of VAD vs. no VAD support for comprehensive VT ablation.

Table 3: Procedural Outcomes

<table>
<thead>
<tr>
<th>Modality</th>
<th>Acute Complications</th>
<th>Follow-up</th>
<th>CHF requiring &gt; 24 h ventilation</th>
<th>vascular injury</th>
<th>Inducible MMVT at conclusion of procedure</th>
<th>Recurrent VT/VF and/or appropriate ICD therapy</th>
<th>Late Death-VAD-OHTx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miller et al 13</td>
<td>Impella TM 2.5</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>not reported</td>
<td>0</td>
<td>2/8 patients</td>
</tr>
<tr>
<td>Bunch et al 11</td>
<td>Tandem Heart TM</td>
<td>1*</td>
<td>1*</td>
<td>1</td>
<td>not reported</td>
<td>0</td>
<td>4/12 patients</td>
</tr>
<tr>
<td>Friedman et al 10</td>
<td>Tandem Heart TM</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>not reported</td>
<td>4/13 patients</td>
</tr>
<tr>
<td>Abuisa et al 12</td>
<td>Impella TM 2.5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1^</td>
<td>1 patient</td>
</tr>
</tbody>
</table>

Abbreviations: CHF: congestive heart failure; IABP: intra-aortic balloon pump; ICD: implantable cardioverter-defibrillator; MMVT: monomorphic ventricular tachycardia; OHTx: orthotopic heart transplant; VAD: ventricular assist device; VT/VF: ventricular tachycardia or fibrillation.

1^ same patient.

Appendices:

A2 units of packed cells transfused and an arteriovenous fistula.

B1 death, 1 ventricular assist device, 1 orthotopic heart transplant.

C4 deaths, 1 orthotopic heart transplant.

References

12. Abuisa H, Roshan J, Lim B, Asirvatham SJ. Use of the Impella microaxial blood pump for ablation of hemodynamically
