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Durable left ventricular assist device therapy in advanced heart failure: Patient selection and clinical outcomes

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ABSTRACT

The increasing adoption of left ventricular assist devices (LVADs) into clinical practice is related to a combination of engineering advances in pump technology and improvements in understanding the appropriate clinical use of these devices in the management of patients with advanced heart failure. This review intends to assist the clinician in identifying candidates for LVAD implantation, to examine long-term outcomes and provide an overview of the common complications related to use of these devices.

The increasing adoption of left ventricular assist devices (LVADs) into clinical practice is related to a combination of engineering advances in pump technology and improvements in understanding the appropriate clinical use of these devices in the management of patients with advanced heart failure. This review intends to assist the clinician in identifying candidates for LVAD implantation, to examine long-term outcomes and provide an overview of the common complications related to use of these devices. In the early 1990s, larger pulsatile LVADs (i.e. Novacor LVAD and Thoratec HeartMate XVE) were initially used for left ventricular support in patients awaiting cardiac transplantation. This strategy was not based on randomized data but was adopted out of necessity, given the long waiting times for cardiac transplantation.[1] As confidence grew, the Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) trial was launched, which randomized 129 nontransplant candidates with end-stage heart failure to ongoing medical therapy (72% of patients supported with continuous intravenous inotropes) versus a pulsatile HeartMate XVE and demonstrated a dramatic survival advantage at one year (53% survival in the LVAD group and 25% survival in the medical therapy group).[2] This affirmed the proof of concept and viability of lifetime or destination therapy using mechanical circulatory support (MCS) systems. The initial adoption of pulsatile devices was low due to lesser device durability and frequent morbidity, but as LVAD technology advanced, the advent of smaller and more reliable continuous flow devices (HeartMate II LVAD and HeartWare HVAD) led to a dramatic rise in utilization of LVADs in the past decade. In 2013, the

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number of durable MCS devices in the United States ($n = 2642$, 97% continuous flow LVADs, 44% for destination therapy) exceeded the number of cardiac transplants performed.[3,4] For the past decade, the number of cardiac transplants per annum worldwide has remained stagnant at around 4000 related to the relatively fixed donor pool, with the vast majority of cardiac transplants being performed in the United States and Europe. Attempts at increasing the donor pool have been outpaced by the improving clinical outcomes experience with current generation LVADs contributing to a growing population of transplant ineligible patients supported with these devices as destination therapy. Balancing the risk–benefit ratio to match the device to the patient's condition will be paramount in prolonging and improving life while achieving cost-effectiveness.[5]

1. Patient selection

1.1. *Selecting patients with the appropriate severity of heart failure*

Determining a level of severity of illness in patients with advanced heart failure relies heavily on the degree of symptoms, refractoriness to traditional disease modifying therapy, and the worsening hemodynamic profile. As advanced-stage heart failure sets in, the traditional New York Heart Association classification system is no longer sufficient to characterize patients. Thus, the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) profile system assigns a level (INTERMACS level 1 through 7) to patients based on the severity of illness (Table 1). Currently, the majority of patients undergoing LVAD implantation are either categorized as INTERMACS level 1 (critical cardiogenic shock), level 2 (progressive decline on inotropic therapy), or level 3 (stable but inotropic therapy dependent).[3] INTERMACS level 1 patients (those in critical cardiogenic shock) pose a challenge to LVAD implantation. Specifically, there is an increased risk of perioperative mortality (relative risk 1.55).[6] In response to the realization of the perioperative risk in patients with cardiogenic shock, the proportion of patients undergoing durable MCS implantation at INTERMACS level 1 has decreased over the past decade.[3,6,7] This increased risk is at least in part related to the end-organ dysfunction associated with cardiogenic shock and the inflammatory state of severe shock, leading to increased postimplant bleeding, infection, multisystem organ failure, and need for right heart support. Avoidance of support is not an adequate strategy and management algorithms in INTERMACS I patients have evolved to use temporary MCS devices, such as intra-aortic balloon counter-pulsation, percutaneous or surgical centrifugal devices (TandemHeart, Centrimag), percutaneous axial flow devices (Impella), or venoarterial extracorporeal membrane oxygenation (VA ECMO) in an effort to restore end-organ perfusion, stabilize the patient, and potentially reduce the risk of subsequent durable LVAD implantation.[8]

In general, patients with cardiogenic shock who can be stabilized with percutaneous support may be candidates for a durable LVAD, whereas patients who suffer from irreversible end-organ dysfunction (renal, hepatic, neurologic, etc.) or refractory shock despite temporary MCS are likely at higher risk and are suboptimal candidates for LVAD implantation.

Patients who are inotropic therapy dependent (INTERMACS levels 2 and 3) currently represent nearly two-thirds of all LVAD implantations and likely also represent the most appropriate use of the current technology. Patients treated with inotropic therapy due to refractory end-organ hypoperfusion or refractory symptoms related to advanced heart failure have an overall very poor prognosis with medical therapy alone. Of the 61 patients in the medical therapy arm of the REMATCH trial, 72% of patients were on continuous inotropic infusion, and by one year, only 25% of medically treated patients were alive, which decreased to 8% by two years.[2] The Investigation of Non-Transplant Eligible Patients who are Inotrope Dependent (INTrEPID) and Continuous Outpatient Support with Inotropes (COSI) trials are two other small prospective analyses, which demonstrated a 1-year survival of 11% and 6%, respectively in patients bound to continuous inotropic therapy support.[9,10] In contrast, the expected one-year survival of patients following implantation of a continuous flow LVAD now approaches 80% (Fig. 1).[6] Although the patient populations in these trials differ, these data infer a dramatic survival advantage for durable MCS in INTERMACS levels 2 and 3 patients with advanced heart failure.

Patients in INTERMACS levels 4 through 7 suffer from advanced heart failure but are not inotrope dependent. Not only are patients with this severity of illness more difficult to define, it is possible for an individual patient to transition between levels over time. Currently, only 18.5% of patients who undergo durable MCS are levels 4 through 7 (mostly INTERMACS level 4).[6] Of these patients, the INTERMACS 4 profile is increasingly gaining acceptance as an appropriate candidate group. Such patients exhibit symptoms of dyspnea and fatigue on minimal activity, are typically house bound due to the severity of symptoms, and suffer from a poor quality of life and excess 1-year mortality. The recently concluded ROADMAP trial provides insight into the selection of patients for LVAD therapy from this group of individuals.[11] Further estimation of prognosis in this ''less sick'' patient population is warranted with the use of other prognostic indicators in chronic heart failure, many of which are listed in Table 2.[12–19]

Table 1 – Current distribution of durable mechanical circulatory support devices across INTERMACS levels.

INTERMACS Level	Definition	% Of durable MCS
1	Critical cardiogenic shock	14.3%
2	Progressive decline	36.0%
3	Stable but inotrope dependent	29.6%
4	Resting symptoms	14.5%
5	Exertion-intolerant	3.0%
6	Exertion-limited	1.2%
7	Advanced NYHA Class 3	0.7%

INTERMACS, Interagency Registry for Mechanically Assisted Circulatory Support; MCS, mechanical circulatory support; NYHA, New York Heart Association.

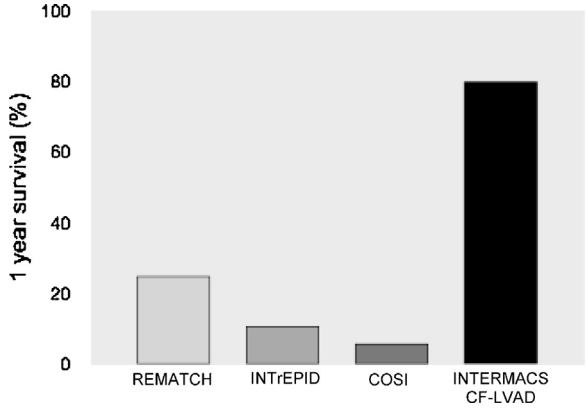

Fig. 1 – One-year survival of patients on continuous inotropic support compared to those supported with a durable continuous flow left ventricular assist device. One-year survival was 25% in the medically treated arm of the REMATCH trial, 72% of whom were dependent on inotropic therapy. Survival was 11% and 6% in the prospective analyses INTrEPID and COSI, respectively at one year. In comparison, based on the 7th INTERMACS annual report, the one-year survival of patients supported with a durable continuous flow left ventricular assist device is approximately 80%. REMATCH, Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure; INTrEPID, Investigation of Non-Transplant Eligible Patients who are Inotrope Dependent; COSI, Continuous Outpatient Support with Inotropes.

Table 2 – Poor prognostic markers in heart failure.

- Symptoms at rest (NYHA class IV) or with minimal exertion
- Recurrent heart failure hospital admissions
- Tachycardia
- Sustained ventricular arrhythmia
- Hypotension
- Cardiac cachexia
- Hyponatremia
- Renal dysfunction
- Hepatic dysfunction
- Anemia
- Prior or current need for inotropic therapy
- High diuretic requirement (furosemide equivalent >160 mg/day)
- Circulatory or renal limitations to neurohormonal antagonists
- Nonresponder to cardiac resynchronization therapy
- Lower EF and large left ventricular volume
- Mitral regurgitation
- Pulmonary hypertension and right ventricular dysfunction
- Six-minute walk distance <300 m
- Peak VO_2 < 14 mL/kg/min (not on beta blocker) or <12 mL/kg/min (on beta blocker), or <50% of predicted
- Ve/VCO_2 slope >35

NYHA, New York Heart Association; EF, ejection fraction; VO_2, oxygen consumption; Ve/VCO_2, ventilatory efficiency (Ve, minute ventilation; VCO_2, production of carbon dioxide per minute).

MEDAMACS is an ongoing registry coupled to the INTERMACS registry that aims to further characterize medically managed patients in INTERMACS levels 4–7.[20] The pilot data from the first 166 patients enrolled in MEDAMACS demonstrate a 1-year survival of 78% in INTERMACS level 6/7, a 67% 1-year survival in INTERMACS level 5, and a 39% 1-year survival in INTERMACS level 4. Based on this limited data, there is unlikely to be a significant survival advantage to LVAD implantation in INTERMACS level 6 or 7. INTERMACS levels 4–6 patients were analyzed prospectively in the recently reported prospective observational ROADMAP trial, which offered all enrolled patients implantation of a continuous flow LVAD, and compared those who underwent implantation to those who chose medical therapy.[11] Of the 196 patients enrolled, 95 underwent implantation of an LVAD. By intention to treat, there was no difference in mortality (since advancing symptoms in the medical therapy arm resulted in transition to LVAD implant), but showed improvements in functional capacity, quality of life, and depression in the LVAD group.

Patients in INTERMACS levels 6 or 7 are likely too well to benefit substantially from durable MCS and implantation in this cohort of patients with current generation devices is likely to be too early. A decision to implant a durable MCS device in INTERMACS 4 patients should be based on the potential benefit in functional capacity and quality of life versus the risks (namely stroke, hemorrhage, thrombosis, and infection) associated with durable MCS therapy. An appropriate informed consent process that simplifies the education regarding LVAD therapy and defines these risk-benefit ratios objectively is needed to involve the patient as the principal decision maker in such scenarios.

1.2. *Understanding the role of heart failure phenotype in decision making*

Prior to consideration of LVAD implantation, the likelihood of spontaneous recovery should be assessed. Patients who are likely to recover and able to be stabilized on medical therapy should not have a durable mechanical support device implanted, and those who are likely to benefit from valve surgery or revascularization should have these attempted prior to LVAD implantation. There is often significant uncertainty as to whether or not revascularization or valvular intervention prior to LVAD will preclude the need for mechanical support; in those cases it is prudent to evaluate a patient fully for candidacy of LVAD therapy prior to the proposed intervention in case of the need for a "bail out" strategy. Cardiac resynchronization therapy (CRT) in inotrope-dependent patients has been associated with poor outcomes, and therefore implanting a CRT device in patients on inotropic therapy may only cause delays in LVAD implantation risking further end-organ dysfunction or death.[21] However, even if 1 in 3 patients were to benefit substantially from CRT, it makes prudent sense to employ this strategy as a preemptive move, but it is imperative that the response to CRT be assessed early with planned escalation of therapy once nonresponder status is confirmed.

Typically, patients undergoing MCS are those with a dilated left ventricle since cannula positioning is difficult in those with smaller ventricles. Those with a restrictive or hypertrophic cardiomyopathy pose a technical challenge related to inflow cannula placement in a small ventricular cavity; however, in those patients in whom implantation of an LVAD is technically feasible, perioperative and one-year outcomes do not appear

to differ from those without a restrictive or hypertrophic cardiomyopathy.[22] Patients with a recent myocardial infarction involving the left ventricular apex theoretically have an increased surgical risk. Certain valvular pathologies may need to be addressed at the time of MCS implantation and should be fully evaluated prior to surgery. Typically, while supported with a continuous flow LVAD, the aortic valve opens infrequently and may be at increased risk for thrombosis; therefore, mechanical aortic prostheses are often replaced with a bioprosthetic valve. Aortic regurgitation often worsens following continuous flow LVAD implantation, which decreases pump efficiency by recirculation, imposing an increased volume load on the left ventricle. Therefore, patients with moderate or severe aortic regurgitation often undergo concurrent closure, oversewing, or replacement of the aortic valve.[23] Mitral regurgitation improves in most of the patients following LVAD implantation when it is functionally related to left ventricular dilation and volume, and does not often require surgical intervention; conversely, significant mitral stenosis limits LVAD filling and requires replacement of the stenotic mitral valve with a bioprosthesis.[24] Atrial septal defects and patent foramen ovale should be identified prior to surgery and should be closed at the time of LVAD implantation given the decrease in left atrial pressure following LVAD implantation and the possibility of postoperative right to left shunt, facilitated by residual right ventricular failure.

1.3. *Assessment of the right ventricle*

Ongoing right ventricular dysfunction following isolated left ventricular mechanical support may pose a persistent limitation to functional capacity and impair end-organ function. Right ventricular failure following LVAD implantation increases the risk of death and may necessitate the implantation of a right ventricular mechanical support device or use of prolonged continuous intravenous inotropic therapy. In the current era, right ventricular mechanical support is only available to those patients who are listed for cardiac transplantation (since discharge to home is often difficult), thereby placing profound importance in identifying those at risk for postoperative right ventricular failure, especially in patients not eligible for cardiac transplantation.

LVAD implantation may not only unmask preexisting right ventricular dysfunction, but several factors associated with left ventricular MCS may further impact right ventricular performance. Ischemic injury associated with cardiopulmonary bypass may at least temporarily worsen right ventricular function. Increased systemic venous return with left ventricular mechanical support causes an increase in preload to the right ventricle, which in concert with a reduction of left ventricular pressure due to direct unloading may shift the septum toward the left ventricle causing worsening right ventricular dilation and tricuspid regurgitation and decreased septal contribution to right ventricular forward output.[25]

Assessment of right ventricular function should incorporate a combination of imaging findings (to assess RV contractility and diastolic compliance) with hemodynamic (to assess systemic elevation of filling pressures and contractile insufficiency) and biochemical data (to assess hepatorenal end-organ perfusion). Preoperative severe right ventricular dysfunction by qualitative and quantitative echocardiographic evaluation, inability to decrease the right atrial pressure to below 15 mmHg with optimal medical therapy, a low right ventricular stroke work index, low right atrial to pulmonary artery pulse pressure ratio, high right atrial to pulmonary artery wedge pressure ratio, and persistent elevations in creatinine, bilirubin, and international normalized ratio (INR) all indicate an increased risk for postoperative right ventricular failure.[25] No single factor has been shown to be adequate in the prediction of right ventricular failure; therefore, during the evaluation of a patient referred for left ventricular mechanical support, all of these factors should be comprehensively examined.

In addition to assessing right ventricular function, special attention should be directed toward the arrhythmia burden. Significant ventricular arrhythmias may result in a hemodynamic embarrassment in patients with isolated left ventricular mechanical support; therefore, strong consideration should be given to biventricular MCS in patients with very frequent or refractory ventricular arrhythmia.

1.4. *Estimating the impact of comorbid conditions*

Data regarding the impact of advanced age on LVAD outcomes are variable. A single center reported outcomes of 30 patients over the age of 70 with a 97% 30-day and 70% two-year survival following LVAD implantation, which was not different from patients at the same institution undergoing LVAD implantation at an age less than 70 years old.[26] This is contrary to the seventh INTERMACS registry report, which revealed an increased perioperative and late mortality in older patients.[6]

Given the hemorrhagic and thrombotic complications, which are unfortunately common following LVAD implantation, patients with hypercoagulable disorders or coagulopathies should be considered at increased risk for postoperative complications. All patients who undergo LVAD implantation must be able to tolerate systemic anticoagulation, which at the current time consists of warfarin with an INR of 2.0–3.0 and aspirin (or an alternate antiplatelet agent).[25]

Renal and hepatic dysfunction are associated with an increase in perioperative mortality, the risk of which relates to the degree of impairment. These two end organs typically predict underlying chronicity of the disease, a worse right heart function, and predispose to a greater propensity for bleeding and infection-related complications. Despite this association, on average, both renal and hepatic function improve by six months following LVAD implantation.[27] Patients on hemodialysis have an overall poor prognosis and are likely at increased risk of device infection and most centers consider LVAD implantation in this population unattractive. In patients with marginal renal function, improvement with a trial of inotropic therapy and lack of significant proteinuria may suggest a greater likelihood of renal recovery following LVAD implantation. Chronic elevation in right atrial pressure resulting in longstanding hepatic congestion may ultimately lead to hepatic cirrhosis. Patients with chemistry or imaging data indicating the possibility for cirrhosis (or even extensive hepatic fibrosis) should undergo liver biopsy, as patients with cirrhosis are suboptimal

candidates for LVAD implantation given an increase in operative bleeding and perioperative mortality, especially those who are Childs-Pugh class B or C or have an elevated Model for End-Stage Liver Disease (MELD) score.[28]

The presence of peripheral arterial disease at the time of LVAD implantation may increase the risk of stroke, and limb and mesenteric ischemia; this depends largely on the extent of vascular disease, and in some cases, this may be considered a relative contraindication to durable LVAD implantation. In addition, significant disease of the ascending aorta may contraindicate the anastomosis of the outflow graft, necessitating alternative connections, such as in the descending aorta, in some cases.

Psychosocial barriers including inadequate social support, substance abuse, and medical noncompliance all should be assessed prior to consideration of LVAD therapy. Poor nutritional status and frailty increase the risk of death following LVAD implantation, although no method of improving these parameters to mitigate this risk has been demonstrated.[29] Frailty is increasingly recognized as a risk marker for poor outcome and should be evaluated independent of the patient's age. A simple 6-second ''shuttle'' test to see if the patient can walk 5 meters and assessment of hand grip strength (<20th percentile for age and gender) can be used to establish frailty.[29,30] Another important consideration is in the neuropsychological evaluation of cognitive function; recent studies have shown that cognitive function, which is often poor in advanced heart failure, improves significantly after LVAD implantation. However, advanced cognitive decline may be a harbinger for poor adherence to the medical regimen and complicate LVAD management.[31]

2. Outcomes following LVAD implantation

2.1. *Survival*

Based on data from the INTERMACS registry, perioperative (30-day) survival is 95% following LVAD implantation.[32] Survival following LVAD implantation has improved as device technology and patient selection have advanced. One-year survival following LVAD implantation for transplant ineligible candidates was 53% in the pulsatile HeartMate XVE arm of the REMATCH trial; most recently, the INTERMACS registry data from the years 2008 to 2014 demonstrated a 1-year survival of 80% and median survival of nearly four years for patients supported with a continuous flow LVAD. The greatest risk of death following LVAD implantation is in the early postoperative period and reaches a nadir by 3 months postoperatively. Factors that have the greatest impact on perioperative mortality include age, female sex, prior stroke, mechanical ventilation, INTERMACS level 1 or 2, LVAD for destination therapy, hepatic or renal dysfunction, right ventricular dysfunction or need for right ventricular mechanical support, and prior or other concurrent cardiac surgery.[3,6]

2.2. *Quality of Life*

The impact of LVADs on symptom burden and quality of life in patients with severe heart failure has been favorable.[6] In the HeartMate II destination therapy trial, all patients experienced NYHA class III or IV heart failure symptoms at the start of the trial, and by the end, 80% of those undergoing support with a continuous flow LVAD were NYHA class I or II.[33] In addition, patients in this trial demonstrated meaningful improvements in the Minnesota Living with Heart Failure questionnaire and Kansas City Cardiomyopathy questionnaire, with a significant increase in a 6-min walk distance by 12 months. This should be tempered by the understanding that complications following LVAD implantation are often unrelated to heart failure, and therefore, heart failure specific quality of life assessments may overestimate the benefit of LVAD therapy.

2.3. *Complications following LVAD*

The most common complications in patients supported with an LVAD are bleeding, LVAD thrombosis, stroke or systemic thromboembolism, and infection.

Following the 30-day perioperative period, bleeding (mostly gastrointestinal) occurs at a rate of 8–23% by one year.[34] Several factors place patients with continuous flow LVADs at risk for gastrointestinal bleeding. Background antithrombotic therapy with warfarin and an antiplatelet agent (usually aspirin) increase the overall bleeding risk. Shear stress from the pump itself may lead to platelet dysfunction and degradation of large von Willebrand factor multimers in the setting of low pulsatility leads to further coagulopathy.[35] Gastrointestinal arteriovenous malformations are common and difficult to treat lesions in patients with LVADs and are likely related to the reduced arterial pulsatility related to continuous flow support; this phenomenon is similar to Heyde's syndrome, which was initially described in calcific aortic stenosis.[35] The effects of low pulsatility on the microcirculation, coupled with increased oxidative stress, are the most likely mechanistic candidates that predispose to development of this unique gastrointestinal complication, in concert with the hematological abnormality encountered universally with continuous flow LVADs.

Pump thrombosis occurs with an annual incidence of 6–12% and is associated with an increase in neurologic events and a higher rate of mortality.[36–38] LVAD thrombosis is often initially suspected when there is biochemical evidence of hemolysis caused by turbulent VAD flow or elevation in the device power; later, signs include an inability to unload the left ventricle as determined by noninvasive imaging or invasive hemodynamic study, decompensated heart failure, and possibly hemodynamic compromise.[39] Lactate dehydrogenase (LDH) has proven to be an excellent biomarker of hemolysis and hence impending or established pump thrombosis. Elevation of LDH often precedes pump thrombosis by several weeks, and is therefore often monitored as routine surveillance for LVAD thrombosis in an effort to initiate intensified therapy to prevent surgical pump exchange, although this strategy may be fraught with peril.[36] From the time of confirmed pump thrombosis, there is a two-fold increase in mortality at 30 days, 90 days, and 6 months.[37] Patients who have suspected LVAD thrombosis and do not undergo LVAD exchange or cardiac transplantation have a 6-month mortality of 48.2% inferring that medical therapy for VAD thrombosis may be inadequate or cause harm (as in the case of

thrombolytics). Reoperation (pump exchange) carries a modest 6.5% perioperative mortality risk and a 65% 2-year survival following exchange.[40]

Infection is common and occurs in about 20% of patients following LVAD implantation, which may manifest as sepsis or a driveline infection.[34] Infection associated with LVAD therapy should be treated aggressively and may require long-term suppressive antibiotics unless the device is exchanged or the patient undergoes cardiac transplantation. Infection and its inflammatory sequelae predispose to a prothrombotic milieu, as well as heighten the risk of neurological complications.

Cerebrovascular complications, especially strokes, remain an Achilles heel of LVAD implants, with an annual incidence exceeding 6%. This complication is certainly more common with certain devices such as the HVAD (HeartWare, Framingham, MA) which exhibitis an excessively high rate of stroke at 2 years (29%), in women, and in those with a pre-implant history of stroke or atrial fibrillation. A complex weave of stroke-related events in the setting of infection or with pump thrombosis has been observed. Unless this complication is reduced with newer devices or enhanced management strategies, adoption of LVADs to less sicker patients will remain limited since the occurrence of a disabling stroke is tantamount to a less meaningful survival benefit.[41]

In aggregate, by one year, 80% of patients undergoing LVAD implantation will be alive and on average will have an improved quality of life. Fifty-five percent will be rehospitalized for any cause, 30% will have major bleeding within the first month, and 20% will have major bleeding over the following 11 months. Ten percent of patients will have a stroke, 5% will have a device malfunction related to clotting, 20% will have a serious infection, and 18% will have ongoing heart failure.[34] These summary statistics are a reasonable way of developing a well-crafted informed consent process for patients and their caregivers to help them understand the expectations post implantation.

3. Summary

The application of LVAD therapy continues to evolve with technological advances on the background of a limited donor supply and a growing population of patients with advanced heart failure. The ideal patients for durable LVAD implantation either as a bridge to transplantation or as destination (lifetime) therapy are those requiring continuous inotropic support (INTERMACS 2, 3) or nearing the need for such therapy (INTERMACS 4). This cohort of patients should be stable enough to undergo an operation safely and continued medical therapy is associated with a poor prognosis (<50% 1-year survival). Patients in cardiogenic shock who ultimately undergo durable LVAD implantation have a median survival of three and a half years, and therefore should be considered candidates for durable mechanical support ideally following a period of temporary mechanical support to improve end-organ function and potentially reduce perioperative risk.

Despite the success of the contemporary devices in providing circulatory support, the bane of complications limits the expansion of this therapy and will need to be overcome with future device iterations. The HeartMate III is a new promising centrifugal pump currently in trial (MOMENTUM III), which aims to reduce complications by addressing some of the pathophysiologic mechanisms thought to be responsible for bleeding and thrombosis associated with current generation devices.[42] The HeartMate III LVAD features an automated speed variability at 30 cycles per minute, which produces flow pulsatility, large blood flow gaps to reduce hemolysis, and textured surfaces, which are meant to improve hemocompatibility. As device technology continues to advance, LVADs will inevitably move beyond an option only for select patients and will migrate toward a broader population of less sick heart failure patients. Pushing technology forward will likely need to be coupled with a reduction in complications and a better understanding of the cost-effectiveness and financial impact of this transformative therapy.

Conflicts of interest

The authors have none to declare.

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