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Review

Medical Management of Left Ventricular Assist Device Patients: A Practical Guide for the Nonexpert Clinician

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ABSTRACT

Left ventricular assist devices (LVADs) provide short- or long-term circulatory support to improve survival and reduce morbidity in selected patients with advanced heart failure. LVADs are being used increasingly and now have expanded indications. Health care providers across specialties will therefore not only encounter LVAD patients but play an integral role in their care. To accomplish that, they need to understand the elements of LVAD function, physiology and clinical use. This article provides a concise overview of the medical management of LVAD patients for nonexpert clinicians. Our presentation includes the basics of LVAD physiology, design, and operation, patient selection and assessment, medical management, adverse event identification and management, multidisciplinary care, and management of special circumstances, such as noncardiac surgery, cardiac arrest, and end-of-life care. The clinical examination of LVAD patients is unique in terms of

RÉSUMÉ

Les dispositifs d'assistance ventriculaire gauche (DAVG) permettent d'offrir à certains patients atteints d'une insuffisance cardiaque avancée une assistance circulatoire à court ou à long terme afin d'améliorer la survie et de réduire la morbidité. Les DAVG sont de plus en plus souvent utilisés et sont maintenant indiqués dans un plus grand nombre de cas. Les dispensateurs de soins de santé de différentes spécialités seront donc appelés non seulement à traiter des patients porteurs d'un DAVG, mais aussi à jouer un rôle de premier plan dans les soins qui leur sont prodigués. Pour bien jouer ce rôle, ils doivent comprendre les différents aspects de la fonction, de la physiologie et de l'utilisation clinique des DAVG. Nous présentons donc un aperçu de la prise en charge médicale des patients porteurs d'un DAVG à l'intention des cliniciens non experts. Nous abordons notamment les notions fondamentales de la physiologie, de la conception et du fonctionnement des DAVG, de la sélection et de

Overview

Left ventricular assist devices (LVADs) improve survival and reduce morbidity in selected patients with advanced heart failure.[1-3] LVADs are increasingly used and have been implanted in more than 16,500 patients worldwide.[4] Current-generation continuous-flow devices are associated with 1-year and 2-year survival rates of 80% and 70%, respectively.[5] Although survival remains lower than with heart transplantation,[4] LVADs play an important role as a short-term (bridge) strategy to support a patient with heart failure. Expanded indications for LVADs as a lifelong (destination) strategy were recently approved in some Canadian jurisdictions based on a health economics analysis.[6,7] With the increasing prevalence of LVADs, clinicians across many specialties will encounter these patients and must develop comfort in their care. We here present a practical guide to clinicians for the long-term care of LVAD patients.

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See page 213 for disclosure information.

LVAD system overview

Three durable LVADs are approved for use in Canada: Heartmate II (St Jude Medical, St Paul, MN), Heartmate 3 (St Jude Medical), and Heartware HVAD (Heartware, Framingham, MA). The basic components are: 1) an inflow cannula which serves as a conduit for blood from the LV to the pump; 2) a pump with an impeller that delivers continuous blood flow; 3) an outflow graft which serves as a conduit for blood from the pump to the aorta; and 4) a tunnelled driveline that connects the pump to an external controller. Two power cables connect the external controller to a power source (battery or alternating current). The device will still function if only 1 power cable is connected but will alert the patient to connect a second power source. A manufacturer-specific programmer is required to interrogate, troubleshoot, or reprogram the device. Additional peripherals may include a charger, additional batteries, and a backup controller. All external components should be regularly maintained.

LVAD operating parameters

There are 4 major operating parameters of an LVAD: pump speed (rpm), power (W), flow (L/min), and pulsatility (pulsatility index or peak-to-trough flow speed; Table 1).[8] The

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blood pressure and heart rate assessment, LVAD "hum" auscultation, driveline and insertion site inspection, and device parameter recording. Important potential device-related adverse events include stroke, gastrointestinal bleeding, hematologic disorders, device infection, LVAD dysfunction, arrhythmias, and heart failure. Special considerations include the approach to the unconscious or pulseless patient, noncardiac surgery, and palliative care. An understanding of the principles presented in this paper will enable the nonexpert clinician to be effective in collaborating with an LVAD center in the assessment, medical management, and follow-up of LVAD patients. Future opportunities and challenges include the improvement of device designs, greater application of minimally invasive surgical implantation techniques, and management of health economics in cost-constrained systems like those of Canada and many other jurisdictions.

l'évaluation des patients, de la prise en charge médicale, de la détection et de la prise en charge des événements indésirables, des soins multidisciplinaires et de la prise en charge des cas particuliers, par exemple lorsqu'un patient doit subir une intervention chirurgicale non cardiaque, subit un arrêt cardiaque ou reçoit des soins de fin de vie. L'examen clinique des patients porteurs d'un DAVG présente des particularités à différents égards : mesure de la pression artérielle et de la fréquence cardiaque, auscultation du bruit du DAVG, inspection du câble percutané et du point d'insertion, et consignation des paramètres du dispositif. Les événements indésirables graves pouvant survenir chez un patient porteur d'un DAVG sont l'accident vasculaire cérébral, l'hémorragie gastro-intestinale, les troubles hématologiques, l'infection du dispositif, le mauvais fonctionnement du DAVG, les arythmies et l'insuffisance cardiaque. Parmi les considérations particulières, citons l'approche à adopter en présence d'un patient inconscient ou sans pouls, les interventions chirurgicales non cardiaques et les soins palliatifs. Le clinicien non expert qui comprend bien les principes présentés dans le présent article pourra collaborer efficacement avec un centre spécialisé dans les DAVG pour l'évaluation, la prise en charge médicale et le suivi des patients porteurs d'un DAVG. Les possibilités à exploiter et les défis à relever comprennent l'amélioration de la conception des dispositifs, l'adoption élargie de techniques chirurgicales d'implantation minimalement invasives et la gestion des paramètres de l'économie de la santé dans des systèmes où les budgets sont limités, comme c'est le cas au Canada et dans de nombreux autres pays.

pump speed determines the speed of the impeller pump and is the fundamental parameter than can be altered. Power output is modulated and measured by the system controller to achieve the set pump speed. Flow is an estimated value based on the pump speed and power output and can be inaccurate in altered physiologic states. Pulsatility is a measure of temporal power fluctuation and is expressed as pulsatility index by Heartmate devices and as peak-to-trough flow speed by the HVAD.

Device-specific considerations

There are key differences between the 3 approved durable continuous-flow LVADs. The Heartmate II pump generates axial flow and is larger, necessitating a preperitoneal pocket. The HVAD and Heartmate 3 devices are centrifugal pumps and can be implanted intrapericardially through a less invasive approach owing to their smaller profile. Centrifugal pumps are more sensitive to preload and afterload and therefore require tight blood pressure control. Centrifugal pumps provide automatic pump speed modulation, through proprietary algorithms (ie, Lavare Cycle in the HVAD and Artificial Pulse in the Heartmate 3), which consists of rapid slowing and acceleration of pump speeds. This is intended to enhance washing of the pump and allow for possible aortic valve opening to reduce vascular and thrombotic complications.[9,10]

Table 1. Operating parameters of the 3 durable left ventricular assist devices approved for use in Canada

Parameter	Heartmate II	Heartmate 3	HVAD
Typical speed, rpm	8000-10,000	5000-6000	2400-3200
Flow, L/min	4-7	4-6	4-6
Power, W	5-8	4.5-6.5	3-7
Pulsatility index	5-8	3.5-5.5	N/A
Peak to trough	N/A	N/A	2-4 L/min/beat

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LVAD physiology

The aberrant physiology of continuous-flow LVADs primarily relates to a lack or near lack of pulsatility and explains the nuances of patient care and adverse events. The arterial waveform is a reflection of loading conditions, aortic valve function, and the relative contributions of the LVAD and left ventricle (LV) to circulatory flow. Continuous-flow LVADs continuously move blood from the LV to the aorta, albeit not at a constant rate. LVAD pump flow is affected by loading conditions: Compared with the LV, continuous-flow LVADs are ~ 3-4 times more sensitive to afterload and 3 times less sensitive to preload.[11-13] The LVAD and LV can be thought of as competing for preload and in their contribution to circulatory flow. This relationship is routinely demonstrated during hemodynamic ramp studies by changing LVAD pump speed. As LVAD pump speed and flow increase, diastolic blood pressure increases while systolic blood pressure remains relatively constant, leading to an overall reduction in pulse pressure.[14] In addition, increased LVAD flows reduce LV volume and preload, resulting in reduced LV contractility and intrinsic stroke volume.[13] With increasing LVAD support, LV contractility may decrease to the point where LV systolic pressure does not exceed aortic pressure, resulting in an absence of aortic valve opening. Conversely, if LVAD support is reduced, LV preload, pressure, and intrinsic stroke volume will increase while diastolic blood pressure will decrease, resulting in increased pulsatility. LVAD patients may

therefore lack pulsatile circulation, which confounds their clinical exam and predisposes them to adverse events. In such patients, measurement of blood pressure by means of an oscillometric or auscultatory blood pressure cuff is problematic. Doppler blood pressure is the preferred method, with the assumption that it represents the mean arterial pressure. The clinician must be mindful that in a patient with pulsatile circulation, the Doppler blood pressure represents systolic blood pressure and is increasingly inaccurate with increasing pulsatility.

Selection of an LVAD Patient

There are no universally accepted patient criteria for LVAD implantation.[15,16] Canadian guidelines recommend consideration for advanced heart failure strategies in patients who, despite optimal treatment, continue to exhibit progressive or persistent New York Heart Association (NYHA) functional class III or IV heart failure symptoms accompanied by at least 1 finding of advanced heart failure (Table 2).[16] We recommend referral of such patients to a multidisciplinary advanced heart failure clinic to determine the best advanced heart failure strategy, which may include cardiac transplantation, mechanical circulatory support (MCS), or palliative care.

In those who receive an LVAD, the implant strategy is determined by their eligibility for heart transplantation (Fig. 1). Bridging strategies are used for current or potential candidates for transplantation. A bridge-to-transplant (BTT) strategy is used in a patient actively listed for heart transplantation to improve survival, reduce symptoms, and improve organ function while awaiting a suitable donor heart. A bridge-to-candidacy (BTC) strategy provides the opportunity to resolve medical, social, or financial barriers to transplantation in a patient who would otherwise be eligible, and a bridge-to-decision (BTD) strategy provides additional time to assess the transplant candidacy of a patient. A bridge-to-recovery (BTR) strategy allows time for myocardial recovery and subsequent LVAD explantation. Destination therapy (DT) is for patients who are not qualified for heart transplantation but require lifelong circulatory support. DT is now funded in parts of Canada as an up-front strategy for LVAD patients.[6] The specific LVAD strategy may evolve over time with changes in a patient's clinical status. For example, a BTT-LVAD patient who develops a debilitating stroke may change to a DT strategy. Conversely, a BTT-LVAD patient who achieves myocardial recovery may change to a BTR strategy followed by LVAD explantation.

Table 2. Indication for advanced heart failure therapies assessment

Advanced heart failure despite optimal medical treatment with persistent New York Heart Association functional class III or IV symptoms and at least one of:

- Left ventricular ejection fraction < 25%
- Peak exercise oxygen consumption < 14 mL/kg/min (or < 50% predicted)
- Progressive organ dysfunction due to hypoperfusion, not inadequate filling pressures
- Recurrent heart failure hospitalizations not due to a clearly reversible cause
- Diuretic refractoriness associated with worsening renal function
- Inotropic support required for symptoms or end organ function
- Worsening right heart failure and post-capillary pulmonary hypertension
- 6-minute walk test distance < 300 m
- 1-year mortality > 20%-25% predicted by heart failure risk scores
- Progressive renal or hepatic dysfunction
- Persistent hyponatremia (< 134 mEq/L)
- Cardiac cachexia
- Inability to perform activities of daily living

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Assessment of an LVAD Patient

We describe the basic assessment of an LVAD patient and provide a checklist for future reference in Table 3.

History and physical assessment

A focused history relating to the LVAD and its complications should be obtained in all patients with an LVAD, regardless of their presenting issue. The history should include symptoms of heart failure, infection, neurologic events, exercise intolerance, hemolysis (dark urine), bleeding, medication adherence, tolerability, and adverse effects, and device parameters and alarms, if present. Quality of life may be assessed with the use of questionnaires at regular intervals.

The clinical examination of a patient with an LVAD is unique in the method of blood pressure assessment (ie, sometimes using Doppler ultrasound probe on the brachial artery and a sphygmomanometer), heart rate assessment (by means of electrocardiography or, in HVAD patients, the device waveform), auscultation of the LVAD "hum," inspection of the driveline and its insertion site, and recording of device parameters.

Device interrogation

Device interrogation should include assessment of pump speed, power, flow, and alarms (Table 4). The pulsatility index of Heartmate devices and flow range of HVAD devices should be examined. The LVAD team should be involved for alarm troubleshooting (eg, low flow alarms) and device parameter changes.

Laboratory and imaging testing

Routine laboratory assessment includes hematology and electrolyte profiles, renal function, coagulation parameters, liver enzymes, and B-type natriuretic peptide. Screening for hemolysis is performed with the use of plasma-free hemoglobin or lactate dehydrogenase (LDH). An LDH level significantly above the patient's baseline or 2.5 times the upper limit of normal should raise suspicion of hemolysis and prompt consultation with an LVAD center.[18] Electrocardiography should be used to determine the rhythm at each clinic visit if there are concerns of arrhythmia. Cardiopulmonary exercise testing can be used to evaluate functional capacity. Chest radiography is used to evaluate the pump position and proximal driveline with the use of modified anterior-posterior and lateral views. Transthoracic echocardiography can be used to assess ventricular function, ventricular unloading, valvular function (eg, aortic valve opening), and the inflow and outflow. Guidelines for the use of echocardiography in the assessment of LVAD patients are available from the American Society of Echocardiography.[19] Contrast-enhanced gated computed tomographic (CT) scans can be used to assess LVAD components outside of the metallic pump enclosure,

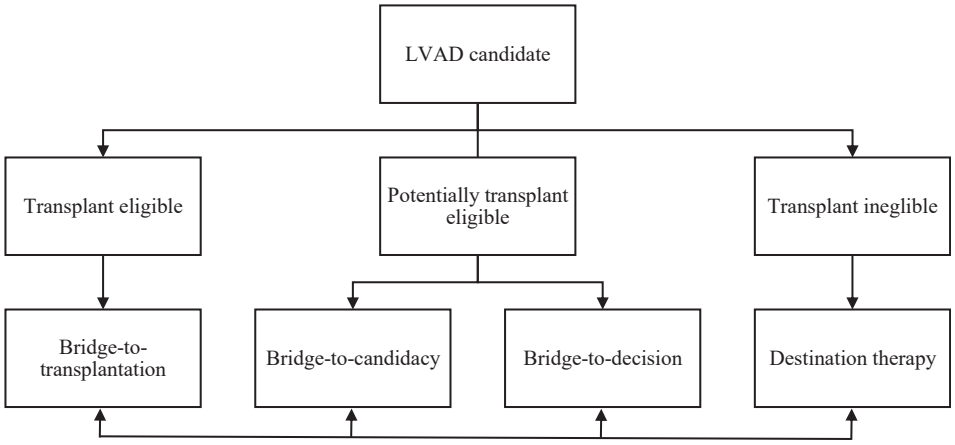

Figure 1. Left ventricular assist device implantation strategies are based on recipient transplant eligibility and may evolve based on changes in the patient's clinical status.

such as outflow cannula positioning and patency.[20] If infection is suspected, microbiologic samples may be obtained from the driveline site, urine, sputum, and blood. Additional imaging with the use of ultrasonography, transesophageal echocardiography, CT, or nuclear imaging is useful in selected cases to identify the source of infections.

Outpatient Care of an LVAD Patient

Antithrombotic therapy

Antithrombotic therapy is necessary to prevent thrombotic complications of an LVAD and must be balanced against the bleeding risk of the patient. Aspirin is used daily in combination with warfarin to maintain the international normalized ratio (INR) within a device-specific range (usually 2.0-3.0 for the devices being discussed here).[21] Direct oral anticoagulants have not been adequately studied in this population and should not be used.[21,22]

Medical therapy

Heart failure medications may be started on most LVAD patients. Diuretics are useful to manage volume overload. Antiarrhythmics can reduce the burden of atrial and ventricular arrhythmias. Neurohormonal therapy with beta-blockers, angiotensin-converting enzyme inhibitors/angiotensin receptor blockers, and mineralocorticoid receptor antagonists should be considered.[21,22] However, the efficacy of these evidence-based heart failure therapies as BTR is unknown.[21]

Risk factor modification

Blood pressure control is necessary to maximize LVAD output and ensure adequate LV decompression. Preexisting hypertension may return after a patient's heart failure improves with an LVAD. This is problematic, because continuous-flow LVADs are afterload dependent such that for a given pump speed the LVAD output is reduced with higher blood pressures. Blood pressure control is also associated with a reduced risk of stroke in HVAD patients.[23] International guidelines recommended a target Doppler mean blood pressure of $\leq$ 80 mm Hg in LVAD patients.[21] We recommend intensive modification of standard cardiovascular risk factors, which is outlined elsewhere.[24] This is particularly important for BTT-LVAD patients, because uncontrolled cardiovascular risk factors, such as morbid obesity and diabetes with end-organ damage, may contraindicate transplantation.[25]

Cardiac rehabilitation

Cardiac rehabilitation in LVAD patients is both safe and effective in improving quality of life and functional ability.[26,27] All capable patients should be enrolled in cardiac rehabilitation after LVAD implantation.[21]

Adverse Events

Major adverse effects continue to limit the long-term success of durable LVADs. At 1 year, $\sim$ 56% of patients with LVADs are "living well," defined as freedom from death, stroke, bleeding requiring reoperation, pump exchange, RV mechanical support, and device-related infection. The following complications should be considered during any LVAD patient encounter, and should always be managed in close collaboration with the LVAD team.

Ischemic and hemorrhagic strokes

Stroke is the major cause of death between 6 and 24 months after LVAD implantation and occurs at a rate of 8.7% per year.[5,28] Ischemic strokes may result from embolic sources on the aortic valve, pump, inflow cannula, and outflow graft.[29] Hemorrhagic strokes may occur secondary to coagulopathy, hypertension, endocarditis, or hemorrhagic conversion of ischemic strokes.[29] The centrifugal HVAD device showed equivalent stroke rates compared with the axial Heartmate II as long as blood pressure is controlled.[23] The newer Heartmate 3 resulted in a lower stroke rate (9.9% vs 19.4% at 2 years) compared with the Heartmate II.[3]

Gastrointestinal bleeding

Gastrointestinal bleeding is a common and potentially severe adverse event in LVAD patients and occurs with a frequency of 0.31-0.56 events per patient-year.[3,30] Causes of bleeding include 1) antithrombotic therapy, 2) acquired

Table 3. Left ventricular assist device (LVAD) patient evaluation checklist

Category	Assessment
History	Symptom (heart failure, infection, bleeding, stroke, hemolysis)
	Medication adherence, tolerability, and adverse effects
	Quality of life, caregiver stress/burnout
Examination	LVAD exam: • Doppler blood pressure • LVAD "hum" • Heart rate (via electrocardiography) • Driveline inspection • Standard physical exam
Device	Parameters (pump speed, flow, power, pulsatility, alarms)
	Equipment inspection (damage, connections, battery health)
Investigations	Blood work (CBC, chemistries, BNP, INR, LDH)
	Urine analysis
	Electrocardiography
	Chest x-ray
	Pacemaker/ICD interrogation
	Microbiology samples (if infection suspected)
	Advanced imaging (if device complication suspected)
Medication review	Antithrombotic therapy: • Aspirin • Vitamin K antagonist (INR range 2-3)
	Antihypertensives (target Doppler blood pressure $\leq$ 80 mm Hg)
	Heart failure medications
	Antiarrhythmics
Complications	Device malfunction
	Heart failure
	Arrhythmia
	Infection
	Bleeding
	Hypertension (blood pressure $>$ 80 mm Hg)
Follow-up plan	Notify primary care provider and LVAD team
	Prescriptions, laboratory requisitions, follow-up appointments

BNP, B-type natriuretic peptide; CBC, complete blood count; ICD, implantable cardioverter-defibrillator; INR, international normalized ratio; LDH, lactate dehydrogenase.

coagulopathy, and 3) the development of angiodysplasia, which may be related to elevated levels of circulating angiogenic mediators.[31] LVAD design may affect gastrointestinal bleeding risk. There was no difference in gastrointestinal bleeding between the HVAD and the Heartmate II,[30] whereas the Heartmate 3 resulted in a lower incidence of gastrointestinal bleeding (24.5% vs 30.9% at 2 years) compared with the Heartmate II.

Most clinically significant gastrointestinal bleeding can be managed conservatively in consultation with gastroenterology.[21] Endoscopic evaluation is recommended for first and repeated episodes of gastrointestinal bleeding.[21] In cases where a source is not identified, investigation of the small bowel may be considered.[21] The LVAD team should be contacted, if possible, before withholding or reversing antithrombotic therapy.

Hematologic disorders

Continuous-flow LVADs result in blood flow rheology that induces a number of hematologic effects due to shear stress.[32] This results in a low-grade hemolysis and an acquired coagulopathy related to acquired von Willebrand syndrome, platelet dysfunction, and fibrinolysis.[32]

Acquired von Willebrand syndrome is the main bleeding risk factor in LVAD patients. Von Willebrand factor (VWF) circulates in the blood as the largest soluble protein and exists as a high-molecular-weight multimer of identical subunits.[33] Shear stress causes proteolysis and a measurable reduction of VWF multimers, resulting in acquired von Willebrand syndrome and platelet dysfunction.[34–36] The magnitude of VWF reduction is typically modulated by pulsatility, which is a trigger for compensatory endothelial release of VWF and absent in most LVAD patients.[37] The resultant bleeding syndrome is similar to Heyde syndrome in aortic stenosis, which also involves shear stress, low pulse pressure, angiodysplasia, and bleeding.[38] There is near immediate and complete recovery of acquired von Willebrand syndrome after LVAD explantation.[39]

Increased fibrinolysis and endothelial dysfunction are present in LVAD patients at baseline due to longstanding heart failure.[40,41] Fibrinolytic responses initially increase after LVAD implantation and then gradually normalize by 12 months.[41]

The bleeding risk associated with LVAD-related acquired von Willebrand syndrome, platelet dysfunction, and fibrinolysis is compounded by required antithrombotic therapy using antiplatelets and vitamin K antagonists.

LVAD malfunction

LVADs may develop electrical and mechanical malfunctions. Electrical malfunction typically presents with alarms and should be managed by stabilizing the patient, ensuring device connections, and reviewing the alarms. Mechanical malfunction may be intrinsic or extrinsic to the LVAD and can present with hemolysis, heart failure, or abnormal LVAD parameters. Intrinsic mechanical pump failure is rare. Extrinsic mechanical pump malfunction typically results from LVAD thrombosis.

LVAD thrombosis may occur on the inflow cannula, pump, or outflow graft. The presentation of LVAD thrombosis varies from asymptomatic hemolysis, to changes in pump parameters (ie, power or flow), to biventricular failure and cardiogenic shock. Suspected LVAD thrombosis should be quickly investigated by means of biochemical and imaging studies. Treatment varies from adjusting antithrombotic therapy to thrombolysis or emergent surgical pump replacement. The LVAD team should be involved in all cases of suspected pump thrombosis.

There are device-specific differences in rates of LVAD thrombosis. Whereas the HVAD showed no difference in pump thrombosis compared with the Heartmate II,[30] the Heartmate 3 was associated with a lower rate of suspected or

Table 4. Assessment and management of left ventricular assist device (LVAD) alarms

Potential cause	Advisory (noncritical)	Critical
Power	Power source disconnect	Driveline disconnect
	Lower battery power	Depleted batteries
	System controller internal battery depleted	Power module disconnect (if not connected to batteries)
Hardware	System-controlled dysfunction	Pump stoppage (failure)
	Lead fracture	System-controlled malfunction
Low flow	Low flow and/or suction event:	Extremely low flow:
	• Speed too high or low	• Speed too high or low
	• Hypovolemia	• Hypovolemia
	• RV dysfunction	• RV dysfunction
	• Tamponade	• Tamponade
	• Hypertension	• Hypertension
	• Inflow/outflow obstruction	• Inflow/outflow obstruction
	• Arrhythmia	• Arrhythmia
High power	Increased power:	
	• Thrombus	
	• Hypertension	
	• Electric fault	
Evaluation	Call LVAD team	Call LVAD team
	Assess within 24 hours	Immediate evaluation
	Auscultate device	Auscultate device
	Doppler blood pressure	Doppler blood pressure
	INR/PT, PTT	INR/PT, PTT
	LDH	LDH
	ECG	ECG
	CT/CXR to assess cannula/device positioning	Inspect driveline and power cable connections
	Inspect power cable connections	Pulmonary artery catheterization
Management options	Replace batteries or connect to power module	Replace batteries or connect to power module
	Intravenous fluids	Exchange system controller
	Inotropes	ACLS (when appropriate)
	Exchange system controller	Treatment for cardiogenic shock
	Hypertension control	
	Anticoagulation/thrombolysis	

ACLS, advanced cardiac life support; CT, computed tomography (CT); CXR, chest x-ray; LV, left ventricle; RV, right ventricle; INR, international normalized ratio; PT, partial thromboplastin; PT, partial thromboplastin time; LDH, lactate dehydrogenase; ECG, electrocardiography.

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confirmed pump thrombosis (1.4% vs 13.9% at 2 years) compared with the Heartmate II.[3] The Heartmate 3 uses an "artificial pulse" by changing the rotor speed every 2 seconds to reduce zones of recirculation and stasis.[42]

Device infections

Infection is the second-most frequent adverse event (after bleeding) in the first 3 months after implantation and the most frequent adverse event thereafter.[5] Driveline infections are the most common (85%) and are frequently associated with invasive infections.[43]

LVAD patients are educated on strategies to minimize risk of infection, including minimizing driveline movement and trauma, regular dressing changes, and driveline site surveillance.

The evaluation of an LVAD infection includes driveline cultures, blood cultures, and imaging with the use of ultrasound or CT. The most common pathogens are skin organisms. International guidelines for the management of infections in LVAD patient are available.[21]

Arrhythmia

Atrial and ventricular arrhythmias are commonly observed in LVAD patients, and their impact on outcomes is not well defined. Ventricular arrhythmias generally require antiarrhythmic or antitachycardia therapies. Canadian and American guidelines suggest consideration of implantable cardioverter-defibrillator (ICD) implantation in LVAD patients, but noting the lack of evidence to support a mortality benefit.[44,45] If an ICD is implanted, a conservative programming strategy is recommended to minimize ICD shocks, given that sustained ventricular arrhythmias are often well tolerated in LVAD patients.[44]

Heart failure

Heart failure in LVAD patients often results from RV-LVAD interactions and is associated with worse outcomes.[46–52] Before LVAD implantation, LV failure limits RV preload and increases RV afterload. LVADs improve RV function by decompressing the LV, which in turn leads to a reduction of pulmonary vascular resistance. However, the LVAD may also impose deleterious effects on the RV. RV volume loading may unmask occult RV failure, increase tricuspid annular dilation, and worsen tricuspid regurgitation. LV decompression leads to a leftward shift of the interventricular septum, which may decrease septal contribution to RV contraction and impair myocardial mechanics.[53,54] RV failure may be exacerbated by atrial and ventricular arrhythmias, which are common after LVAD implantation.[55,56] Heart failure may result also from aortic regurgitation, which commonly results from commissural fusion or trauma.[57,58] The regurgitant fraction is disproportionately

high relative to the valvular defect because regurgitation is continuous throughout the cardiac cycle.

Decompensated heart failure in an LVAD patient should be approached by the predominant phenotype. Isolated left-side heart failure should prompt the clinician to exclude pump malfunction or valvular regurgitation, treat hypertension if present, consider augmenting cardiac output with inotropes or increasing LVAD pump speed, and consider diuresis. Biventricular heart failure should prompt the same considerations with a greater emphasis on diuresis. Isolated right-side heart failure requires a careful assessment of RV function and hemodynamics, often with the use of echocardiography, with consideration for diuresis, inotropes, vasodilators, additional MCS, and palliative care.

The LVAD Team

The LVAD patient and their support person(s) have the most important role in the LVAD team. They require engagement, education, and support from the LVAD team to have the resources and capacity to manage the complexities of LVAD care. The LVAD team consists of specialized medical, surgical, and allied health professionals. Physician specialists include cardiac surgeons and cardiologists with expertise in advanced heart failure along with ancillary subspecialties such as psychiatry, palliative care, and others as required. Allied health specialists include nurses, social workers, psychologists, pharmacists, dieticians, physical therapists, occupational therapists, and rehabilitation services. The LVAD coordinator oversees all aspects of LVAD patient care and commonly acts as the central liaison person. LVAD patients can provide the contact information of their LVAD program or coordinator to a requesting physician. They may also have access to 24/7 LVAD support telephone lines, which may be useful to a consulting clinician.

Transitions Between Hospital and Home

Before discharge, LVAD patients and their support person(s) require training in LVAD care. This includes the daily management of LVADs, alarm management, battery changes, system controller changes, and an understanding of when to seek medical attention. Pharmacy-led teaching on the proper use of medications, particularly antithrombotic therapy, is imperative. Postoperative and cardiovascular rehabilitation should be completed as either inpatient or outpatient, depending on local resources. When ready, the LVAD patient may transfer to the local outpatient setting for 6-12 weeks (depending on program requirements) before returning to their home locale.

LVAD patients often report an improvement in symptoms of heart failure shortly after surgery, whereas symptoms of chronic illness, such as deconditioning and malnourishment, take longer to resolve. Early and intensive cardiac rehabilitation is recommended.[59,60] LVAD patients can gradually return to most of their activities of living. Some activities are possible with modification, whereas others are prohibited. For example, showering is possible with the use of accessories to protect the device, whereas activities that involve submerging the device, such as taking a bath or swimming, are prohibited. The physical demands of returning to work, strenuous exercise, and sexual intimacy may also be prohibitive.[60,61] We work with LVAD patients to enable activities of special significance. For example, driving may promote independence, enable social interactions, and reduce caregiver burnout. The ability to drive is patient specific and dependent on local laws. Canadian recommendations permit private driving for continuous-flow LVAD patients with NYHA functional class I-III symptoms who remain stable 2 months after LVAD implantation, whereas commercial driving is prohibited for all LVAD patients.[62] Return to daily activities such as these offers a sense of normalcy to patients and contributes to an improved quality of life.[32]

Transitions to hospital may occur for LVAD-related or non−LVAD-related issues on either elective or nonelective bases. Regardless of the indication for hospitalization, we recommend a systematic approach to the evaluation of an LVAD patient and early notification of the LVAD team (Table 3).

Special Considerations

Unconsciousness or cardiac arrest

In an unconscious LVAD patient, it can be difficult to determine if altered mental status is due to hypoperfusion or a neurologic event such as stroke.

A conscious LVAD patient typically has no palpable pulse because the device provides continuous nonpulsatile systemic flow. Vital signs such as noninvasive blood pressure and oxygen saturation may be hard to obtain, and heart sounds will be replaced by an LVAD "hum." Although standard advanced cardiac life support algorithms rely on the presence or absence of a pulse to guide therapy, the lack of a pulse in LVAD patients is common and cannot be used to infer that the patient is in a low-perfusion state or cardiac arrest.

There is debate as to whether cardiopulmonary resuscitation (CPR) is safe and effective in LVAD patients. Although manufacturers have warned against external compressions owing to the risk of damage to the outflow graft or inflow cannula,[42] CPR has been safely administered to LVAD patients.[63] A number of protocols for approaching the unresponsive LVAD patient have been published.[64,65]

If an unconscious LVAD patient is encountered by trained health personnel, we agree with recommendations for a rapid assessment of signs of life and LVAD functioning before initiating chest compressions (Fig. 2).[64] This includes signs of peripheral perfusion (skin colour, temperature, capillary refill), Doppler blood pressure, and (if intubated) partial pressure of end-tidal carbon dioxide. LVAD function should be assessed by listening for an LVAD "hum" and identifying any alarms. If the LVAD is not functioning, the driveline, power source, and system controller should be troubleshot. If LVAD function is not restored, CPR is recommended and the LVAD team should be immediately notified.

If an unconscious LVAD patient without any signs of life is encountered by an untrained bystander, CPR should be immediately performed.[64] The LVAD team should also be immediately notified and the patient should be transferred to an LVAD center if possible.

Noncardiac surgery

Noncardiac surgery in an LVAD patient should be planned in collaboration with the LVAD team. Perioperative planning

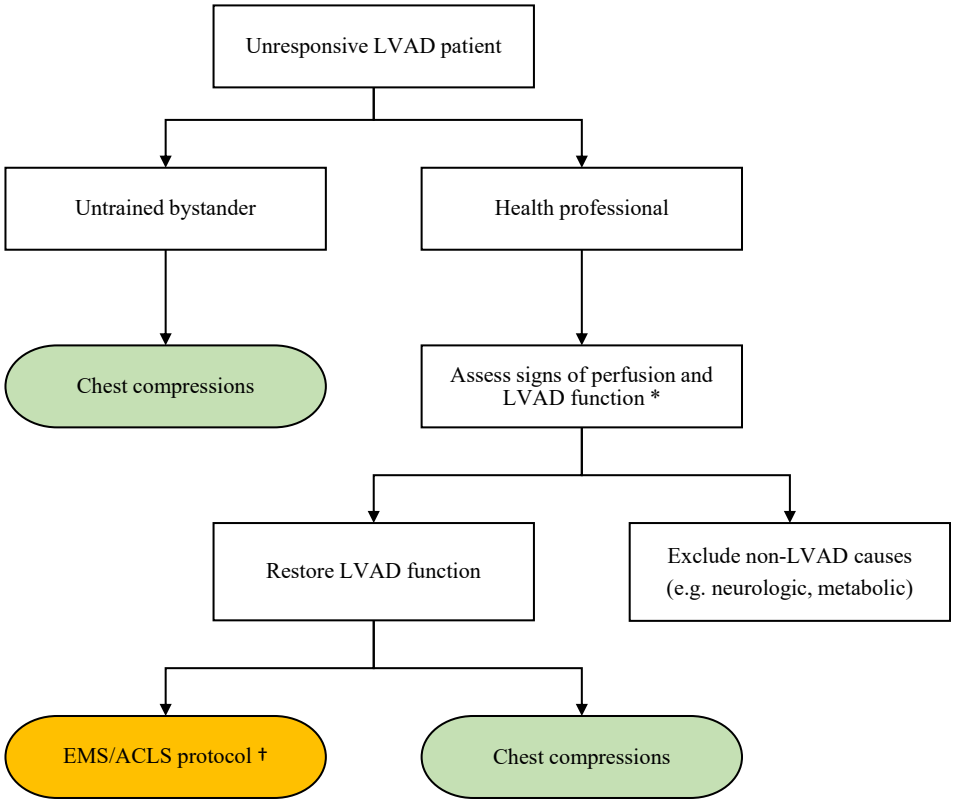

Figure 2. Algorithm for the management of an unresponsive left ventricular assist device (LVAD) patient. ACLS, advanced cardiac life support; EMS, emergency medical services. *Doppler blood pressure, skin temperature and colour, capillary refill, auscultation of LVAD hum, and identification of LVAD alarms may be assessed. †End-tidal CO_2 > 20 mm Hg or blood pressure via Doppler or arterial line, if available, to be used as signs of adequate circulation. Modified from Peberdy et al.[64] with permission from American Heart Association.

may include bridging anticoagulation, infection prophylaxis, device programming and monitoring, defibrillator reprogramming, and consultation with cardiac surgery and cardiac anaesthesia.

LVAD parameters should be continuously monitored by trained personnel, such as an LVAD nurse or perfusionist.[21] Blood pressure monitoring by means of Doppler is appropriate during minor procedures, but during procedures with a risk of hemodynamic instability, an arterial line should be placed and a central venous catheter considered.[21] If the procedure is in close proximity to components of the LVAD, a cardiac surgeon should be immediately available.[21] A cardiac anaesthetist may be required during procedures with hemodynamic instability owing to the unique considerations of preload, afterload, and vasodilation in LVAD patients.

Bleeding is the most common surgical complication in LVAD patients. Blood transfusions are associated with poorer outcomes and may result in allosensitization of the patient. Hemodynamically significant fluid shifts may affect LVAD preload and afterload, and consequently function. Surgical infections must be prevented given the potentially devastating consequence of an LVAD device infection. Antibiotic prophylaxis for prevention of endocarditis has not been well studied in the LVAD population but may be considered.[21]

Outcomes. Limited data suggest that noncardiac surgery is safe in selected LVAD patients.[66] Importantly, in BTT-LVAD patients, there was no association between elective surgical interventions and a reduced likelihood of heart transplantation.[67] Despite the added complexity, the perioperative risk of an LVAD patient may not preclude necessarily surgical interventions.

Palliative care

Palliative care is recommended for all patients with advanced heart failure with the aims to optimize symptoms, enhance quality of life, and provide support to patients and their caregivers.[68] An understanding of the patient's values and preferences is necessary to determine whether an LVAD will help to achieve their goals. The patient and support person(s) must be willing to adapt to life with an LVAD, be capable of LVAD care, and accept the associated risks. Adverse effects, such as stroke, may impair capacity and require additional caregiver support. Comprehensive patient education is necessary to make an informed decision and may result in improved patient decision quality and fewer LVAD implantations.[69]

In patients who proceed to LVAD implantation, we recommend integration of palliative care with their LVAD care. A preparedness plan is recommended, which includes clear health and quality of life goals, advanced directives for LVAD-specific issues, a designated substitute decision maker, and an end-of-life plan.

As patients approach the end of life, a medically, legally, and ethically permissible decision may be made by a competent patient to withdraw MCS or receive medical assistance in dying (MAID). These scenarios require patient-centered planning and involvement of the LVAD team. Some clinicians conflate LVAD deactivation with assistance in dying owing to the rapidity of death.[70] The cause of death after LVAD deactivation is the underlying heart failure syndrome. From an ethical standpoint, LVAD deactivation is no different than separation from a ventilator, deactivation of an ICD, or withdrawal of pacemaker support. LVAD deactivation should be performed by experienced personnel who can deactivate the device without triggering alarms. Symptoms of a decreased cardiac output should be preempted with palliative medications before device deactivation, because decreased circulation may delay the effect of medications.

MAID is permissible in Canada and now accounts for ~ 1.12% of deaths.[71] The presence of an LVAD does not preclude a patient from MAID.

Future Directions and Challenges

LVAD technology development is progressing toward the ultimate goal of not only obviating the need for heart transplantation, but becoming a widely used treatment for an expanding number of patients with advanced heart failure. Work is underway to miniaturize LVADs,[72] enhance biocompatibility to allow lower-intensity anticoagulation,[73] and develop less invasive surgical approaches.[74] A fully implantable LVAD without the need for a driveline would dramatically reduce device infection and improve quality of life. Combined use of an implantable hemodynamic monitoring device (CardioMEMS; Abbott Laboratories, Chicago, IL) to optimize LVAD performance has been described and is being studied.[75,76] Future implementations may include closed-loop feedback systems using real-time hemodynamic data to allow for automatic modulation of LVAD parameters.

As LVAD technology improves, Canadian health care infrastructure must develop in a hub-and-spoke model to identify potential LVAD candidates and care for an expanding number of LVAD recipients. The cost of the device, surgery, and postsurgical complications would have to be significantly reduced to reach the traditionally held upper threshold of $100,000 incremental cost-effectiveness ratio per quality-adjusted life-year.[7]

Conclusion

LVADs are increasingly used to improve survival and reduce morbidity in selected patients with advanced heart failure. Clinicians will increasingly encounter patients with LVADs and should become familiar with their care. We have provided a practical overview of LVAD patient care to assist during those patient encounters.

Disclosures

The authors have no conflicts of interest to disclose.

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