The role of percutaneous left ventricular assist devices during ventricular tachycardia ablation

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Introduction

The risk of sudden cardiac death from ventricular tachycardia (VT) in patients with cardiomyopathy related to structural heart disease has been dramatically mitigated by the wide adaptation of implantable cardioverter defibrillators (ICDs) for primary and secondary prevention. However, with time the ventricular myocardium continues to remodel and scar-related VT evolves to be a more frequent manifestation. Due to modest efficacy of current antiarrhythmic drug medications plus risk of proarrhythmia and end-organ damage, percutaneous catheter ablation of VT has emerged to become the standard of care to prevent recurrent ICD shocks.1–4

Ablation strategies for VT continue to evolve. Procedural outcomes in patients with structural heart disease are often limited by haemodynamically unstable VT. Although substrate- and pace-mapping techniques have become increasingly popular for VT ablation, these approaches can often times may not address inducible clinical and non-clinical VTs. Activation and entrainment mapping can help the operator target VT exit sites in a precise fashion minimizing the amount of radiofrequency ablation needed for a successful ablation. An evolving alternative strategy that allows induction and mapping of VT in the setting of severe cardiomyopathy is through maintaining perfusion with a percutaneous ventricular assist device (pVAD). This review will discuss these pVAD technologies, distinguish technical applications of use, highlight the published clinical experience, provide a clinical approach for support device selection, and discuss use of these technologies with current mapping and navigational systems.

Keywords

Ventricular tachycardia • Catheter ablation • Left ventricular assist device

Percutaneous support options

The TandemHeart® is percutaneously inserted through a 21-French (21F) venous cannula placed transseptally with
in intracardiac echo and fluoroscopic guidance (Figure 1) into the left atrium. A 17F arterial cannula is placed femorally for return of blood from the extracorporeal pump. After obtaining a femoral artery angiogram with a smaller French sheath to rule out severe peripheral vascular disease, the femoral venous access is obtained. Occasionally a vascular cut down may be required. Transseptal access is obtained using a standard technique with Brockenbrough needle and Mullin’s sheath. Anticoagulation with unfractionated heparin to maintain an activated clotting time (ACT) of 300 s is initiated with the transseptal access. After maintaining transseptal access with a guidewire a two-stage dilator (14F/21F) is used to dilate the transseptal access. The transseptal cannula is then introduced into the left atrium over a guidewire after removing the dilator. The position of the cannula is confirmed fluoroscopically by injecting dye into the cannula to make sure that all the side ports of the left atrial cannula are across the interatrial septum. The regular femoral arterial sheath is then exchanged for the 15F arterial perfusion cannula. The transseptal cannula and the arterial cannula are then connected to the respective ports in the external pump after necessary de-airing precautions. The device is typically programmed to 3000–7500 r.p.m. to maintain a cardiac output of 4–5 L/min and heparin given for a goal ACT of 300 s. The cardiac output achieved is often enough alone to maintain systemic mean pressure during rapid ventricular tachycardia (Figure 2).

As mean blood pressure is maintained, oxygenation status must be carefully monitored to assess the right ventricle (RV) for stability. The device output often may have to be decreased temporarily to allow adequate motion of the aortic valve to allow catheter passage for a retroaortic approach to left ventricular (LV) mapping and ablation.

The Impella 2.5 is also percutaneously inserted, but through a 13F sheath in the femoral artery (Figure 3). Since the device utilizes a larger sheath, femoral arterial angiography should be performed after placing a smaller French sheath (typically a 6–7F sheath) to rule out any significant peripheral vascular disease. Once the artery appears favourable, the smaller French sheath should be exchanged over a guidewire to the 13F sheath and anticoagulation with unfractionated heparin to maintain an ACT between 250 and 300 s should be started. Retrograde LV access is then obtained using standard catheters and the guidewire is exchanged with the platinum PLUS guidewire supplied in the set. Once the guidewire is positioned in the LV, the Impella catheter with a leading pigtail

*Figure 1* The figure shows placement of a TandemHeart percutaneous ventricular assist device. (A) Fluoroscopic image shown in a left anterior oblique projection with the intake cannula marked. (B) Figure of the heart with arrowheads that delineate the course of the large cannula that transverses the intra-atrial septum. (C) A second fluoroscopic image of a distinct patient shown in a right anterior oblique projection with the intake cannula marked. (D) Fluoroscopic image on the common right femoral artery used for return access on the TandemHeart bypass system.
is loaded on it and advanced into the LV. Appropriate location is confirmed by fluoroscopy and pressure curve from the sensors in the distal portion of the of the catheter. In contrast to the TandemHeart, the blood inlet and outlet are on the same cannula spaced to be located in the LV and thoracic aorta, respectively. The device can be programmed up to 2.5 L/min, 50 000 r.p.m. The Impella 5.0 can be programmed up to 5.0 L/min, but the pump diameter is 21F requiring a cut down procedure.

Extracorporeal membrane oxygenation (ECMO) is essentially complete cardiac or CPS. ECMO/CPS can be either venovenous or venoarterial. Venovenous is only used for respiratory support as it does not provide haemodynamic support and as such cannot be used in heart failure or VT ablation. For venoarterial, blood is extracted from a large central vein and returned typically to the femoral artery (Figure 4). The technology can be used across a broad range of body sizes and ages. The size of the venous drainage catheter limits the blood flow. Total support is typically 100 cm$^3$/kg/min in small children and 60 cm$^3$/kg/min in adolescents and adults or $\sim$5 L/min in most people.

Intra-aortic balloon counterpulsation (IABP) is a polyethylene balloon catheter introduced typically through the femoral artery over a wire using a 7.5F–9F introducer sheath (Figure 4). It is positioned in the descending aorta with the tip lying a few centimeters distal to the subclavian artery ostium and the proximal end of the balloon above the renal arteries. The balloon, with a volume of 30–50 cm$^3$, inflates during diastole to augment diastolic arterial pressure with minimal impact on the systolic and mean arterial pressure.$^{16,17}$ As the device is gated to trigger in diastole with the QRS, its use is limited during rapid VTs and offers modest hemodynamic support.

In all scenarios a large arterial sheath is required. Various devices can be used with these to assist in haemostasis once the sheath has been removed. We previously reported a double Perclose technique that we use for all TandemHeart procedures at Intermountain Medical Center. With this approach two vascular seals are placed orthogonally to each other in an effort to minimize complications and facilitated extubation and return to ambulation times. This approach has greatly improved recovery following sheath removal and no patients have required open surgical closure.

**Clinical experience**

At this time, studies evaluating the role of pVADs in supporting unstable-VT ablation procedures are limited to relatively small single-centre and multicentre observational studies and case reports.$^{4,11–12,14–15,18}$ Nevertheless, these studies in aggregate provide valuable insight in understanding the potential benefits of...
pVADs in providing haemodynamic support for performing a more complete and accurate assessment of induced unstable VT thereby making catheter ablation easier.

Initial work revolved around the use of a left ventricular assist device to temporarily stabilize patients with hemodynamically unstable VT until an alternate therapy was instituted. The feasibility of percutaneous support during VT led to the real-time use of these devices during ablation. Friedman et al. reported for the first time the use of TandemHeart in a patient who had unstable VT induced during the electrophysiology study which allowed both epicardial and endocardial ablation. In this case report, the previously unstable VT was mapped for 1 h and 45 min with the pVAD in place. The prolonged mapping allowed for successful ablation of the VT and the patients was subsequently non-inducible. Recently, Bunch et al. reported a case series of 13 consecutive patients with haemodynamically unstable VT who underwent a pVAD-assisted ablation. These patients were compared with 18 disease-matched patients. The authors found that at the end of the procedure those patients who underwent a pVAD-assisted ablation, despite being a relatively sicker cohort, were less likely to be inducible and have more VTs mapped and ablated successfully. Long-term outcomes of freedom from ICD shocks and VT were similar between groups. This larger case series showed the feasibility of using a pVAD in very sick patients that require VT ablation and suggests that these patients can do as well as those who were not as sick and were not selected for haemodynamic support.

Recently, Miller et al. reported an observational study evaluating the role of pVAD in unstable VT ablation. They included 23 VT ablations in the study of which 10 were performed with an Impella 2.5 pVAD and the other 13 performed with either an intra-aortic balloon pump (6 procedures) or without any device support (7 procedures). In patients supported with a pVAD, VT was maintained and studied for a longer duration, activation and entrainment mapping was more often achievable without the need to terminate the VT due to poor haemodynamics, and more VTs were terminated during ablation when compared with the other groups. For example, the time in VT in the pVAD group was 66.7 vs. 27.5 min in the others. Since the Impella 2.5 pVAD cannot achieve flow rates similar to TandemHeart pVAD, the observed blood pressure support is often not as significant. In the study by Miller et al., the systolic blood pressure was lower in the pVAD group compared with the other cohort. In this study, the authors used continuous haemodynamic monitoring with cerebral oximetry as another metric of efficient haemodynamic support ensuring adequate cerebral perfusion. They found that there were no significant drops in cerebral oximetry or period of severe hypoxia (≤55%) between the pVAD cohort and the non-supported patients. However, those patients in the pVAD supported groups were maintained in VT for a longer duration, and despite this potential instability, the end-organ perfusion measured by cerebral oximetry was similar. These data not only highlight the feasibility of the Impella 2.5 device, but also demonstrated the use of cerebral oximetry as an important means to assess end-organ perfusion in a real-time manner.

Carbucicchio et al. reported their experience with CPS in 19 patients who underwent catheter ablation with severe LV dysfunction and recurrent unstable VTs. These patients were very sick with 12 who had acute haemodynamic failure refractory to inotropic agents during the index hospitalization. In this unstable cohort, they stabilized the VT in 13 (68%) and in the majority of the other patients the VT burden was reduced. The long-term outcomes were relatively poor, a finding that likely reflects the very sick population (28% were free from VT recurrence, mean follow-up of 42 months). One patient had persistent refractory VT who died shortly after heart transplant. No procedural complications were observed with CPS use.

Complications

All of these support devices are primarily placed through the femoral arterial access with or without femoral venous access. Severe peripheral arterial disease or a previous vascular bypass

Figure 4 The figure displays two fluoroscopic images. On the left is a patient with active venous–arterial cardiopulmonary support and shows the placement of both the intake and out-take cannulas. On the right is a patient with an intra-aortic balloon pump with positioning below the take off of the subclavian artery.
surgery proximal to the access sites are absolute contraindications. As with any invasive vascular device implantation, pVADs are associated with significant bleeding and thromboembolic complications in addition to infections. Thromboembolic complications can be minimized by maintaining the recommended anticoagulation level. In a large, multinational IABP registry including close to 1700 patients, the rate of major complications was 2.6% primarily due to major bleeding and ischaemia to the limb.20 TandemHeart has the additional risk associated with transseptal puncture. It can also be dislodged with the cannula slipping into the right atrium resulting in cardiogenic shock and death.17 There is also a report of a large persistent iatrogenic septal defect after TandemHeart placement that required percutaneous closure to obtain oxygenation stability.21 All these devices can also potentially cause haemolysis, though the incidence and clinical impact when used for a few hours is unknown. Another risk to be aware of is the inability to wean the patient off the device after the procedure, and the need for a more durable VAD implantation.

Technical considerations

All of the currently available devices can be implanted in the electrophysiology lab by experienced operators within 30 min. The selection of each of these devices is primarily based on the availability, experience of the operator extent of haemodynamic support required, technical interference with the ablation procedure, and patient characteristics.

TandemHeart: The primary advantage of TandemHeart is the higher level of haemodynamic support provided by the device (5 L/min of cardiac output). The major limitations are the need for a large venous, transseptal, and arterial accesses there by increasing the risk of vascular complications. The venous cannula and the large transseptal access potentially interfere with the maneuverability of the electrophysiological catheters and remove the option of LV access via a transseptal approach access. A retrograde or epicardial approach is required for ablation. In patients in whom a retrograde approach is used, both femoral arteries require large sheath cannulation. This approach may not be feasible with moderate–severe peripheral vascular disease.

Impella 2.5: The advantages of the Impella device are relative ease of implantation and higher level of haemodynamic support when compared with an IABP. The haemodynamic support is independent of patient’s underlying rhythm and it does not require femoral venous and transeptal access. However, compared with TandemHeart, flow output is less and as such surrogate markers of organ perfusion such as cerebral oximetry should be used to assess patient stability. In addition, the device can cause ectopy and VT due to mechanical irritation of the endocardium, mechanical interference with catheter manipulation in the LV, and electromagnetic interference during mapping often necessitates decreasing the rotor speed or turning the device off, thereby impairing duration of haemodynamic support. Although a transseptal and epicardial approaches are options for catheter ablation approach, retrograde LV access cannot be obtained with this device in place.

Percutaneous cardiopulmonary support/ECMO: The advantage of CPS/ECMO is that it can support the respiratory system in addition to providing a circulatory support up to 5 L/min. Unlike other pVADs, since RV is also supported, the impact of prolonged VT on RV function and pulmonary perfusion is not as great a concern with this system. It maybe the system of choice in patients with severe RV disease. Use of the system still allows both retrograde and transseptal ablation approaches. The disadvantages of these systems are bleeding and thromboembolic complications, LV volume decreases with higher levels of support that can make mapping and ablation difficult and potentially less optimal. A unique complication of CPS or ECMO is the venting effect. With ECMO and VT, the heart tissue circulation still drains into the LV but the LV does not pump blood out. This can be prevented by periodic cardioversion.

Intra-aortic balloon counterpulsation: The advantages to the IABP are the ease of placement, general experience with use, smaller vascular access, lack of mechanical or electrical interferences with the VT mapping, and lesser degree of anticoagulation needed in cases of epicardial VT ablation. The major limitation of this device is that the degree of haemodynamic support provided is unpredictable during VT and is much lesser than the newer pVADs. The femoral artery insertion precludes retrograde access to the LV. Careful attention should be given to the synchronization triggers used for balloon inflation. The default trigger is a ‘pattern’ trigger which uses the height, width and slope of QRS complex in a selected surface lead electrocardiogram (EKG). The same trigger may not be accurate while in VT due to the fast heart rates and complex QRS morphology and can potentially lead to asynchronous counterpulsations resulting in worsening haemodynamics. It is recommended that the trigger should be changed to either a ‘peak of QRS’ trigger on surface EKG or ‘arterial pulse’ trigger, which uses the upstroke of arterial pressure waveform from a sensor at the tip of the device.

Anaesthesia and procedural monitoring

These pVAD-assisted procedures should be performed under general anaesthesia on mechanical ventilation with adequate anaesthesia support in the room. It not only makes the procedure more comfortable for multiple vessel cannulation and the potential need for emergent external defibrillation, but also helps the electrophysiologist in performing a long and complex procedure in a relatively controlled environment. The entire purpose of the pVADs during VT ablation is to provide adequate end-organ perfusion during VT induction. Various tools available to continuously monitor end-organ perfusion are pulse oximetry, arterial blood pressure, electroencephalography, bi-spectral index (BIS), trans-cranial Doppler ultrasonography, and near infrared spectroscopy to measure cerebral oximetry.4 Unfortunately, there is no single, ideal tool to measure adequate end-organ perfusion during VT ablation especially in the setting of pVADs which impair pulsatile flow. Routine tools such as pulse oximetry and automated blood pressure measurements are dependent on pulsatile blood flow and not reliable in patients in VT with a pVADs. Moreover, changes in pulse oximetry happen late during hypoperfusion.22,23 Although continuous arterial blood pressure
monitoring accurately measures central pressures, the actual tissue perfusion and oxygenation is not reflected. As such, when to terminate a VT based upon mean blood pressure is not known. This has prompted the need for adjunctive tools of tissue perfusion.

Although electroencephalogram does provide early signs of cerebral ischaemia, real-time interpretation is difficult and there is significant interference from the electrical mapping of the VT. Continuous BIS monitoring is relatively easy and is more of a reflection of depth of anaesthesia, but it is not very sensitive in identifying less severe hypoperfusion. Continuous transcutaneous Doppler reflects cerebral hypoperfusion, but is tedious and has a significant operator dependency. Cerebral oximetry is promising in accurately reflecting cerebral hypoperfusion and is being evaluated in multiple settings including carotid and cardiac surgeries.

In a recent study evaluating the use of pVADs for haemodynamic unstable VT ablation, cerebral oximetry was used effectively in addition to other routine haemodynamic measurements to evaluate haemodynamic status of patient during VT. In addition, cerebral oximetry predicted cerebral hypoperfusion with supraventricular tachycardia induction with adequate correlation between drop in mean arterial pressure. In general, a cut-off for a significant drop in cerebral oximetry from baseline is still unknown, but various reports have proposed a drop of 12–20% from baseline or an absolute saturation below 55% as a reasonable values to consider termination of VT.

**Clinical approach**

It must be emphasized that current studies have not shown a significant reduction in ICD shocks long term in patients who underwent a pVAD-assisted VT ablation vs. no pVAD assistance nor has any study definitively compared different support techniques. However, as mentioned there is a paucity of long-term data derived from relatively small studies. Therefore, contemporary use of any pVAD must be determined based upon severity of LV dysfunction, anticipated patient stability during VT, anticipated number of VTs that will require induction and/or ablation, and coexistent disease states. These patient and VT characteristics will assist in determining if the clinical benefit and stability will outweigh the added risk of placing a pVAD.

Figure 5 shows a proposed clinical approach. In addition to stability, a patient must be assessed for the presence of clinically significant peripheral vascular disease. In patients with significant PAD, CPS, and Impella is contraindicated and retrograde ablation maybe difficult. In this case there are three options. First, a transseptal and epicardial ablation approach to the LV with substrate-based ablation rather than induction and entrainment maybe used. A second option is ECMO with a transseptal approach. In some cases, the PAD may lead to tortuous vessels that preclude Impella but flow may not be bad enough to prevent TandemHeart. The next decision is to determine what type of approach to the LV is desired with consideration of the VT morphology/rate. Finally, in patients with very severe LV dysfunction, until surrogate markers of organ perfusion are better understood, pVAD support system with higher flow rates are preferable.

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