AANA Journal Course
Update for Nurse Anesthetists

Ventricular Assist Devices and Anesthetic Implications for Noncardiac Procedures

Kristin A. Khoo, RN, BSN

Approximately 5 million Americans experience heart failure, which affects 10 in every 1,000 people older than 65 years. Ventricular assist devices (VADs) are a type of mechanical circulatory support that aids in systemic perfusion by maintaining unidirectional flow while reducing the oxygen demand of the failing ventricle. There are 3 generations of VADs in circulation used as a bridge to transplantation, a bridge to recovery, or as destination therapy. Due to the increasing use of these devices, it is likely that anesthetists will encounter patients with these devices more frequently, which requires adequate preoperative discussion with the care team. Intraoperatively, it is important to realize that patients with VADs are at higher risk for aspiration, to recognize electromagnetic interference from surgical devices, to maintain hemodynamic stability, and to monitor coagulation status. With proper knowledge, and adequate preoperative preparation and intraoperative care, anesthetists should be able to achieve safe and successful patient outcomes through anesthesia care.

Keywords: Anticoagulation, congestive heart failure, hemodynamics, ventricular assist device.

Objectives
At the completion of this course, the reader should be able to:

1. Understand the biomechanical physiology of ventricular assist devices (VADs).
2. Recognize that use of certain medical devices should be avoided during surgery in a patient with a VAD.
3. Discuss the anesthetic considerations for patients with VADs during the preoperative, intraoperative, and postoperative periods.
4. Understand the importance of maintaining normovolemia in patients with VADs during noncardiac surgery.
5. Recognize the most common surgical complication in patients with VADs undergoing noncardiac surgery and how this may be prevented.

Introduction
Heart failure continues to be a major health concern in the United States. More than 500,000 new cases are diagnosed every year, many of which require heart transplantation. However, only 2,000 such procedures are performed annually; thus, the number of patients living with heart failure is continually increasing.1,2 Due to the technological advancements in the field of heart failure, patients have another option: ventricular assist devices (VADs). More than 20,000 VADs have been inserted to date, allowing more patients to return home and live active lifestyles.3 In turn, the number of noncardiac procedures performed on patients with VADs will only increase as more VADs are inserted and patients live longer with these devices. Some studies indicate rates of 20% to 29% of patients with VADs needing to undergo noncardiac procedures.2 It is therefore imperative that anesthetists be familiar with such devices because patients with VADs require additional considerations during the preoperative, perioperative, and postoperative periods.

History and Review of Literature
Despite medical advancements in heart failure treatment, pharmacotherapy is limited.4 Even with the most effective combinations of angiotensin-converting enzyme inhibitors, inotropic agents, β-blockers and diuretics, survival is only 16% at 1 year for patients in stage IV heart failure (Table 1) and drops to 0% by 5 years.4 Currently,
the only definitive treatment for end-stage heart failure is heart transplantation. However, in the United States, fewer than 10% of candidates actually undergo heart transplantation due to the lack of available donor organs. This discordance is expected to worsen as the population ages and the prevalence of heart failure increases.3

Although there have been a number of advancements surrounding heart disease treatment, the most significant progress surrounds the use and implementation of VADs; a recent study found a 48% decrease in mortality with VAD therapy compared with pharmacotherapy after 1 year.2 The left VAD system was created at Baylor College of Medicine, Houston, Texas, in 1961 and 1962 by Domingo Liotta and Michael DeBakey.5,6 One year later, Liotta and Stanley Crawford implanted the first VAD into a patient with cardiogenic shock.7 Although the concept of a mechanical VAD has been around for the last 5 decades, only within the past 10 years has there been significant advancement in the development of VADs. The evolution of these mechanical wonders to their current state of use can be marked by 3 major milestones: the conversion from an external to an internal device, changing from a pneumatic to an electrical power source, and the transition from pulsatile to continuous flow devices.3

Due to the limited availability of donor hearts and the increasing number of patients requiring more cardiac support, criteria have been established for the insertion of a VAD (Table 2).

State of the Art

• Function of VADs. A VAD collects blood that is returned to the heart and assists in pumping blood to the body.8 Such devices are a type of mechanical circulatory support that aids in systemic perfusion by maintaining unidirectional flow while reducing the oxygen demand of the failing ventricle and allowing the heart to heal.8 In VADs, valves connect the left ventricle to the pump and the aorta by taking blood from the left atrium and sending it to the device, which assists in circulating the patient’s blood volume.8,9

On a cellular level, VADs alter the myocardium and decrease the size of cardiac myocytes, helping to improve myocardial function and decrease cell death.3 The effect of calcium on heart failure therapy is continually being studied as VADs can help increase the contractility of cardiomyocytes, decrease the action potential duration, and, therefore, shorten the QT interval.3 Such treatment can increase not only the length of life but also its quality.

Current devices have 3 distinct parts: a pump, an electronic controller, and batteries.10 The pump weighs 1 to 2 lb and is placed in the patient’s left upper abdominal region or outside the body, depending on the type of device. The electronic controller is a small computer that controls the workings within the pump. The batteries are carried in a pack outside the body and are connected through a cable to the pump, allowing for mobility when the patient is not connected to a continuous power supply.10

All VADs can be grouped by the site of placement and the type of flow (Figure). The site of placement can be extracorporeal/paracorporeal (outside the body) or intracorporeal (within the body), and the type of flow is centrifugal or axial.4 In axial flow, blood flow is nonpulsatile, and afterload is the main determinant of pump output. Centrifugal pumps use magnets to couple to an outside power source, and, therefore, blood flow is proportional to pump speed.4

• Three Generations. There are currently 3 generations of devices on the market (Table 3). There are various names, depending on where the device was manufactured. The following discussion centers on the main differences between them. Such information is important for healthcare providers to distinguish between device types as the number of patients in the community with

<table>
<thead>
<tr>
<th>Class</th>
<th>Symptoms</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>No fatigue, palpitations, dyspnea during regular physical activity</td>
</tr>
<tr>
<td>II</td>
<td>No limitation at rest, slight dyspnea upon exertion</td>
</tr>
<tr>
<td>III</td>
<td>Marked fatigue, dyspnea, and/or palpitation upon exertion</td>
</tr>
<tr>
<td>IV</td>
<td>Any physical activity/exertion leads to discomfort; symptomatic even at rest</td>
</tr>
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### Table 1. New York Heart Association Classification of Heart Failure

<table>
<thead>
<tr>
<th>Indications</th>
<th>Contraindications</th>
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<tbody>
<tr>
<td>Cardiac index &lt; 2 L/min</td>
<td>Irreversible liver or kidney damage</td>
</tr>
<tr>
<td>Systolic blood pressure &lt; 90 mm Hg</td>
<td>Active systemic infection</td>
</tr>
<tr>
<td>Pulmonary capillary wedge pressure &gt; 20 mm Hg</td>
<td>Severe lung disease/chronic obstructive pulmonary disease (forced expiratory volume in 1 second/forced vital capacity ratio &lt; 70% with or without chronic symptoms of cough and sputum production)</td>
</tr>
<tr>
<td>Urine output &lt; 20 mL/h</td>
<td>Metastatic cancer</td>
</tr>
<tr>
<td></td>
<td>Blood coagulation disorders, depending on severity (eg, hemophilia, von Willebrand disease)</td>
</tr>
</tbody>
</table>

### Table 2. Indications and Contraindications for Ventricular Assist Devices4
VA Ds increases. With all devices, the aim of treatment is to optimize quality of life, enabling patients to be discharged home to lead a fairly normal lifestyle.

The first-generation devices operate with pulsatile flow. They have inflow and outflow valves and are able to maintain systemic circulation by pumping up to 10 L/min. These devices are implanted and are quite large compared with newer devices. They are electronically driven and, therefore, connected through the driveline to a battery unit, allowing for mobility. The first 2 left VA Ds approved by the US Food and Drug Administration, the Novacor N1000PC (World Heart, Inc, Oakland California) and the HeartMate VE or XVE (Thoratec Corporation, Inc, Pleasanton, California), are first-generation VA Ds. One device, the HeartMate 1 or XVE has a textured surface that does not require concurrent anticoagulation. The disadvantages of these devices include their large size, higher infection rate, limited durability, and noise. The large size can press on adjacent internal organs, causing them to shift. The complexity of cleaning the driveline daily in a sterile manner also increases the risk of contamination. Compared with newer devices, the first-generation devices also have more moving parts, which shortens the life of the device and increases the noise.

The second-generation VA Ds use continuous flow, through a centrifugal pump or axial flow. Second-generation pumps are also known as “axial-flow pumps” because they use electrical energy to propel blood forward. Compared with their first-generation counterparts, these devices are smaller, easier to insert, and more durable due to the fewer number of parts. However, they are known to produce heat due to the high rotation speeds within the pump and can cause hemolysis, leading to thrombolytic events. Because second-generation devices are nonpulsatile, patients will not have a palpable pulse. In the operating room, this becomes relevant when monitoring blood pressure; as an invasive blood pressure monitor is required, and the mean arterial pressure is commonly used to trend blood pressures. If the pulse cannot be palpated, an ultrasound device can be used to find the artery for insertion. These pumps have been reported to decrease myocardial oxygen consumption by 20% and increase coronary perfusion. Examples of second-generation pumps include the HeartMate II and Jarvik 2000.

The third-generation devices also use continuous flow by the way of hydraulics or electromagnetic action to suspend a propeller, giving them only 1 moving part. Therefore, third-generation pumps may also limit the palpability of the pulse. These implantable pumps do not use ball bearings and are programmed to a lower number of revolutions per minute compared with their predecessors, which increases the durability of the device. Current postimplant data indicate that the current third-generation pumps can last up to 10 years. Although many third-generation pumps are still in the testing phase of clinical research, 2 that have received approval include the DuraHeart and VentriAssist.

- **Indications for Use.** The main indication for therapy

**Table 3. Types of Ventricular Assist Devices (VA Ds)**

<table>
<thead>
<tr>
<th>Type of flow</th>
<th>Examples in use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First</strong></td>
<td>Pulsatile</td>
</tr>
<tr>
<td></td>
<td>Novacor N1000PC (World Heart, Inc, Oakland, California)</td>
</tr>
<tr>
<td></td>
<td>HeartMate VE and XVE (Thoratec Corporation Inc, Pleasanton, California)</td>
</tr>
<tr>
<td><strong>Second</strong></td>
<td>Nonpulsatile; continuous</td>
</tr>
<tr>
<td></td>
<td>Heartmate II (Thoratec Corporation, Inc, Pleasanton, California)</td>
</tr>
<tr>
<td></td>
<td>Jarvik 2000 (Jarvik Heart, Inc., New York, New York)</td>
</tr>
<tr>
<td><strong>Third</strong></td>
<td>Nonpulsatile; continuous</td>
</tr>
<tr>
<td></td>
<td>DuraHeart (Terumo Heart, Inc, Ann Arbor, Michigan)</td>
</tr>
<tr>
<td></td>
<td>VentriAssist* (Ventracor, Ltd. Chatswood, Australia)</td>
</tr>
</tbody>
</table>

*This device is no longer manufactured; it is included in table because a considerable number of patients are still using this model.
is stage IV heart failure, as defined by the New York Heart Association, that is refractory to medical management (see Table 1). By providing cardiac support, VADs may be used as a bridge to cardiac transplantation, bridge to recovery, or destination therapy. As the number of patients on the heart transplant list continues to grow and the number of donors remains stagnant, an increasing number of patients are using the bridge-to-transplantation option. More than 12,000 patients have been supported with VADs while awaiting transplantation. In these patients, a VAD will help stabilize end-organ failure and allow patients to increase their quality of life while waiting for a compatible donor organ.

Patients with reversible forms of cardiovascular failure (such as nonischemic cardiomyopathy) who have an ejection fraction greater than 45% have the highest probability of myocardial recovery. These patients are excellent candidates for the bridge-to-recovery VAD, which aids in myocardial recovery by allowing the myocardium time to rest, heal, and regain function.

A third role for VADs is destination therapy, and this currently includes the largest group of patients using this device. Due to their advanced stage of heart failure and multiple comorbidities, the patients have a limited life span of approximately 2 years. The use of a VAD is preferred to help support circulation and improve the quality of life and prolong survival.

• Anesthesia Considerations. The number of patients undergoing noncardiac procedures is expected to increase as more VADs are implanted. Therefore, it will be important that the surgical and anesthesia teams be knowledgeable in the support of these devices. Stehlik et al found that bleeding is the most common postoperative complication in patients with VADs undergoing abdominal surgery and requires reexploration of the abdominal cavity in 20% of patients; however, no deaths were directly caused by surgical complications in patients with VADs undergoing noncardiac surgery. In their cohort of patients, one factor contributing to bleeding risk was the presence of increased intra-abdominal pressure and increased postoperative motion of the VAD weight and function. As providers caring for patients in the operating room, it is important for anesthetists to understand the key elements required to safely administer an anesthetic to patients with a VAD (Table 4).

### Table 4. Preoperative, Intraoperative, and Postoperative Considerations for Patients With Ventricular Assist Devices (VADs)

<table>
<thead>
<tr>
<th>Preoperative</th>
<th>Intraoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussion of case with VAD care team</td>
<td>Assumption that stomach is full (rapid-sequence induction preferred)</td>
<td>Follow-up with VAD team</td>
</tr>
<tr>
<td>Thorough preoperative evaluation (consider status of VAD and additional comorbidities)</td>
<td>Recognition of electromagnetic interference bipolar cautery best; turn implantable cardiac defibrillators off and use external defibrillator pads</td>
<td>Assessment for bleeding (clinical assessments, laboratory values)</td>
</tr>
<tr>
<td>Ensuring reliable power source for device</td>
<td>Maintenance of hemodynamics (low-dose vasopressin preferred)</td>
<td>Assessment of fluid status (intake, output, clinical assessments)</td>
</tr>
<tr>
<td>Infection prevention; management of antibiotics; aseptic technique</td>
<td>Monitoring coagulation (change to intravenous heparin in semielective cases)</td>
<td>Continuing antibiotics as needed</td>
</tr>
</tbody>
</table>

Regardless of the type of VAD in place and the type of surgery, the following discussion is a guide to providing the utmost attention to patient safety.

• Preoperative Care. One of the most important priorities for anesthetists is to identify the VAD care team within their hospital if one exists. These teams manage patients with VADs on a daily basis and will be able to provide invaluable information. Such specialized teams are composed of cardiothoracic surgeons, nurses, physical therapists, cardiopulmonary perfusionists, psychologists, and nutritionists. If the hospital does not have a VAD team, it is crucial to communicate with all persons involved in the case to obtain as much information as possible and decide whether the team feels safe and knowledgeable in providing care to the patient. In emergency situations when noncardiac surgery is required and hospital personnel are not experienced in caring for patients with VADs, staff should obtain essential information from the nearest hospital with a dedicated VAD team or contact the VAD manufacturer’s emergency number.

It is also crucial for anesthetists to perform a thorough preoperative evaluation. In addition to the standard preoperative questionnaire, the evaluation should include the type of device the patient has and the duration of use; this information will aid practitioners in gaining valuable information if complications should arise. Patients can have a wide range of clinical conditions; some recent VAD recipients may still have renal and/or hepatic insufficiency, whereas VAD recipients who have had the device in place longer may be on the road to recovery. A recent study found that patients who had New York Heart Association class IV heart failure had improved to class I by 24 months after VAD insertion. Moreover, obtaining a complete set of laboratory tests will provide insight into the patient’s vital organ functions. This testing should include a metabolic panel including creatinine and liver function studies, complete blood cell count, international normalized ratio,
and partial thromboplastin time. Maintenance of therapeutic anticoagulation levels is important to prevent thromboembolism.\textsuperscript{18} The cardiologist managing the VAD, the anesthetist, and the surgeon must all communicate to establish a safe anticoagulation plan and determine the optimum time to overlap warfarin anticoagulation with heparin anticoagulation. Most urgent procedures can proceed with mild anticoagulation levels; however, during the procedure, hemostasis must be monitored very closely.\textsuperscript{8} Although the first-generation HeartMate XVE does not require anticoagulation due to its textured surface, antplatelet agents are still used.\textsuperscript{8} Anesthetists must, therefore, also be prepared for increased intraoperative bleeding and, if necessary, administer packed red blood cells, platelets, or fresh frozen plasma.

It is also the responsibility of anesthesiologists to secure a reliable power source for the duration of the procedure. Although the HeartMate VE and Novacor have rechargeable batteries lasting up to 6 hours, in the operating room, it is prudent to connect the patient’s device to a main power supply to prevent electrical failure.\textsuperscript{9,18}

In addition, patients with VADs are more susceptible to microorganism transmission due to the direct route from the driveline to the body, so prevention of infection is crucial. Strict sterile technique and appropriate preoperative antibiotics should be used for all invasive procedures.\textsuperscript{18} The type and dose of antibiotics will vary depending on renal and hepatic function and the type of procedure.\textsuperscript{12} While no VAD-specific antimicrobial protocol exists, it is reasonable to use a combination of wide-spectrum antimicrobials for intra-abdominal procedures, for example, vancomycin, levofloxacin, rifampin, and fluconazole. For nonabdominal surgeries, a combination of vancomycin and a cephalosporin would be reasonable.\textsuperscript{16}

- \textit{Intraoperative Care}. There are 4 important considerations when providing anesthesia to a VAD-assisted patient (see Table 4). First, always consider patients with an implantable device to have a full stomach.\textsuperscript{18} This is due to the size and location of the device in the left upper quadrant of the abdomen, which may exert pressure on the stomach. Therefore, minimizing the risk of gastric insufflation and pulmonary aspiration with rapid sequence induction is necessary.

Second, be able to recognize the sources of electromagnetic interference (EMI). There are 2 main sources of EMI: radiated and conducted.\textsuperscript{19} Radiated EMI is generated by magnetic resonance imaging, positron emission tomography, and radiation therapy. Conducted EMI can come from defibrillation and electrocautery and can alter device function. Electrocautery is the most widely used source of conducted EMI. It works by passing a high-voltage, high-frequency current through tissue to assist in cutting or coagulating.\textsuperscript{19} When electrocautery is used, the use of bipolar electrocautery is recommended despite its lower power voltage as the current only flows between the tips of the bipolar instruments.\textsuperscript{9} In comparison, monopolar electrocautery current starts at the tip of the instrument, travels through the body, and returns though a grounding plate, increasing the risk of interference with VAD function.\textsuperscript{19}

Many patients with VADs also have implantable cardiac defibrillators that may interpret EMI as ventricular fibrillation, causing the patient to be defibrillated when electrocautery is being used.\textsuperscript{9} As such, implantable cardiac defibrillators should be temporarily deactivated and external defibrillation pads used during the procedure and until the device has been reassessed postoperatively.\textsuperscript{8,12}

If an abnormal or non–life-sustaining cardiac rhythm occurs—whether by interference or as an underlying issue—standard advanced cardiac life support protocols should be used with the exception of performing cardiopulmonary resuscitation. Chest compressions are never performed on a patient with a VAD because the force may dislodge a cannula or the VAD itself, resulting in exsanguination and immediate death.\textsuperscript{8}

Laparoscopic surgery provides another unique risk; rapid insufflation with carbon dioxide may stimulate the vagus nerve due to fast peritoneal distension, leading to sinus bradycardia, asystole, and other major arrhythmias.\textsuperscript{20} Therefore, vigilance for these arrhythmias and slower insufflation times will assist in decreasing vagal nerve stimulation.

Third, hemodynamic stability is important when caring for a patient with a VAD because the pump function depends on preload and afterload. When preload decreases, there will be a decrease in pump flow. For example, changes in body position (such as to the lateral decubitus), inadequate administration of intravenous fluids, or major blood loss will cause a decrease in venous return and, therefore, pump flow. Avoiding hypovolemia is essential in all cases in which the patient has a VAD. In patients who are hypotensive, low-dose vasopressin is preferred over norepinephrine due to its minimal influence on pulmonary vascular resistance.\textsuperscript{12}

In addition to a strong preload dependence, patients with VADs are also sensitive to afterload. If a patient becomes hypertensive, the emptying of the VAD will decrease. In turn, by slowing the emptying time, blood can pool and result in an increased risk of forming thrombi even if the patient is adequately anticoagulated.\textsuperscript{9}

Fourth, as discussed previously, it is crucial to obtain laboratory values for coagulation status. This should include an assessment of platelet count, international normalized ratio, and partial thromboplastin time. Anticoagulation therapy, although necessary in this population, has been associated with bleeding in up to 50% of patients with VADs undergoing surgery.\textsuperscript{2} For surgery, oral anticoagulation should be changed to intravenous heparin in semi-elective cases.\textsuperscript{12} Because of the risk of thromboembolism, full reversal of anticoagulation (using fresh frozen plasma...
or not giving anticoagulation medications) is reasonable only with the newer, second-generation devices. Most patients with VADs are not candidates for neuraxial anesthesia because of their anticoagulation status and the potential for bleeding complications. However, the use of a peripheral regional anesthetic, such as a Bier block, can be performed in willing candidates. Although a general anesthetic is the most appropriate and safe choice, peripheral regional anesthesia can be considered.

Postoperative Care. Because the most common postoperative complication is bleeding, monitoring hemoglobin levels, platelet counts, and coagulation parameters should be performed routinely. In addition, it is preferable to delay resuming anticoagulation after an elective procedure in patients with VADs because this delay may decrease postoperative bleeding complications. The healthcare team also needs to be astute for any indications of an infection and order the appropriate cultures and antimicrobials accordingly. Last, due to intraoperative fluid shifts, fluid status needs to be monitored carefully to ensure proper intravascular volume. This monitoring should include vital signs, fluid intake and output, and serial clinical assessments.

Summary
Given the technological advances and increasing availability of VADs, it should be anticipated that more patients with VADs will be undergoing noncardiac surgical procedures. Although the currently available VADs differ in their mode of assistance and complexity, anesthetists should be aware of the key preoperative, intraoperative, and postoperative implications to ensure provision of a safe anesthetic. In addition to knowing the type of VAD, it is crucial to communicate with all members of the care team to gain as much information as possible. In the operating room, an understanding of the surgical procedure and equipment being used and vigilance in monitoring hemodynamics is essential. With proper knowledge and adequate preoperative preparation and intraoperative care, anesthetists should be able to achieve safe and successful anesthesia outcomes.

REFERENCES

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