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Medical Management of Patients With Continuous-Flow Left Ventricular Assist Devices

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Introduction

The worldwide prevalence of patients living with chronic heart failure (HF) continues to rise. In developed countries, HF affects 1–2% of the population [1]. In the United States, current estimates suggest that 5.1 million adults are living with HF [2]. Approximately 5–10 % of these patients have advanced HF [3,4], characterized by persistent symptoms, frequent hospitalizations, and high mortality rates despite optimal medical therapy. Continuous-flow left ventricular assist devices (LVADs) may represent an important therapy for a subset of these patients, either temporarily as a bridge to recovery or transplantation, or as permanent, so-called destination therapy.

Current US Food and Drug Administration (FDA)-approved durable LVADs are internal rotary pumps that unload the left ventricle (LV) in a continuous manner throughout the cardiac cycle. A percutaneous driveline connects the pump to an external controller and a power source. The two currently approved LVADs are the HeartMate II (Thoratec Corporation, Pleasanton, CA) and the HeartWare HVAD (HeartWare International, Inc. Framingham, MA). Durable LVAD therapy that generates continuous blood flow for patients with end-stage cardiomyopathy creates unique medical management issues.

The use of LVADs continues to rise at a rapid pace, given the efficacy and durability of contemporary devices. In the United States alone, over 2,100 LVADs were implanted in 2012 compared to 258 LVADs in 2007 [5]. This rapid upswing was spurred by the FDA approval of the HeartMate II device in 2008 for bridge-to-transplant therapy and in 2010 for

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Conflict of Interest

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Human and Animal Rights and Informed Consent

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destination therapy. The HeartWare HVAD was approved for bridge-to-transplant therapy in 2012. Today, essentially 100 % of destination therapy devices are continuous flow. As such, there is a robust and growing surgical experience with these devices, and survival at one year is 80 % [6•].

Given that both the number of patients with LVADs and the life expectancy of these patients are increasing, an understanding of the medical management of patients with a durable LVAD is a growing need. The medical management of LVAD patients is an area of expertise for advanced HF clinicians, but a general understanding of the initial approach to and stabilization of LVAD patients represents an important skillset for many health care providers, including general cardiologists and emergency medical personnel. The rapidly changing field of the medical management of LVAD patients is based largely on clinical experience and limited published data. In this manuscript, we integrate the available published data on the medical management of LVAD patients with the growing clinical experience in order to inform both the general cardiologist and advanced HF practitioner. The reader may refer to previous reviews that discuss the importance of appropriate selection of patients for LVAD therapy [7, 8•, 9,10].

Perioperative medical management

Preoperative patient optimization

- Medical management of patients with advanced HF begins in the preoperative setting, optimizing patients for surgery in an attempt to minimize intraoperative and postoperative complications. The most common postoperative complications are bleeding, infection, and acute right ventricular (RV) failure.
- Efforts to minimize the risk of bleeding at the time of LVAD implantation typically focus on full reversal of anticoagulation (e.g., warfarin) and washout from antiplatelet agents (i.e., P2Y₁₂ inhibitors) before surgery. In addition, the group at the Texas Heart Institute has evaluated plasma exchange therapy before surgery in an attempt to fully replace clotting factors without excess volume [11]. This promising approach requires further validation prior to broad clinical use.
- Postoperative RV failure is associated with worse long-term outcomes and multiple RV failure prediction risk scores have been published [12–16]. Two frequently cited risk scores are from the University of Michigan [12] and from an analysis of the HeartMate II BTT Trial [13]. The Michigan score utilizes the following variables: vasopressor requirement immediately before LVAD, AST 80 IU/L, total bilirubin 2.0 mg/dL, and creatinine 2.3 mg/dL (or renal replacement therapy). This model demonstrated good discriminatory power, with a *c* statistic of 0.73. However, the majority of patients in this study received pulsatile LVADs and only 14 % received a HeartMate II LVAD. In comparison, analysis of the HeartMate II BTT trial found the following independent preoperative predictors of RV failure: a CVP/PCWP ratio of > 0.63, need for ventilatory support, and a preoperative BUN of > 39 mg/dL (*c* statistic 0.68). Thus, important predictors of RV failure include preoperative hemodynamic status and biochemical markers of passive venous congestion and noncardiac end-organ dysfunction.

- Echocardiographic imaging of the RV can also be incorporated into a global RV failure risk assessment through strain analysis, which appears superior to other standard echocardiographic assessments of RV function. In patients undergoing implantation of either a HeartMate II or HeartWare HVAD at the Cleveland Clinic Foundation, reduced RV free wall peak longitudinal strain was an independent predictor of postoperative RV failure [16]. Combining this echocardiographic assessment with the Michigan score improves the discriminatory power of the model (*c* statistic of 0.77).
- These risk scores remain imperfect, but there are limited alternative therapies for patients who *require* LVAD therapy and are at increased risk of RV failure. As such, RV failure remains a significant complication after LVAD placement, with rates varying between 5 % and 44 %, influenced by differing diagnostic criteria and populations [16].
- As a method to reduce the risk of acute RV failure, some centers (including our own) place special importance on the evaluation and optimization of invasively measured hemodynamics prior to surgery. We believe that optimizing right heart filling pressures is a way to minimize RV load and may decrease the risk of postoperative RV failure. At a minimum, preoperative invasive hemodynamic monitoring can inform decision-making for temporary RV support postoperatively. As may be expected, patient outcomes are improved with planned RV support instead of delayed/emergent upgrade to biventricular support [17].
- Unfortunately, there are limited data on the role of specific medical therapies, including vasodilators, and temporary mechanical support, such as intra-aortic balloon pumps, to optimize patients prior to LVAD surgery.

Postoperative pump speeds

- Pump speeds should be chosen to provide a sufficient level of cardiac output while minimizing the load on the RV. High pump speeds that cause leftward septal shift and subsequent increased tricuspid regurgitation [18] or collapse of the left atrium or ventricle by echocardiography should be avoided. Typical pump speeds are 8,600 to 9,800 rpm for the HeartMate II, and 2400–3200 rpm for the HeartWare HVAD.
- Speed optimization in the early postoperative phase is determined by the interplay between antegrade flow through the LVAD, contractility of the heart, right and left ventricular filling pressures, and ventricular afterload. For example, RV pressure overload, with shift of the interventricular septum to the left may require the following: diuretic therapy, reduction in LVAD speed, and/or correction of systemic vasodilation to optimize LVAD function. As volume status fluctuates, dynamic modifications in the postoperative phase are common. Ideal *chronic* LVAD pump speed settings are not known and are the subject of ongoing investigation (see below).

Optimization of volume status

- Volume overload immediately after surgery is common, due to factors including intraoperative blood products, perioperative fluid shifts, and postoperative RV failure. Patients often need significant diuresis and occasionally need echo-guided pump speed changes or invasive hemodynamics to adjust diuretics and vasoactive medications. This fact also highlights the importance of early mobilization after surgery and aggressive physical therapy, as supported by data for recovery following other major cardiovascular surgeries [19].
- There are observational data that renal failure after LVAD implantation has a strong association with poor short-term and long-term outcomes [20]. The impact of over-diuresis is not known for patients with LVADs, but optimizing fluid status after surgery must be balanced with the trade-off of worsening renal function.
- Common postoperative hemodynamic scenarios and suggested management strategies are listed in Table 1.

Anticoagulation immediately after surgery

- The management of antiplatelet and anticoagulant therapy postoperatively considers the competing risks of bleeding and device thrombosis. A general approach is outlined in recent guidelines [8•] and summarized here.
- After cardiopulmonary bypass, complete reversal of heparin is recommended. Aspirin therapy is typically initiated within the first 24 hours, if possible. Our practice is to start patients with a HeartMate II on aspirin 81 mg daily and patients with a HeartWare HVAD on aspirin 325 mg daily, consistent with manufacturer recommendations [21,22]. Depending on bleeding risk and other indications for anticoagulation, unfractionated heparin is started on postoperative day 1 or 2 with an initial goal partial thromboplastin time (PTT) of 40–60 seconds. By postoperative day 2 or 3, patients are typically receiving therapy with aspirin (81–325 mg), warfarin (goal INR 1.5–2.5 for HeartMate II; goal INR 2.0–3.0 for HeartWare HVAD), and unfractionated heparin (goal PTT 60–80 seconds) or another intravenous anticoagulant in the setting of heparin allergy. The use of novel anticoagulants in LVAD patients has not been rigorously evaluated and has not been adopted by our center.
- Some studies have suggested that perioperative intravenous anticoagulation may not be required, which may allow for reduced bleeding complications [23]. The impact of this strategy on longterm thrombosis risk has not been evaluated and warrants additional investigation.

Preparation for hospital discharge

Device alarm education and home safety evaluation

- While the number of LVAD implants continues to rise at a rapid pace in the United States, most family members, caregivers, and community medical personnel will not be experienced in dealing with LVAD emergencies. We provide education to

patients on device alarms and discuss contingency plans with patients and primary caregivers preoperatively, immediately prior to discharge, and at early follow-up visits. Key aspects of the contingency plans include ensuring uninterrupted electrical access (and where to go during power outages), ensuring access to a working telephone for emergencies, and understanding the limitations of battery life.

- It is also important to consider including local emergency response personnel and local emergency room staff when providing educational materials for patients. The most recent International Society of Heart and Lung Transplantation (ISHLT) Mechanical Circulatory Support Guidelines [8•] have recommendations for these providers and examples of educational materials.

Transition to outpatient care

- For the vast majority of patients, another required part of our discharge process includes an overnight stay in a local hotel before discharge to home. This serves as a pilot trial prior to formal hospital discharge, and helps us identify patient and caregiver questions and concerns prior to returning home. We also encourage patients to have one or two primary caregivers immediately available for the first few weeks after surgery.
- We have formed co-management programs with referral hospitals over an hour from our facility. These facilities either do not have LVAD surgical programs or are in the process of creating one. These partnerships not only provide convenience for patients, but also create regional medical centers with expertise in LVAD care for emergencies.
- Within 6 months of surgery, 60 % of patients enrolled in INTERMACS experience a major adverse event, defined as infection, bleeding, device malfunction, stroke, or death [6•]. While these numbers are anticipated to improve over time, patients need to be prepared for potential complications and indications for rehospitalization. This includes education on a gradual outpatient recovery over months, continued monitoring of fluid status, and recognition of gastrointestinal (GI) bleeding, driveline infections, and the many possible signs and symptoms of hemolysis and pump thrombosis [24].

Driveline management including dressing changes

- In patients with continuous-flow LVADs, bleeding and infections are the most common causes of adverse events [6•]. There is a paucity of data available to understand optimal practices for infection prevention including antibiotic prophylaxis and driveline site care. At our institution, we recommend aggressive interventions for driveline stability early after surgery, in order to reduce the likelihood of the driveline site acting as a portal of entry for infection. Patients are also counseled on daily dressing changes and identifying the signs and symptoms of infection at the driveline exit site. Regardless, data suggest that most driveline infections may be unavoidable [25]. That is, most infections occur as a result of

trauma to the driveline exit site, often from unpredictable events, such as dropping a controller or battery pack, or catching the driveline on a nearby object during movement.

Speed optimization

- Optimal speed settings for LVADs at discharge and for long-term management are not clear. Some practitioners advocate for full LV support, while others advocate partial support. The former strategy minimizes left HF symptoms and perhaps the risk of pump thrombosis and systemic thromboembolism. Putative benefits of partial support include allowing for intermittent aortic valve (AV) opening, which may reduce the risk of GI bleeding [26] and AV insufficiency [27–29]. Lower pump speeds may also reduce the risk of ventricular arrhythmias by minimizing contact of the decompressed LV with the inflow cannula. The most appropriate long-term LVAD settings are likely not a simple recommendation for all patients, and should be considered a dynamic therapy that is dependent on patient-specific variables such as right heart function, tolerance/preference of left HF symptoms, and risk of GI bleeding and AV insufficiency.
- Determining the impact of various flow speeds on resting LV size and performance is routinely assessed by echocardiography prior to discharge from the hospital post-implantation. While there are various center-specific methods to define optimal speed, a recently published protocol is the Columbia Ramp Study [30•]. This protocol assesses blood pressure, heart rate, LV size, frequency of AV opening, severity of AV regurgitation, severity of mitral valve regurgitation, and estimated RV systolic pressure at escalating speeds of the LVAD. The optimal speed was determined to be a setting that allowed intermittent AV opening while maintaining mean arterial blood pressure > 65 mmHg and minimizing mitral valve regurgitation. This study demonstrates the safety and feasibility of this approach, and outlines a diagnostic algorithm for LVAD dysfunction due to suspected thrombosis. The impact of this protocol on clinical outcomes requires further study.

Ventricular arrhythmias and ICD therapy

- Ventricular arrhythmias are common after LVAD implantation. In clinical trials of patients receiving LVADs as a bridge-to-transplant, 21–24 % received a cardioversion or defibrillation post-implant for ventricular arrhythmias [31, 32•]. Of note, half or more of these events occurred in the first 30 days after implant. Data from single-center studies also report high rates of ventricular arrhythmias, ranging from 18 to 52 % [33–37], with high rates of associated implantable cardioverter-defibrillator (ICD) shocks, 16–42 % [38–41].
- Even though ventricular arrhythmias are common, patients with LVAD support may tolerate these arrhythmias for hours without hemodynamic compromise, calling into question the need for routine use of ICDs. One recent single-center study suggested that patients at low risk of ventricular arrhythmias may not need a primary prevention ICD [42]. The identification of which patients are most likely to benefit from an ICD remains poorly characterized, but a major risk factor for

postoperative ventricular arrhythmias is a history of *preoperative* ventricular arrhythmias [34,40]. Based on these data, it is not clear if patients without an ICD at the time of LVAD placement need a primary prevention device. Similarly, the need for replacing depleted ICD generators remains a question that needs further investigation.

- Another important issue in the postoperative setting relates to potential changes in ICD function following LVAD implantation surgery. In one study, significant changes in RV lead parameters were noted on postoperative device interrogations, and 13 % of patients required lead revision and 20% required ICD testing [43]. We typically perform a routine device interrogation on patients after LVAD surgery prior to discharge from the hospital.

Routine outpatient follow-up

- Effective outpatient management requires significant infrastructure and a multidisciplinary approach to patient care. Our outpatient care team includes physicians, surgeons, physician assistants, nurse practitioners, and social workers. We have regular clinic hours and an around-the-clock emergency number. Routine follow-up care can be relatively time and labor intensive in terms of the acuity and potential severity of common clinical events (see below). In addition, patients may require assistance with the management of device equipment and dressing change supplies. There is no defined interval for follow-up assessments. At our institution, we begin with monthly assessments and adjust the frequency depending on clinical stability.

Physical examination of a patient with a continuous-flow LVAD

- Patients supported by a continuous flow LVAD will have no pulse if the majority of blood flow is through the LVAD, not the AV. Given this, the presence of a pulse can be a sign of either health or pathology. For example, improved cardiac systolic function or new LVAD dysfunction could both be suggested by the presence of a newly palpable pulse.
- The so-called “hum” on auscultation of the LVAD can vary depending on stress on the pump. Auscultation of S2 can provide information on the frequency of AV opening. Mitral valve regurgitation and continuous AV regurgitation may also be auscultated, and are important to identify during routine clinical evaluations.
- Most LVAD infections involve the percutaneous driveline [44•] and examination of the driveline exit site should be performed during each physical examination.
- Another essential aspect of the physical examination that may be overlooked is the blood pressure. The details of assessing mean arterial pressure (MAP) are described thoroughly in other forums [45]. In brief, current technology for noninvasive blood pressure measurement can be unreliable when a patient’s pulse pressure is minimal, as is often the case with continuous flow LVADs. A more reliable method is to utilize a manual blood pressure cuff to briefly occlude the brachial artery and then record the pressure at which the sound of blood flow returns in the brachial artery

as it passes through the medial aspect of the antecubital fossa, as measured by a Doppler ultrasound. This measurement is considered equivalent to the MAP generated by the LVAD. At our center, we target a MAPG90 mmHg to reduce stroke risk and minimize afterload, an especially important issue in the setting of AV insufficiency. Care must be taken to identify whether there is contribution from the LV through the AV in addition to LVAD flow. If there is increased pulsatility (and a widened pulse pressure), then the Doppler measurement may be representative of the systolic blood pressure, not the MAP. Treatment goals should be adjusted to minimize periods of hypotension.

Routine laboratory testing and imaging studies

- Similar to general HF patients, serum electrolytes and renal function are routinely assessed at outpatient clinic visits [46]. Unique to the LVAD population is the practice of screening for hemolysis. There are no data to support the practice of screening for and treating asymptomatic hemolysis, though the consequences of pump thrombosis can be fatal.
- Screening for hemolysis may be done by either a plasma free hemoglobin or lactate dehydrogenase [47]. INTERMACS requires documentation of a plasma free hemoglobin ≥ 40 mg/dL for the definition of hemolysis, though some data support the use of lactate dehydrogenase for screening [47].

Medical therapy

- The data for continued pharmacologic therapy for HF after LVAD implantation are limited. In general, the rates of myocardial recovery after LVAD implantation have been disappointingly low. In a retrospective analysis of the HeartMate II BTT and DT trials, only 1.5 % of patients were successfully explanted for myocardial recovery [48]. However, higher recovery rates after LVAD implantation have been reported, and aggressive pharmacologic therapy for HF appears to be an integral component of the reported weaning strategies [49–51].

Routine echocardiography

- Echocardiography plays an essential role in the management of patients with LVADs. We obtain routine echocardiograms to assess LVAD function, monitor for valvular regurgitation, and evaluate for myocardial recovery. These studies are obtained prior to discharge and then approximately every 6 months, depending on the clinical course of the patient.
- Concerning findings on a routine echocardiogram include increased LV diameter and/or mitral regurgitation, both indications that the LVAD is unable to fully decompress the LV. Other notable assessments include opening of the AV, AV insufficiency, LV ejection fraction, RV function, tricuspid valve insufficiency, estimated pulmonary artery pressures, and flow through the inflow/outflow cannulas. The reader may refer to previous reviews for further details [52–54].

Common complications

- By 2 years, 81 % of patients in INTERMACS have experienced a major adverse event, most commonly bleeding, infection, and/or arrhythmias [6•]. Common complications are discussed below and outlined in Table 2.

Bleeding

- Bleeding events after LVAD implantation typically take the form of bleeding from the thoracic cavity or GI tract. Around 36% of patients will have at least one bleeding episode in the first year after continuous-flow LVAD implantation [55], and bleeding is a common cause for hospital readmission after LVAD surgery [56]. The reasons for this common complication are likely related to the use of antithrombotic therapy, acquired von Willebrand factor deficiency, acquired impaired platelet aggregation, and angiodysplasia. These last three causes are related to continuous flow technology, as previously reviewed [57].
- Our general approach to the treatment of bleeding is to control the source of bleeding, hold antithrombotic therapy until bleeding resolves, and then reduce the amount of chronic antithrombotic therapy to prevent bleeding. Bleeding from the thoracic cavity that is not self-limited requires surgical intervention and typically occurs early after LVAD surgery. GI bleeding can occur at any time after implantation.
- Patients with GI bleeding are transfused appropriately (with recognition of the potential for antibody sensitization in potential transplant patients) and antithrombotic therapies are held until endoscopic evaluation can be completed. Our general approach to the evaluation and management of GI bleeding is outlined in Fig. 1.
- Despite changes in anticoagulation, some patients develop recurrent GI bleeding. Many of these patients have diffuse angiodysplasia of the GI tract. Some centers have advocated turning down the LVAD pump speed in an attempt to restore pulsatility, reduce angiodysplasia development, and improve acquired von Willebrand factor deficiency. The typical trade-off includes an increase in the amount of HF symptoms. Other therapies that have been attempted in select patients include hormone therapy and octreotide. Both of these therapies have been studied in angiodysplasia related to other conditions [58–60] and the data for octreotide are most encouraging. Other therapies with theoretical benefit include thalidomide, erythropoietin, and surgical bowel resection [61]. In select cases, we have transplanted patients with refractory bleeding, given that LVAD explantation is associated with correction of acquired von Willebrand factor deficiency [62].

Driveline and pump pocket infections

- Infectious issues in a patient with an LVAD range from a superficial skin infection at the driveline exit site to systemic infections involving the LVAD pocket, the LVAD pump, heart valves, and/or ICDs. Notably, in the current era, LVAD pockets are primarily used for the HeartMate II device. This pump is intended to sit

in the pre-peritoneal abdomen, under the rectus muscle but anterior to the posterior rectus sheath. In contrast, the HeartWare device is intended to sit at the LV apex within the pericardial space.

- The most common pathogens in LVAD-related infections are *Staphylococcus* and *Pseudomonas*, though fungal infections, especially *Candida*, and polymicrobial infections also occur. This distribution of pathogens has been consistent across multiple studies and clinical centers over the past few decades, despite improvements in LVAD surgical techniques and pump technology [44•, 63–65]. A comprehensive study of LVAD infections was recently published by the Ventricular Assist Device Infection Study Group [44•]. This study included 150 patients from 11 US clinical centers. VAD infections occurred in 22 % of the patients. In contrast, non-VAD related infections, such as urinary tract infections or *C difficile* colitis, occurred in 39 % of patients during the period of follow-up. The median time to infection was 68 days; the risk of infection peaked at postoperative day 18 and was lower and constant after 60 days.
- The signs and symptoms of an LVAD infection can be insidious, despite the fact that most LVAD infections [44•] involve the percutaneous driveline. Patients are encouraged to be vigilant for any abnormalities involving the driveline, including drainage, pain, or poor wound healing. We have a low threshold for blood culture collection to evaluate for an occult bloodstream infection (bacteremia may occur without an overt clinical syndrome of sepsis) and are aggressive with empiric antibiotics after blood cultures that cover *Staphylococcus* and *Pseudomonas* are obtained. A recent publication by the ISHLT includes useful definitions for infections involving LVADs [66]. In this document, ultrasound is encouraged for evaluating the driveline and pump pocket. In addition, at our center, we utilize computed tomography (CT) scans as a first-line test to evaluate for extension of driveline and/or pump pocket infections.

Ventricular arrhythmias

- The mechanism of ventricular arrhythmias is important to consider. One scenario is contact of the inflow cannula with the LV, as can occur during a suction event when the LV is completely decompressed by continuous inflow [67]. Scar related to myocardial fibrosis is also common. In a study of patients referred for catheter ablation, electroanatomic mapping revealed that the origin of ventricular tachycardia was related to intrinsic myocardial scar more commonly than the apical cannulation site [68].
- In patients who develop symptomatic ventricular arrhythmias, there are multiple treatment options, but limited data comparing these options. Initial treatment strategies include optimization of fluid status (treating both hypovolemia to avoid suction events and volume overload) and optimization of hemodynamics with medical therapy and LVAD optimization. Additional medical therapy consists of beta blockers and other antiarrhythmics, including amiodarone, lidocaine,

mexiletine, and sotalol. For patients with refractory ventricular tachycardia, catheter ablation is an option [68,69], as is heart transplantation.

Atrial arrhythmias

- Atrial fibrillation is common in patients with advanced HF [70], and the impact of LVAD therapy on atrial fibrillation burden and symptoms is not known. Approximately 20 % of patients in the HeartMate II DT trial presented with atrial arrhythmias during 2 years of follow-up, though the specific atrial arrhythmias and their clinical impact are not well characterized [71,72]. In our experience, atrial fibrillation can be most symptomatic in patients with poor RV function when RV filling time and a coordinated atrial contraction are important for preserved cardiac output. Unfortunately, in these patients, high doses of rate-control agents, such as beta blockers and calcium channel blockers, are poorly tolerated. As such, it may be necessary to pursue rhythm control strategies for atrial fibrillation despite the use of an LVAD. We typically increase our INR goal to 2–3 for patients with atrial fibrillation and an LVAD.

Aortic valve insufficiency

- Postoperatively from LVAD implantation, aortic valve insufficiency (AI) can develop de novo or underlying AV pathology may be exacerbated. The process is more common with continuous-flow LVADs [73] and is associated with reduced rates of AV opening [27–29]. This most likely occurs due to commissural fusion of the AV leaflets from immobility and abnormal collagen production and remodeling. The leaflets may also experience trauma and thrombus formation with high-pressure continuous flow from the outflow cannula [74].
- The implications of worsening AI are not entirely clear. There is no association of progressive AI and increased mortality [29,73], though the futile circuit created by AI reduces the efficiency of the LVAD and can exacerbate HF symptoms. Medical management of AI includes aggressive blood pressure management to reduce the pressure gradient between the aorta and LV. The combination of this high pressure gradient between the aorta and the decompressed LV on an LVAD and continuous blood flow explains, in part, why a small regurgitant orifice can lead to a large volume of regurgitant blood flow. Percutaneous closures of the AV [75–78] and transcatheter aortic valve replacements [79,80] have been reported for the management of AI, though long-term data are limited. In select cases, some patients also require surgical intervention for AV replacement or LV outflow tract closure by suturing closed the AV.

Pump dysfunction

- Continuous flow devices are more likely to fail due to pump thrombosis rather than mechanical pump failure [81]. Aggressive antithrombotic therapy is utilized to prevent thrombosis as outlined above. Typical presentations for pump thrombosis range from an asymptomatic rise in laboratory values (plasma free hemoglobin or

lactate dehydrogenase), evidence of hemolysis (hemoglobinuria), HF, or LVAD alarms for low flow or power spikes.

- Initial management strategies focus on patient stabilization and consideration of emergent surgical interventions or thrombolytics. If the diagnosis is in question, echo ramp studies similar to the Columbia protocol [30•], cardiac catheterization and/or CT angiogram may be performed to look for either thrombus or anatomic causes of pump thrombosis, such as a kinked outflow graft.

Conclusions

The use of continuous-flow left ventricular assist devices (LVADs) is rising at a rapid pace and at the same time, the survival of patients on LVADs continues to improve. Patients treated with the current generation of continuous-flow LVADs have unique medical challenges that require input from a variety of healthcare providers and specialties.

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Opinion statement

The prevalence of patients living with advanced heart failure continues to rise. For a subset of these patients, continuous-flow left ventricular assist devices (LVADs) are a life-saving therapy. Given the efficacy and durability of contemporary LVAD devices, their use has increased exponentially in recent years. The medical management of patients with an LVAD is an area of expertise for advanced heart failure clinicians, but a general understanding of the initial approach to, and stabilization of, LVAD patients is an important skillset for many health care providers. The rapidly changing field of the medical management of LVAD patients is largely based on clinical experience and limited published data. In this manuscript, we integrate the available published data on the medical management of LVAD patients with the growing clinical experience.

Figure 1.

The Duke approach for evaluation and management of gastrointestinal tract bleeding in patients with a continuous-flow LVAD. Adopted with permission from Fig. 1 from Suarez et al [57]. GI: Gastrointestinal; ASA: Aspirin; INR: International Normalized Ratio; LVAD: Left Ventricular Assist Device.

Table 1

Common postoperative hemodynamic scenarios and suggested management strategies

	Hypovolemia	RV Failure	Tamponade	Systemic Hypertension
Signs and Symptoms	• Low urine output • Suction events • Ventricular arrhythmias	• Low urine output • Suction events • Ventricular arrhythmias • Volume overload	• Low urine output • Apparent volume overload • Hypotension	• Often asymptomatic, but may have dyspnea
LVAD Findings	↓ Flow ↓ PI ↑ Power	↓ Flow ↓ PI ↑ Power	↓ Flow ↓ PI ↑ Power	↓ Flow ↑ PI ↑ Power
CVP	↓	↑	↑	↑
Echo Findings	↓ LV diameter, AV not opening	Dilated RV, LV septum shifted to left, Under-filled LV	Signs of RV compression ** circumferential effusion not required	Typically normal
MAP	↓ or normal	↓ or normal	↓	↑
Management Strategies	Evaluate for bleeding. Consider transfusion ± fluid resuscitation	Diuretics, Reduce LVAD speed, Inotropic support, Pulmonary vasodilators, Temporary RV mechanical support	Emergent surgical intervention	Systemic antihypertensives

RV: right ventricle; LVAD: left ventricular assist device; CVP: central venous pressure; MAP: mean arterial pressure; PI: pulsatility index; LV: left ventricle; AV: aortic valve

Table 2

Common complications in patients treated with continuous-flow LVADs

	Evaluation	Management
Bleeding	Hemoglobin, INR, endoscopy	Control bleeding source and hold antithrombotic therapy, Consider lower antithrombotic therapy in future
Driveline and Pocket infections	Assess driveline, blood cultures, ultrasound of pocket, CT scan of chest and abdomen, echo	Empiric antibiotics should cover <i>Staphylococcus</i> and <i>Pseudomonas</i>
Ventricular arrhythmias	Assess volume status, echo, consider ischemia evaluation	Optimize volume and hemodynamics, Lower pump speeds if suction events, Beta blockers and other antiarrhythmics, Consider ablation
Respiratory failure	Assess volume status, chest X-ray, consider invasive hemodynamics	Optimize volume and hemodynamics, Treat concomitant pulmonary disorders including chronic lung disease and pneumonia
Cerebrovascular complications	LDH, plasma free hemoglobin, echo, CT scan of head	Careful management of anticoagulation to balance risk of recurrent embolic stroke from device and hemorrhagic conversion
Chronic right heart failure	Assess volume status and perfusion, echo	Diuretics, Reduce LVAD speed, Inotropic support, Pulmonary vasodilators
Aortic valve insufficiency	Blood pressure, echo	MAP<90 mmHg, LVAD speed optimization, Aortic valve interventions (see text)
Pump dysfunction	LDH, plasma free hemoglobin, echo, CT scan of LVAD	If thrombus, increase anticoagulation, Consider thrombolytics or pump exchange

INR: international normalized ratio; CT: computed tomography; LDH: lactate dehydrogenase; LVAD: left ventricular assist device; MAP: mean arterial pressure