Management of the VAD Patient for Non-Cardiac Procedures
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The patient with a ventricular assist device (VAD) who presents for non-cardiac surgery often presents a challenge to non-cardiac anesthesiologists due to the unfamiliarity most general anesthesia practitioners have with the devices and the physiology of the VAD-supported state, as well as the high level of illness and comorbidity with which many supported patients present. Further, the infrequency with which many practitioners are required to deliver care to such patients results in a very flat learning-curve.

Regardless, the current generation of devices have demonstrated vastly superior outcomes and increased durability compared to their predecessors, large and increasing numbers of VADs are being implanted to manage advanced heart failure, and the inevitable reality is that anesthesia practitioners will increasingly encounter patients on VAD support.

When highly comorbid or unstable patients supported by an LVAD present for complex or urgent surgical procedures associated with large volume shifts, it is reasonable to assume that the patient would be best served by having a cardiac anesthesiologist do the case. The same likely applies to patients supported by short-term devices providing a “bridge-to-recovery” from an acute cardiac decompensation or “bridge-to-next-decision” following an acute cardiac arrest.

In contrast, stable LVAD patients who are living at home with their VAD while awaiting a heart transplantation, or who have had the LVAD implanted as a permanent solution for end-stage heart failure (“destination therapy”) who present for “straightforward” cases not associated with large volume shifts may reasonably be cared for by non-cardiac anesthesiologists once they have received an educational intervention to familiarize them with the essential concepts of mechanical circulatory support and the anesthetic considerations for a patient supported by a VAD. That said, preoperative consultation with a knowledgeable colleague, the physician managing the VAD or a VAD-nurse is strongly encouraged (as discussed below) and the availability of perioperative consultation with knowledgeable personnel and/or intraoperative cardiac anesthesia backup remains prudent should questions or issues arise.

At this point in history, it seems unlikely that a VAD patient would be an acceptable candidate for surgery in a free-standing ambulatory center or outpatient setting in the United States, however, this may change in the future. Endoscopy centers seem a particularly likely place where VAD patients may one day be cared for outside of the hospital setting given the large number of endoscopies performed in the population of patients supported by the current generation of non-pulsatile devices (the lack of pulsatility appears to induce vascular dilatations that require surveillance and management).

CASES to consider

• A 73 year old man with ischemic cardiomyopathy presents for left femoral-to-tibial artery bypass grafting. He is active and enjoys fly-fishing, but is progressively limited by leg claudication. As he is not eligible for heart transplantation, he is managed at home with a HeartMate II left ventricular assist device as “destination therapy”. Concurrent medical issues include: coronary artery disease s/p three prior myocardial infarctions, congestive heart failure (CHF), hypertension, non-insulin dependent diabetes mellitus, prostatic hypertrophy, and elevated cholesterol.

• A 59 year old woman with dilated cardiomyopathy presents for a colonoscopy. She is currently supported by a HeartMate II left ventricular assist device as a bridge-to-transplantation. Her INR is 2.5. Concurrent medical issues include: congestive heart failure, hypertension, mild renal insufficiency, and hiatal hernia. An implantable cardioverter defibrillator (ICD) is present.

• A 42 year old woman presents for left carpal tunnel release. She is supported by a Jarvik 2000 Flowmaker as a bridge-to-transplantation. She reports “a paralyzed vocal cord” following thyroid surgery 15 years ago and does not want to be intubated for the procedure.

• A 64 year-old male presents with an acute abdomen for exploratory laparoscopy and possible...
laparotomy. He is supported by a HeartMate II LVAD as Destination Therapy. His INR is 2.0 and his hematocrit is 23 after receiving 2 units of packed red blood cells.

- A 55 year old man supported by a HeartMate II LVAD presents for debridement and myocutaneous flap closure of a stage IV sacral decubitus ulcer in the prone position. The device was implanted as a bridge to transplantation 2 months ago. Additional procedures at the time of VAD implantation included mitral valve replacement, aortic valve replacement, and coronary artery bypass graft surgery to the right coronary distribution. The postoperative course was complicated by renal failure, anemia, and prolonged respiratory failure for which he had previously undergone tracheostomy. He is chronically in atrial fibrillation. There is an indwelling right femoral arterial pressure cannula and a 7.5F triple-lumen catheter in the right internal jugular vein. An 8.0 cuffed Shiley tracheostomy tube is present.

**QUESTIONS to consider**

- What considerations will guide your preoperative assessment of these patients?
- How will you optimize these patients prior to anesthetic induction?
- What are your goals for fluid management in the perioperative period?
- What will you tell the surgeons regarding perioperative anticoagulation?
- How will you manage the patient’s pacemaker and/or ICD?
- What anesthetic technique will you employ? What agents will you use?
- What intraoperative monitors will you use?
- When are central venous lines and/or a pulmonary arterial catheter helpful in a patient with an LVAD?
- How will you determine if the depth of anesthesia is adequate during maintenance?
- How will you determine if the output from the VAD is optimized?
- What are the parameters on the HeartMate II LVAD console?
- What alarms might you hear annunciated? What alert conditions do you need to be aware of?
- What are the important post-operative considerations in the LVAD-supported patient?

**VADs- review of general concepts**

Though there are a number of different devices and support strategies out there, in general, VADs are pumps that collect blood returning to a failed side of the heart and eject it downstream of the failing ventricle. At the current time, VADs themselves neither oxygenate nor remove waste from the blood; they are simply pumps which ensure output from the failed side of the heart.

Typically, for left ventricular support, oxygenated blood is drained from the left ventricular apex to the pump, and returned to the ascending aorta. For right ventricular support, blood is typically drained from the right atrium and returned to the pulmonary artery.

The goal is either to decompress an acutely ischemic and failing ventricle (thereby reducing its oxygen demand) so it can recover (“bridge-to-recovery”), or to provide long-term support for a chronically failing heart as either a “bridge to transplantation” or as “destination therapy” (permanent support of an end-stage failing ventricle in lieu of planned heart transplantation). An additional modern indication for intermediate and long-term VAD support is to improve multi-organ function in a less-than optimal transplant candidate to improve their candidacy to receive a heart (“bridge-to-candidacy”). Modern indications for short-term mechanical circulatory support include: “bridge-to-immediate-survival” (e.g., from acute cardiogenic shock), “bridge-to-next-decision” (e.g., following a cardiac arrest where neurological or other organ status is uncertain), “bridge-to-a-bridge” (e.g., to another device), etc, but patients in these categories are not likely to be encountered presenting for elective general surgical procedures.

By and large, in the US in 2013, the LVAD patient presenting for an elective non-cardiac procedure will most likely be supported by a HeartMate II LVAS, which is a second generation, axial flow pump. It is further most likely that the indication for their LVAD support will be as a “bridge-to-transplantation”, though some might have their device permanently implanted as “destination therapy”.

The first generation of implantable LVADs was designed to capture the entire output of the failed left
ventricle and eject it in a pulsatile fashion into the ascending aorta. Although successful, they were large, noisy devices, with complicated pulsatile mechanisms that required artificial valves to prevent retrograde flow during pump systole. Dissatisfaction with these characteristics and a high incidence of complications (e.g., mechanical difficulties and thromboembolic complications) encouraged the development of the next generation of miniaturized continuous-flow devices currently being implanted in increasing numbers.

The “next generation” VADs currently in use are nonpulsatile devices that unload the failing ventricle through the action of an impeller rotating at high speed. The nature of the impeller can be either axial (like an Archimedes screw) or centrifugal. Although these new devices are much smaller than their predecessors, they can produce the same high flows and they operate silently. At this point, the continuous-flow devices have essentially supplanted the first generation pulsatile VADs, and there are very few patients out there still supported by a first generation, pulsatile VAD.

As the use of mechanical circulatory support has steadily increased, many institutions have established dedicated VAD personnel and “VAD teams”, typically composed of heart failure specialists, cardiac surgeons, nurses, perfusionists and technologists. Such staff persons are an invaluable asset to ensure appropriate management of the VAD-supported patient wherever they may be in the hospital. Such personnel rarely remain in the OR, however, and it is incumbent on the modern Anesthesiologist to become familiar with the anesthetic considerations for a patient supported by a VAD. This being said, consultation with a knowledgeable colleague (e.g., a cardiac anesthesiologist), and the physician managing the VAD are highly recommended in advance, and coordination of patient care on the day of the procedure is necessary to ensure an optimal outcome.

**Clinical pearls**

**Preoperative considerations**

- The preoperative clinical status of an LVAD-supported patient depends primarily on the extent of end-organ damage sustained during low-output states prior to VAD implantation, any post-implantation complications, and the present surgical problem. A thorough, thoughtful assessment of the complete patient is mandatory, even for the most minor of cases.
- Preoperative discussions about key issues with a knowledgeable colleague, the physician managing the VAD, the surgeon, and dedicated VAD staff are helpful and strongly encouraged.
- One of the most serious complications of VAD usage is thromboembolism, and all currently available short-and long-term VADs require anticoagulation. While the level of anticoagulation may be decreased toward the lower limit of manufacturer’s recommendations, it is not generally advisable to completely reverse anticoagulation in a VAD-supported patient except in the most dire of circumstances. The physician managing the VAD, the anesthesiologist, and the surgeon should work together to plan a safe anticoagulation regimen for the perioperative period. Most general surgical procedures (with the exception of ophthalmological and neurosurgical procedures) can be safely conducted under mild anticoagulation.
- It is not uncommon for the VAD-supported patient to have a pacemaker and/or implantable cardioverter defibrillator (ICD), and perioperative considerations and practices regarding pacemakers and ICDs are the same in LVAD-supported patients as in all other patients. The antitachyarrhythmia therapies of an ICD are routinely disabled preoperatively if electromagnetic interference (EMI) from the surgical electrocautery is anticipated. Pacemakers are only reprogrammed to an asynchronous mode in pacemaker dependent patients, and only if substantial EMI is anticipated. A suggested algorithm for management of the patient with a modern pacemaker or ICD appears below.

**Intraoperative considerations**

- Plug the VAD in. Patients supported by a VAD will be transported to the operating room with the device running on battery power, which may last for several hours, and there is always a backup battery brought along. Nevertheless, it is advisable to connect the device to mains AC power once in the OR.
Patients with an implanted first generation LVAD (e.g., HeartMate XVE) are considered a “full stomach” due to the pre-peritoneal location of the large pump head, and appropriate precautions should be considered. In contrast, patients with second-generation, continuous flow devices are not a priori considered full stomachs due to their smaller size and frequent intrathoracic location. The decision to intubate the VAD-supported patient should be based on the usual criteria for intubation during an anesthetic, and NOT the presence of the VAD.

Regardless of the type of LVAD present (pulsatile or continuous flow), intravascular volume status must always be optimized, and adequate right ventricular function must be assured because it is the output from the RV that ultimately is ejected/impelled from the LVAD. The effect of surgical positioning and/or high intrathoracic pressures (e.g., from excessively large tidal volumes) on venous return to the heart must be considered, as adequate intravascular volume is the most important factor in maintaining LVAD output.

The selection of anesthetic agents and the dosages used should take into account the potentially dysfunctional unassisted RV as well as insufficiency of, or prior injury to major organ systems. Continuous hemodynamic optimization with judicious adjustments to intravascular fluid status, and the use of inotropic and vasoactive agents is mandatory.

LVADs themselves neither indicate nor contraindicate any particular anesthetic agents, but their presence imposes considerations for the anesthetic technique due to the requisite anticoagulation. Most VAD-supported patients will receive a general anesthetic but in selected cases, sedation with local skin infiltration, regional blocks placed with ultrasound guidance, or a regional intravenous technique may be appropriate.

While non-invasive blood pressure (NIBP) determinations and pulse oximetry are reliable in patients with pulsatile VADs, this is not always the case with continuous-flow VADs which by design produce non-pulsatile output. However, most patients supported by a non-pulsatile device will still demonstrate some level of pulsatility pre-operatively (though the pulse pressure may be small), and they may retain that pulsatility during MAC cases or even after induction of GA if intravascular volume status is kept optimized. Even a small pulse pressure (e.g., 10 - 15 mmHg) can allow for the use of standard monitoring (e.g., a NIBP cuff and a pulse oximeter), especially during minor operative procedures. Hypovolemia and/or vasodilitation will predictably result in a loss of the pulsatility, and an arterial pressure monitoring line and cerebral oximetry are often necessary for major cases where large fluid shifts or significant blood loss are anticipated. Elevated pulmonary vascular resistance (e.g., as might accompany hypercarbia, pain, use of α-agonist vasopressors, hypothermia, acidosis or hypoxemia) and/or RV failure will decrease the amount of blood getting to the LV, and will also result in decreased LVAD flows and pulsatility.

The HeartMate II control console displays an index of pulsatility in the top right corner of the clinical screen (the Pulsatility Index, or the PI). Typical desired “normal” values are in the range of 4 – 7. A drop in the PI from a baseline observed value likely reflects either relative hypovolemia, vasodilitation (or both). Elevated PVR and/or RV dysfunction should always be included in the differential diagnosis of decreased LV filling.

BIS monitoring can be helpful to assess depth of anesthesia, as some of the usual signs of light anesthesia (e.g., hypertension, tachycardia) may not always be overtly manifest in the VAD-supported patient. This is less of an issue with the non-pulsatile devices than it was with the previous generation of pulsatile VADs.

Hypotension in the VAD-supported patient can result from:

- relative hypovolemia
  - pulsatile devices: hypovolemia → slowed pump filling → slowed rate of pumping → decreased overall “cardiac” output → hypotension
  - non-pulsatile devices: hypovolemia → underfilled arterial tree and possibly “LV suckdown” → hypotension
- vasodilitation
- failure of the RV to get blood across to the LV to fill the LVAD
  - RV failure
  - dysrhythmia
  - excessive pulmonary vascular resistance

TEE is the monitor of choice if there is hemodynamic instability or a question about the filling status.
and function of the RV, or possibly LV suckdown.

- It is unlikely that any intraoperative changes will need to be made to VAD settings of patients who have been stable on those settings preoperatively. Judicious infusion of volume is the intervention most likely to be required to correct relative hypotension. On rare occasions, significant rapid hypovolemia may result in LV “suckdown” by the LVAD, which may require a temporary decrease in the pump speed of a HeartMate II to allow reestablishment of LV filling.

- The decision to place a central vascular access for CVP monitoring and/or pulmonary artery catheter insertion requires due consideration of the potential risks and benefits. PACs generally provide little useful hemodynamic information in LVAD-supported patients because the device console continuously displays the left-sided cardiac output. On the other hand, decreasing LVAD output associated with rising central venous pressure might suggest the need to decrease PVR with selective pulmonary vasodilators and/or start inotropes to support right ventricular function. The availability of a cardiac anesthesiologist, TEE, and dedicated VAD support staff may be helpful to assist with intraoperative management should hemodynamic instability develop.

- One can roughly estimate systemic vascular resistance (SVR) in the LVAD-supported patient with an indwelling CVP monitor by substituting the VAD output for the cardiac output in the hemodynamic formula, as follows:

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SVR = \left(\frac{MAP - CVP}{\text{LVAD output}}\right) \times 80 \text{ dynes-sec/cm}^2
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This calculation is a very rough estimate, however, and assumes that all cardiac output is going through the VAD. The utility of such an estimate is decreased in patients with any significant amount of pulsatility (e.g., the LV is also ejecting through the aortic valve).

- Cardiac arrest is managed with the usual pharmacological components of standard advanced cardiac life support (ACLS) protocols in LVAD-supported patients. It can be argued that external chest compressions probably should not be performed on a VAD-supported patient as potential dislodgement of the VAD inflow cannula will result in certain death. That being said, external compressions may be a life-saving maneuver and have been successfully performed in patients with VADs. VADs will likely be damaged by external defibrillation if the paddles/pads are placed directly over the device.

- Although most infections associated with VADs tend to occur in the percutaneous tract through which the driveline exits from the abdomen, it must be appreciated that VADs are large foreign bodies that once infected may not be adequately treated. Strict aseptic technique is absolutely mandatory for all invasive procedures in VAD-supported patients, and appropriate prophylactic perioperative antibiotics are routinely employed.

- The VAD driveline itself should not be prepped with povidine-iodine containing solutions because these can result in breakdown of the plastic. When necessary, drivelines can be draped out of the field or covered temporarily with a sterile incise drape.

Postoperative considerations

- Extubation criteria are the same in the VAD-supported patient as in any other patient. Prolonged intubation is to be avoided because it can lead to respiratory infection.

- Due consideration should be given to the postoperative disposition of the VAD-supported patient. In the majority of cases, it is prudent to recover the VAD-supported patient in a monitored environment where the staff is familiar with VAD-supported patients.

- Pacemaker and ICD settings should always be restored to their preoperative values. The necessity for routine postoperative interrogation of all CIEDs remains controversial. Table 2 provides guidance in this regard.