Left Ventricular Assist Devices: A Brief Overview

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Introduction

Second and third generation left ventricular assist devices (LVAD) have been increasingly utilized as both a bridge to transplantation and as destination therapy (in patients who are not considered transplant candidates) for advanced heart failure. Currently approximately 2500 LVADs are implanted yearly, with an estimated one year survival of >80% (1). Almost half of these patients undergo implantation as destination therapy. A recent systematic review and meta-analysis found no difference in one-year mortality between patients undergoing heart transplantation in comparison with patients undergoing LVAD placement (2).

Early LVADs were pulsatile pumps, but had multiple limitations including duration of device function, and requirement for a large external lead that increased risk of infection. Currently utilized second and third generation devices are continuous flow (first generation were pulsatile flow). Second generation devices have axial pumps (HeartMate II®). The third generation LVADs ((HeartMate III®, HVAD®) are also continuous flow, with centrifugal pumps, which are thought to decrease possibility of thrombus formation and increase pump duration in comparison to the second generation axial pumps. It is also felt that a lack of mechanical bearings contributes to this effect.

LVADs support circulation by either replacing or supplementing cardiac output. Blood is drained from the left ventricle with inflow cannula in the left ventricular apex to the pump, and blood is returned to the ascending aorta via the outflow cannula (3) (Figure 1).
Figure 1. Third generation Left Ventricular Assist Device. Heartware System ™. Continuous flow left ventricular assist device (LVAD) configuration. One of the third generation LVADs is the HeartWare System. With this device the inflow cannula is integrated into the pump. The pump is attached to the heart in the pericardial space, with the outflow cannula in the aorta. A driveline connects the device to the control unit. This control unit is attached to the two batteries. (Figure used with permission from Medtronic).

The device assists the left ventricle by the action of the axial (second generation) or centrifugal (third generation) pump that rotates at a very high speed and ejects the blood into the aorta via the outflow cannula. A tunneled driveline connects the pump to the external controller that operates the pump function. The controller connects to the power source via two cables, which can be battery or module-powered.

LVADs offload volume from the left ventricle, and decrease left ventricular work. Pulmonary pressures and the trans pulmonary gradients are also decreased by the reduced volume in the left ventricle (4). End organ perfusion is improved secondary to enhanced arterial blood pressure and micro perfusion.

There are four main parameters of pump function:

- Pump speed: the speed at which the LVAD rotors spin, and is programmed. Measured in RPM.
- Pump power: the wattage needed to maintain speed and flow, which is the energy needed to run the pump. Measured in Watts.
- Pump flow: estimate of the cardiac output, which is the blood returned to the ascending aorta, and is based on pump speed and power. Measure in L/min
- Pulsatility index (PI): a calculated value that indicates assistance the pump provides, in relation to intrinsic left ventricular. A higher number indicates higher left ventricular contribution to pulsatile flow.

The cardiac output of currently utilized LVADs is directly related to pump speed and inversely related to the pressure gradient across the pump. As the pump speed is fixed, right ventricular failure can decrease the volume of blood transmitted to the pump and decrease LVAD flow (3, 4). With right ventricular failure, inotropic support may be needed to improve the LVAD pump flow. High afterload, such as may be seen with an increase in systemic vascular resistance can decrease pump flow.

Complications

Adverse events occur in more than 70% of LVAD patients in the first year (5). These complications include infections, bleeding, stroke, and LVAD thrombosis. More than 50% of patients are readmitted within the first 6 months after LVAD implantation (6).

Driveline infections are the most commonly reported LVAD infection, and are the most likely to respond to treatment (7). Pump pocket infections may require debridement...
plus/minus antibiotic bead placement. Bloodstream infections are less commonly reported, and more difficult to treat, and many patients are placed on chronic suppressive antibiotic therapy (7). There is a possible association between stroke and bloodstream infection, reported in some studies. Patients who were younger and had a higher body mass index were noted to have a higher incidence of LVAD infections.

Gastrointestinal bleeding is a major cause of nonsurgical bleeding, reported in almost 30% of patients after LVAD placement (1). Patients may develop acquired von Willebrand factor deficiency secondary to high shear forces in the LVAD that lead to breakdown of von Willebrand protein (6). Antithrombotic therapy is commonly instituted after LVAD implantation which also increases risk of bleeding. A high incidence of arteriovenous malformations is reported in these patients, although the etiology is not clear. Transfusion, holding antithrombotic therapy, and identifying possible sources are included in the standard approach to management.

There is a high risk of both ischemic and hemorrhagic strokes in the first year after LVAD placement (8). Surgical closure of the aortic valve and off-axis positioning of the cannulas have been suggested as altering shear forces, increasing thrombotic risk, and thus risk of stroke. Post-surgical risks may include pump thrombosis, infections, supratherapeutic INR, and poorly controlled hypertension. Early diagnosis has led to consideration of interventions such as thrombectomy (8).

LVAD thrombosis can occur on either cannula (inflow or outflow) or the pump. Typically patients receive ongoing anticoagulation, commonly with warfarin, and antiplatelet agents, and often aspirin. Heartmate II® may have higher rate of thrombosis than HVAD or Heart Mate 3, although this is under debate (6). Thrombotic complications range in severity from asymptomatic increase in lactate dehydrogenase or plasma-free hemoglobin, to triggering of LVAD alarms, up to development of heart failure. The inflow and outflow cannulas and pump can be the site of thrombosis. Management typically involves revising the antithrombotic management. If there is no improvement or worsening, replacement of LVAD may be indicated. There is limited evidence to suggest that systemic thrombolysis may be of benefit in treating pump thrombosis, particularly in regards to the HVAD, though better data would be useful.

**Procedural Management**

When a patient with an LVAD requires non cardiac surgery, optimal management includes having an on-site VAD technician, and close involvement of VAD cardiology and cardiac surgery in consultation. Anticoagulation will often be transitioned to heparin infusion prior to elective procedures (9). Suction events (LV wall is sucked into the inflow cannula) can occur secondary to under filled left heart, and this can become more apparent perioperatively. This can also decrease right heart contractility by moving the interventricular septum to the left, and thus decrease cardiac output. Management often involves fluid bolus. Suction events can lead to decreased flow, left ventricular damage, and ventricular arrhythmias. Hemodynamic management can be challenging with non-pulsatile flow, and placement of an arterial line can facilitate optimal management.
Postoperative care in a monitored setting is beneficial in case of further volume related events and to watch for bleeding.

**Emergent Complications**

Arrhythmias occur in many patients after LVAD implantation. Atrial arrhythmias are reported in up to half of LVAD patients, and ventricular arrhythmias in 22-59% (10, 11). Loss of AV synchrony can lead to decreased LV filling and subsequent RV failure. Rhythm or rate control with rapid atrial arrhythmias is necessary to decrease development of heart failure. Ventricular arrhythmias may be hemodynamically tolerated for some time secondary to the LVAD support (6). If there is concern that the inflow cannula is touching the LV septum, as may occur with severe hypovolemia, echocardiography can help determine if volume resuscitation should be the initial step in treating ventricular arrhythmia.

If cardiac arrest occurs, the first step of cardiopulmonary resuscitation in patients with LVAD is assessment of appropriate perfusion via physical examination (12). If perfusion is poor or absent, assessment of LVAD function should take place. If the LVAD is not functioning appropriately, checking for connections and power is the next step. If unable to confirm function or restart LVAD, chest compressions are indicated by most recent guidelines from the American Heart Association. There is always concern of dislodgement of LVAD cannula or bleeding during these situations.

**Conclusion**

Currently implanted LVADS are continuous flow, and provide support via a parallel path from the left ventricle to the aorta. As the number of patients with LVADs increase all medical providers should have a basic understanding of the function and common complications associated with these devices. This will enhance the ability to initiate appropriate care.

**References**

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