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Ventricular Assist Devices Patients for Non-Cardiac Surgery

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ABSTRACT

Ventricular assist devices **(VAD)** are designed to be used in patients with heart failure. There are a range of scenarios that can be encountered by the anesthesiologist in an active VAD program. First, the anesthetic plan should be focused in maintaining an adequate VAD function and systemic perfusion. Second, VAD are associated with a high incidence of complications, and these kinds of patients are likely to require sedation and mechanical ventilation for prolonged intensive care unit **(ICU)** stay, due to hemodynamic instability or significant end-organ dysfunction. Lastly,the increase in the number of VAD implantations will inevitably lead to an increase in non-cardiac surgery in VAD patients, so anesthetic management can represent a difficult challenge to the anesthesiologist.

Considering the significant impact of noncardiac surgery in these cases, general anesthesia and sedation can be necesary for semi-elective, emergent or elective non-cardiac surgery in patients with implanted long-term VAD. This chapter describes numerous resources to manage this complex patient population.

Keywords: Anesthetics; Heart failure; Non-cardiac surgery; Ventricular assist devices

INTRODUCTION

The number of patients with heart failure has increased drastically in recent years. An estimated 5.1 million Americans live with this disease, of whom 10% progress to advanced stages[1]. The Food and Drug Administration **(FDA)** approved ventricular assist devices **(VADs)** in 1994. Initially, these support devices were approved to bridge end-stage heart failure patients awaiting transplant, termed "bridge-to-transplant", but their indications and prevalence have continued to expand [2]. Assist devices can be placed either one ventricle or both of them, but long-term type devices used by ambulatory patients with heart failure are left ventricle type (Left Ventricular Assist Devices **(LVAD)**), so this are the kind of apparatus discussed in this document.

Currently, there are 3 therapeutic goals for LVAD implantation: Bridge to transplant **(BTT)**, bridge to candidacy **(BTC)**, or destination therapy **(DT)** [3,4]. BTT LVAD is indicated for patients who are current transplant candidates and require additional left ventricular support to survive until cardiac transplantation. By contrast, BTC patients are not currently transplant candidates because of some modifiable contraindication to transplantation. Some of these modifiable risk factors may be a history of morbid obesity or a recent diagnosis of cancer (within 5 years). In this situation, LVAD implantation is used to help improve the patient's condition with the ultimate goal of making him/her transplant eligible. DT patients are those in which LVAD implantation is intended to provide long-term cardiac support to those patients who not have transplantation indication [5]. Nowadays the rate of LVAD insertion continues rising and the number of patients with these devices increases, so it can be anticipated that the number of patients with LVADs undergoing no cardiac procedures will increase in following years [6,7].

Types of VADs

Nowadays there are three types of LVADs [8]. First-generation LVADs, which attempted to assist the failing ventricle by assuming its pump function. This type of LVAD requires a large pumping chamber that limits the number of patients who can have an intracorporeal pulsatile LVAD to those with a large body surface area.

Subsequent generations of LVADs led to a design shift from pulsatile to continuous-flow, so any pulsatility of blood flow in the systemic circulation is the result of the patient's intrinsic left ventricular function across the aortic valve. An inflow cannula is placed in either the left atrium or, more commonly, the apex of the left ventricle **(LV)** and blood is pumped via a rotating impeller (in an axial or centrifugal fashion) to the ascending aorta [9,10]. The main difference between second and the third-generation devices is that the latest have hydrostatic or magnetic bearings, minimizing shear stress and the incidence of thrombus formation [11].

PREOPERATIVE EVALUATION

Preoperative management should begin with discussing the patient and the proposed procedure with a multidisciplinary team of specialists coordinating their care. This should

include not only the primary surgical and anesthesia teams, but also cardiac surgery, heart failure cardiologists, and dedicated VAD personnel [2,6,9,12–14]. Discussion with the patient's cardiac surgeon may be helpful for planning surgical approaches for thoracic and abdominal procedures so that the LVAD and its driveline can be safely avoided [6]. It may also be necessary to contact the VAD manufacturer for emergency resources [15].

The anesthesiologists involved must understand the complex and systemic changes of patients with heart failure, as well as the LVAD physiology. These patients have reduced stroke volume and cardiac output associated with decreased end-organ perfusion. Compensation mechanisms occur via neurohormonal activation, which results in ventricular remodeling. The long-term effects of this hypoperfusion and overly compensated state frequently result in hepatic, renal, or pulmonary insufficiency, which can be common in DT patients [16,17].

Baseline physical exam findings should be noted, with special concern to organ systems which may be affected by the baseline heart failure (renal, hepatic, or pulmonary) or by LVAD complications, such as a neurologic deficit secondary to a thromboembolic event [7,15]. Electrocardiogram is an important test in these patients, due to they may also have internal cardioverter defibrillators **(ICDs)** or pacemakers [18,19]. Prior echocardiography findings, particularly transesophageal echocardiography **(TEE)** is a key element, in order to compare baseline findings with the intraoperative evaluation, as hemodynamics can change throughout the procedure [14].

For elective procedures, patients should be admitted to the hospital in advance of their procedure to allow for bridging of their anticoagulation from warfarin to heparin [4]. However, in emergent cases, the use of fresh frozen plasma, vitamin K or prothrombin complex [20] may be necessary to partially reverse the effects of a patient's anticoagulation. Vitamin K and prothrombin complex never should be administered because of the risk of pump thrombosis, although in life-threatening circumstances (such as emergency intracranial surgery) the risks of thrombosis need to be balanced against the risk of real ongoing blood loss. Because of that, full reversal of patient's anticoagulation should be avoided, and the degree of anticoagulation reversal should be agreed on ahead of time by the surgical, anesthesia and LVAD teams [21]. Withholding anticoagulation perioperatively has been shown to be safe, although a hematologist may need to be consulted regarding the anticoagulation strategies involved, particularly when anticoagulation strategies are complex [2,14,22]. Furthermore a higher blood loss that normal should be anticipated, so contacting with blood bank staff prior to surgery is mandatory.

Besides of anticoagulation regimen needed for LVAD, another important physiologic consideration is the coagulopathy associated with shear stress and nonpulsatile flow. Evidence suggests that an acquired von-Willebrand Syndrome exists in these patients, where a decreased amount of circulating high-molecular-weight von-Willebrand multimers are found, similar to that observed in patients with severe aortic stenosis [11,23–25].

Likewise, a coinciding platelet dysfunction occurs, which is more significant in nonpulsatile pumps than in their pulsatile predecessors [11]. All these factors place patients at an increased risk of nonsurgical bleeding as evidenced by an increased incidence of gastrointestinal bleeding [14], being endoscopies the no cardiac procedures more frequent performed in this patients [3]. This risk is also increased due to arteriovenous a malformation that exits in the gut of these patients, secondary to the nonpulsatile flow and decreased capillary pressure [23].

Antibiotic prophylaxis for surgical procedures is particularly important in this population. Post-LVAD implantation sepsis has been shown to increase the length of hospitalization and in-hospital mortality rates, and there's an overall decreased survival in patients with non–LVAD-related infections [26–28]. Antibiotic selection should be tailored to the specific surgical procedure but should remain broad enough to cover multidrug-resistant organisms and nosocomial organisms. Typical antibiotic regimens for LVAD insertion include 2 to 3 antibiotics with or without the addition of fluconazole. These regimens can serve as a starting point for helping to determine the most appropriate perioperative antibiotic regimen for an individual patient and the procedure that the patient is undergoing. In addition, all invasive monitors should be placed using a strict aseptic technique to minimize the risk of bacteremia and other LVAD infections [15,16].

Similarly, phosphodiesterase-3 inhibitors such as sildenafil are used in patients high pulmonary vascular resistances **(PVR)**, so patients with these types of medications should be allowed to take them before, during, and after surgery. Any inotropic support on which the patient comes to the operating room should be continued during the perioperative period. The right ventricle **(RV)** is the primary means of LVAD filling, so maintaining RV function is imperative in these cases [15].

INTRAOPERATIVE MANAGEMENT

Patients should have blood available before most of the procedures. The multidisciplinary team has to be coordinated and the patient must be optimized before the surgery. After that, when patient condition permits, the patient can be taken to the operating room. All practitioners should familiarize themselves with basic VAD alarms as well as its intricacies, such as connecting the portable power supply, control console and changing and VAD settings if necessary. Once in the operating room, the device should be attached to a secure power supply during all the procedure [2,6,7,9,13,14,29]. Just before coming to the operating room the ICDs should be turned off, and external defibrillator pads should be applied [15,16,18,19]. The electrosurgical unit grounding pad should be placed as far as possible from the LVAD to limit electromagnetic interference [6,7,13,30]. After checking previous steps, induction of anesthesia may then proceed.

The LVAD's base/module also allows for monitoring of the device parameters, such as pump speed, flow rate and, in the case of the HeartMate model, the pulsatile index **(PI)** [4]. The monitoring of this parameters together with central venous pressure **(CVP)** is crucial to understand the volume status and right ventricular **(RV)** function of the patient. The PI is a measurement of flow pulse through the pump and it's determined by the degree of native left

ventricle contractility and pump speed, showing an excellent measure of intravascular volume and right ventricular performance. A high CVP with a low PI is generally the most worrisome combination and can suggest right ventricular dysfunction with poor filling of the left ventricle, what happends in a possible cardiac tamponade, for instance. Pulsatility may be variable as the physiologic environment changes and is inversely related to how well the LVAD is off-loading volume from the native ventricle. If pulsatility increases significantly, it may be an indication of volume overload to the left ventricle **(LV)** [11]. Overall, the goal is to maintain flow by ensuring adequate preload and RV contractility, while managing systemic vascular resistance to allow for optimal pump function, since increases in systemic vascular resistance will have adverse effects on device output [19].

Before instrumentation of the airway an adequate depth of anesthesia should be achieved, because light anesthesia can result in an abrupt increase in systemic vascular resistance **(SVR)** during laryngoscopy and cause a drastic drop of cardiac output [6,13,19]. The increase in SVR not only provokes a decreased VAD flow and impair peripheral perfusion, but it may also promote stasis of blood in the device and increase the risk of thromboembolic events [6,9]. Standard induction agents and balanced anesthetic techniques have been used safely [6,7,9,29], but this patients should be considered as "full stomachs" because of the position of the LVAD in the upper abdomen, so a rapid-sequence induction must be performed [7,15,16,19].

Table 1: Intraoperative checklist.

1. Verify blood reserves
2 Connect to power supply in the operating room
3. Standard ASA monitors
a. Evaluate if other monitors are needed: processed EEG, cerebral tissue oxygenation, invasive arterial line, central venous
pressure, PA catheter
b. Evaluate if fluid shifts are expected and a central venous catheter is needed
c. TEE available
4. Check VAD control console
5. External defibrillator pads in place

ASA: American Society of Anesthesiologists, EEG: Electroencephalography, PA: Pulmonary Artery, TEE: Transesophageal Echocardiography, VAD: Ventricular Assist Device.

Haemodynamic Monitoring

Standard ASA monitors, such as pulse oximetry and noninvasive blood pressure monitoring, rely on pulsatility and oscillations, respectively. An LVAD patient presents unique challenges due to their nonpulsatile nature, so intraoperative monitoring can be very difficult with this kind of monitors. Some patients may have some pulsatility and can be monitorized with standard ones, but almost all LVAD patients should have an arterial catheter placed for blood pressure monitoring, overall if hemodynamic fluctuations are expected [6,7,31,32]. The relative lack of pulsatile blood

flow does not seem to impair the accuracy of the pulse oximeter readings. However, in cases in which the pulse oximeter does not work at all or is believed to be inaccurate, serial arterial blood gas measurements or cerebral oximetry have been used as alternatives in these patients [9,15,19]. All the monitoring should be placed pre-induction while the patient is awake, and efforts should be directed at maintaining these baseline values throughout the procedure [14].

Depending on the patient's RV function, either a central venous catheter **(CVC)** or a pulmonary artery catheter should be used to monitor preload and RV function [7]. Pulmonary artery catheters are not required if there's no significant pulmonary hypertension at risk for RV failure [7,19,33], and CVC may also be indicated if significant fluid shifts are expected. Intraoperative hemodynamic management should focus on maintaining an adequate preload, forward flow and adequate perfusion. The anesthesiologist must focus in avoiding abrupt changes in SVR and maintaining RV contractility, cardiac rate and rhythm [6,9,13]. Fluid management requires a careful balance between maintaining preload and avoiding right ventricular failure, and should be guided by CVP measurements and the assessment of PI. Keeping in mind the LVAD's preload dependence and after load sensitivity is key to managing changes in hemodynamics [6,14,33]. Hypoxia, hypercarbia, and acidosis should be avoided because they may increase pulmonary vascular resistances **(PVR)** and place additional strain on RV [15].

Ventilator settings should be adjusted to provide adequate ventilation without generating unnecessarily high intrathoracic pressures that hamper venous return and preload [19], and if there's any doubt about a patient's fluid status, TEE should be used. Maintaining spontaneous ventilation, when possible, may augment venous return as well [3,7,19,29]. Extubation should be as hemodynamically careful as induction, and care should be taken to minimize hemodynamic changes such as hypertension and tachycardia, which may negatively impact in LVAD output.

Changes in VAD flow should be combined with other available information, such as operative conditions, arterial pressure, central venous pressure, and TEE findings to diagnose the etiology of decreased flow. Generally, decreases in pump flow should first be treated with a fluid challenge trying to increase preload of RV. Hypovolemia should be avoided and intraoperative losses should be replaced aggressively [9,15]. Second line treatment should include inotropic support for the RV [6,14]. Another common device issue that may happen is obstruction of the inflow or outflow cannula, being caused by thrombus, a kinked cannula, or a "suction event". Obstruction presents as decreased pump flow, decreased arterial pressure, and increases or decreases in pump power, and a suction event occurs when the LV is under filled due to hypovolemia or RV failure. TEE is extremely useful to diagnose any problem with LVADs, and should be ready for use in case of any suspicion of mechanical problem or for the evaluation of LVAD function [8,15,19].

Any change in patient position should be done slowly and carefully, with close hemodynamics monitoring. Frequently, inadequate preload will manifest as a sudden decrease in blood pressure and cardiac output when there's a change in patient position. In most cases, intravenous fluid

administration is adequate to increase preload and restore initial status, but occasionally the patient will need to be returned to a supine position until the hemodynamic changes can be addressed appropriately [34]. Certain types of surgery that rises peritoneal pressure, like laparoscopic procedures, also increases after load and has detrimental effects on preload. However standard insufflations pressures have been utilized safely for laparoscopic surgery safely if steep Trendelenburg position is avoided [6,14,35].

Another parameter that should also be monitored carefully throughout the procedure is cerebral tissue oxygenation, as well as processed electroencephalography **(EEG)**, given the fact that hypertension and tachycardia may not be a reliable indicator of inadequate anesthetic depth in LVAD patients [19]. Significant decreases from baseline should first be treated with increased inspired oxygen. If the decreased SctO2 is accompanied by decreases in LVAD flow, it should be treated as described above with first a fluid challenge, then inotropic support [14].

Managing arrhythmia may present a unique challenge in LVAD-dependent patients, due to the fact that the RV function is crucial to maintain LVADs preload. Standard advanced cardiovascular life support guidelines should be followed; however, external chest compressions should be avoided during cardiac arrest [6,15,36], because can risk cannula dislodgment, which may result in life- threatening hemorrhage and potential massive air embolization [6,15,16,19].

Table 2: Hemodinamyc management.

1. Optimize preload
2. Support RV function
3. Avoid increases in afterload
a. RV: Avoid hypoxia, hypercarbia, acidosis
b. LVAD: Avoid vasoconstriction
4. Avoid excessive fluid administration
5. Control cardiac rate and rhythm

RV: Right Ventricle, **LVAD:** Left Ventricular Assist Device.

POSTOPERATIVE MANAGEMENT

Most of the postoperative care of LVAD-dependent patients undergoing non-cardiac surgery is uneventful. Although these patients initially may appear to be hemodynamically stable, residual anesthetic and hypoventilation may cause sudden decompensation. This makes transportation a particularly vulnerable time even for patients who underwent an uneventful surgical procedure. Patients should be extubated when they meet standard criteria and can be recovered in the standard post- anesthesia care unit, unless intensive care is otherwise indicated [2]. However the ICU is the most common location of postoperative care listed among various case reports and case series [19,21,37].

A major concern in the postoperative course will be the resumption of anticoagulation. Patients who are both anticoagulated and on antiplatelet therapy are at risk for hemorrhagic postoperative complications [33]. Patient bleeding in inicial hours should be treated as standard procedures, and heparin infusion should be resumed when the risk of postoperative bleeding is acceptable [22,30,33,35]. Oral anticoagulation can be resumed when bleeding from surgical drains ceases, though the heparin infusion should be continued until the patient reaches their goal INR [12,33].

CONCLUSION

Noncardiac surgery is becoming more widespread in patients with LVADs because of increasing implantation of these devices and favorable survival rates. Operations with the patient under general anesthesia can be performed safely in multidisciplinary centers used to care for patients with LVADs. However, optimization of patient outcomes requires a large infrastructure and numerous resources to manage this complex patient population. Anticoagulation can be safely discontinued or withheld in the perioperative period if bleeding concerns during or after surgery exist. Postoperative bleeding requiring transfusion occurs commonly after noncardiac surgery. Early mortality after this type of patients is usually attributable to worsening preoperative organ dysfunction or unrelated events after discharge.

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