Ventricular Assist Device Implantation

Anesthesia Guideline
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Overview

Patients
Patients coming for left ventricular assist device (LVAD) implantation are in acute, chronic, or acute-on-chronic heart failure. Mechanical circulatory support for patients in advanced heart failure has evolved considerably over the last 25 years, and is now a standard therapy option in many medical centers all over the world. Patient selection is based on heart failure acuity and end-organ morbidity. Depending on the degree of heart failure, i.e. inotrope dependence or presence of cardiogenic shock, devices may be implanted in an emergent operation or within a few days or weeks. Implantation before irreversible end-organ failure occurs or delaying the implant until comorbidities can be reversed or controlled, can improve post-implant survival.

Whenever possible, LVAD implantation should happen as an elective surgery. Patients are generally stratified in different groups, depending on the postoperative long-term treatment plan.

- Bridge-to-transplant
- Bridge-to-recovery/reevaluation
- Destination therapy

However, patients should not be considered for LVAD if irreversible end-organ failure, uncertain neurologic status, prolonged mechanical ventilation, infection and sepsis, major coagulopathy are present. Significant right ventricular (RV) failure can be an issue, but is not necessarily a contraindication. Patient's RV function may improve after left ventricular (LV) unloading by the LVAD and inotropic support and afterload reduction can be helpful. Some patients, however, will need right ventricular assist device (RVAD) support.

Devices
Numerous devices are available for LVAD, RVAD, and biventricular (BiVAD) mechanical support.

- Short-term extracorporeal
  - IABP (intraaortic balloon pump)
  - CentriMag
  - TandemHeart

- Long-term paracorporeal
  - Abiomed
  - BerlinHeart ExCor
Long-term intracorporeal
  - VAD
    - Pulsatile flow
      - Novacor
      - Thoratec HeartMate I
      - Thoratec IVAD
    - Continuous flow
      - Axial pumps
        - Thoratec HeartMate II
        - BerlinHeart InCor
        - Jarvik 2000
      - Centrifugal pumps
        - VentrAssist
        - HeartWare
  - TAH (total artificial heart)
    - CardioWest
    - Syncardia

At UWMC, IABP and TandemHeart are used for short-term support in acute heart failure patients. These devices will be implanted either at the end of a cardiac operation, in the cath lab, or in the ICU. For long-term support, we occasionally use the Abiomed, but most commonly the HeartMate II device is implanted.

The Abiomed is a pulsatile device, which is pneumatically driven. It has an inflow cannula generally inserted into the LV apex. Alternatively, the LVAD inflow can be inserted into the left atrium (LA). The outflow cannula is placed into the ascending aorta. The pump chamber is located outside of the patient's body and is usually situated somewhere on the left chest/abdomen region. The pump chamber has a blood side and an air side. Major hemodynamic characteristics include intermittent unloading of the ventricle, active ejection of blood, and pulsatile arterial pressure. The VAD ejection is asynchronous with the heart. LVAD output is dependent on LVAD chamber size and rate set. The rate can be set either in fixed or in automatic mode, and device is preload-dependent. The pump chamber is connected to a pump controller, which is part of a larger console together with the power supply and battery. The Abiomed can also be used for RVAD or even BiVAD support. Cannulas for RV support are placed in the right atrium (RA) and the pulmonary artery (PA), respectively.

The HeartMate II is a continuous axial flow device, which is electrically driven. Inflow and outflow cannulas are placed in a similar fashion as for the Abiomed. The actual pump sits inferior to the patient's heart between the anterior and posterior rectus muscles. The pump contains a rotating impeller to generate flow. A driveline connects the pump with the extracorporeal controller and battery. Unlike the Abiomed, the HeartMate II does not have any valves. Flow is determined by the pump speed and is pre- and afterload-dependent. The LV is continuously unloaded and while on full VAD support. The patients have non-pulsatile arterial pressure, which is generally measured invasively or manually using a Doppler device. The HeartMate II is comes in one size only, and is used only for LV support.
Preoperative Considerations

1. Patients will often have a right internal jugular (IJ) vein introducer with a PA catheter as well as a femoral arterial line with an IABP inserted on the day before surgery. Therefore, they are generally on the intensive care unit (ICU) and need to be transported directly to the operating room (OR) as the preoperative holding area staff will not accept patients on IABP support. Plan to be on the ICU early enough to get the patient ready to move. This includes nursing to anesthesia handover, adequate transport monitoring, and availability of perfusionists to facilitate transfer. If the patient is on IABP support, an additional monitor is not necessary since the IABP monitor shows electrocardiogram (ECG) and arterial blood pressure (oxygen saturation monitoring should not be needed in patients that are awake). A perfusionist is required to accompany any patient with an IABP in case of technical issues that need troubleshooting.

2. LVAD recipients are in advanced heart failure and virtually always have an implanted cardioverter-defibrillator (ICD). The defibrillator function of the ICD has to be turned off prior to using cautery in the OR (contact the cardiac rhythm device team or the electrophysiology fellow on-call). Occasionally, patients' ICD has been interrogated the night before the operation, and the defibrillator function is already turned off. In this case, the patients must be transported with an external defibrillator immediately available. Make sure that the defibrillator function needs to be reactivated postoperatively and that the ICD will need general interrogation of function. In the process of the preoperative interrogation it is sometimes desired to increase the patient's preset heart rate to 80 beats or higher if they are continuously paced.

3. The cardiac drip setup is similar to other cardiac cases. In addition to that, milrinone is commonly used. Almost every patient will receive inhaled nitric oxide (NO). Make sure that an NO tank is delivered to the room (call respiratory therapy) ahead of time.

4. Inotropic drug infusions should usually be continued until the patient is on cardiopulmonary bypass. Sometimes it is handy to spike a second bag of the patient's inotropic infusion into the general cardiac drip setup, so the patient can be transferred to our drip set.

5. Always make sure that there are enough blood products available, generally 10 packed red blood cell concentrates (PRBC), 10 fresh-frozen plasma (FFP), 2 platelet, and 2 cryoprecipitate. Some patients with previous cardiac surgery present the challenges of redo cardiac surgery and coagulopathy with major bleeding is anticipated.

Intraoperative Management

Induction of Anesthesia

The room setup for LVAD implantation is similar to other cardiac cases and the crash room. As previously described, patients are often brought to the OR directly from the ICU and do not go to the preoperative holding area. Patients often have a preexisting central line with a PA catheter as well as an arterial line with an IABP. Therefore, additional lines for induction are generally not needed. Careful induction is performed, as maintenance of perfusion pressure is crucial in these patients.
Additional Monitoring

The patient will need placement of another arterial line, usually in the radial artery since the IABP will be removed together with the femoral arterial line at the end of the case in almost all patients. A separate large-bore intravenous (IV) line has to be placed because the preexisting central line introducer is sometimes a smaller size and will not allow for rapid volume infusion when occupied by a PA catheter. This additional large-bore IV line can be a short introducer sheath in the left IJ vein, a peripheral rapid infusion catheter (RIC), or an introducer sheath in a femoral vein (usually placed by the surgeon on the sterile field). All patients will have an intraoperative transesophageal echocardiography (TEE) exam.

Role of TEE

Intraoperative TEE is essential for identifying valvular pathologies, intracardiac clot, and atrial septal defect (ASD) or persistent foramen ovale (PFO). Moderate to severe aortic insufficiency and mitral stenosis must be corrected before LVAD implantation. Atrial or ventricular clot should be removed, and any ASD or PFO should be closed prior to LVAD placement. After LVAD implantation, TEE is used to interrogate cannula position, LV chamber size, opening of the aortic valve, septum shift, and RV function.

Surgical Procedure

1. Unless specified otherwise, preoperative antibiotic prophylaxis includes cefazolin and vancomycin IV. Patients will also receive PO fluconazole and rifampicin in the morning before going to the OR. Please pull up the patient's ORCA chart for timeout to make sure that these medications have been administered.

2. Surgical access is via a regular median sternotomy. The first steps of the operation are performed before heparinization and initiation of cardiopulmonary bypass (CPB). This includes preparation of a LVAD pocket in the left rectus sheath, tunneling of the LVAD driveline out towards the right subcostal margin, and sometimes the end-to-side anastomosis of the LVAD outflow cannula on to the ascending aorta.

3. After heparinization and measurement of an adequate activated clotting time (ACT), the ascending aorta and the RA are cannulated and CPB assumed. In case of a surgical intervention on the mitral valve or the interatrial septum, venous cannulation will be performed via the superior and inferior venae cavae. This procedure is performed with the heart beating without aortic cross-clamping and cardioplegia.

4. Any additional procedure such as an aortic valve replacement or PFO closure is performed at this point.

5. The LVAD inflow cannula is implanted into the LV apex or distal anterior wall. The surgeon will thoroughly check the cannula position throughout the operation, the inflow cannula should point posteriorly toward the mitral valve. If the cannula is pointing toward the septum or free wall, partial cannula occlusion with poor LVAD inflow and subsequent hemolysis or thrombosis may occur. TEE is used to check for cannula position after completion of LVAD implantation and after chest closure.

6. The outflow cannula is sewed onto the ascending aorta in an end-to-side fashion if not completed before. The inflow cannula and the heart are now deaired followed by connection of the LVAD pump with the outflow graft, which is then cross-clamped. Deairing cannulas (vents) are placed in the outflow graft and in the ascending aorta. Under continuous deairing, the LVAD is initiated at the minimum speed of 6000 rpm. CPB flow is subsequently decreased and the cross-clamp on the outflow graft is removed. Careful attention is needed
to avoid air entrainment into the VAD around the inflow cannula, which is submerged in blood for the initial period. The CPB flow is further reduced and then stopped. The venous cannula is removed, and under volume retransfusion to the patient, the LVAD speed is increased slowly up to about 8000 rpm. After emptying the CPB circuit, the arterial cannula is removed. Successful deairing is monitored by TEE, and once completed, the vents can be removed. Once the patient has stabilized, protamine can be administered.

**Anesthetic Management**

1. Most patients will need intraoperative vasopressor support. Vasodilation from chronic intake of afterload-reducing drugs is aggravated by the systemic inflammatory response caused by CPB. Vasopressin is often chosen over phenylephrine because it does not increase pulmonary vascular resistance. In case of severe vasodilation and profound reduction in systemic vascular resistance (vasoplegia syndrome), an IV bolus of methylene blue is often helpful.

2. LVAD patients are prone to intraoperative bleeding, especially if they are undergoing redo cardiac surgery. All patients will receive aminocaproic acid after initial heparinization because of its small but favorable effect on blood loss.

3. All patients will need inotropic support for separation from CPB. The focus is on the RV. Although RV afterload reduction is accomplished by LV unloading under LVAD support, the RV will initially need pharmacologic help to properly function. This includes vasopressors to maintain RV perfusion pressure, inotropes to increase contractility, and vasodilators to further reduce RV afterload. A reduction in RV afterload is most commonly achieved by a milrinone bolus with or without subsequent infusion and by inhaled nitric oxide, which is almost always used. Milrinone should be used with care as it also causes a significant decrease in systemic vascular resistance in an already vasodilated patient.

4. After separation from CPB and careful protamine administration, adequate blood products should be given to restore coagulation. The majority of these patients will need some support with coagulation factors and platelets. This should be tailored to the results of a coagulation panel and thromboelastogram (TEG) obtained toward the end of the CPB run.

5. As described above, RV dysfunction is common in these patients. If there is more than moderate tricuspid regurgitation, repair should be considered, especially in the setting of preexisting pulmonary hypertension. If RV dysfunction is due to ischemia, revascularization can be considered if adequate targets exist. RV overload should always be avoided after separation from CPB. However, volume should be administered to maintain a central venous pressure (CVP) around 15 mmHg (depending on the baseline) and to improve forward flow. A potentially life-threatening situation occurs when the RV fails and the LVAD speed is relatively high in order to maintain flow. The flows will, however, decrease and the LVAD will cause leftward septal shift and ventricular collapse. This will change the geometry of the RV further aggravating RV dysfunction and tricuspid regurgitation. The right intervention in this situation is to turn the pump speed down, support the RV, and correct the patient's volume status. If pump flows remain low despite inotropic support and adequate RV preload, a temporary RVAD should be implanted, i.e. CentriMag or Abiomed.
Postoperative Management

1. Following control of bleeding and chest closure, the patient is transferred to the ICU bed. The IABP is removed in the OR and a compression device, i.e. FemStop, is placed on the IABP insertion site.

2. The patient is assessed for hemodynamic stability including heart rate and rhythm, arterial blood pressure, and pump flows. Patients are often continuously paced via a preexisting device. The mean arterial blood pressure (MAP) in the initial postoperative period should be between 60 and 80 mmHg, and should not exceed 90 mmHg. On full LVAD support (continuous flow device), there will be minimal pulse pressure. The HeartMate II device console shows the pump speed and provides additional information such as actual pump flow, pulsatility index, and pump power. One member of the mechanical circulatory support team will be present for the transport period.

3. Once stabilized, the patient may be transferred to the ICU similar to other cardiac patients. If on inhaled NO, respiratory therapy will assist with the transport.

4. Patients should ideally be normothermic, not acidotic, adequately ventilated, and not actively bleeding prior to transfer to the ICU. Assure that the patient receives sufficient analgesia and sedation for the transport. Electrolyte and glucose imbalances should ideally be addressed before transporting.