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Optimization of Left Ventricular Assist Device Support

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Introduction

The past 10 years have seen an increase in left ventricular assist device (LVAD) implantation, sicker patients at implant, and improved long-term LVAD survival.[1] This article provides an updated review of the fundamentals and limitations of LVAD optimization, particularly in the perioperative phase.

Current Limitations

Notable areas for improvement in postoperative LVAD care are lack of a consensus definition for right ventricular failure (RVF), limited long-term options for persistent RVF, and the absence of randomized trials to guide perioperative therapies.

Recent Developments

Right ventricular failure following LVAD placement is common, occurring in 10% to 40% of patients within 2 weeks after surgery, and confers substantial mortality and morbidity.[1] The 2014 Interagency Registry for Mechanically Assisted Circulatory Support definition of RVF, along with RVF severity, is provided in Table I.[2,3] Patients with severe or acute severe RVF exhibit significantly higher mortality.[3] Although no validated predictive model for RVF exists, preoperative risk assessment and optimization remain valuable to gauge and minimize postoperative RVF. Postoperative RV management targets optimization of volume status and pulmonary vascular resistance; providing inotropic support; and minimization of tachyarrhythmias, hypotension, acidemia, and coagulopathy. Barring vasoplegia, bleeding, and substantial tricuspid regurgitation, a central venous pressure of 12 mm Hg or less should be targeted.[4] Pulmonary vascular resistance reduction can be achieved by using inhaled nitric oxide or an inodilator, especially milrinone, which causes a concurrent reduction in systemic vascular resistance and should be used with caution in hypotensive patients. If feasible, early extubation should be pursued because negative intrathoracic pressure minimizes RV afterload and is associated with reduced RVF.[4] Postoperative RVF necessitates gradual LVAD speed increases and a prolonged inotrope wean. If medically necessitated, early preemptive RVAD strategies are superior to rescue strategies in terms of mortality and end-organ preservation.[4,5]

Postoperative tachyarrhythmia management mirrors that in the non-LVAD heart failure population, with amiodarone often being the first-line antiarrhythmic agent. β-Blockers should be used with caution given their potential to worsen RV dysfunction. The presence of RVF imparts added susceptibility to hemodynamic compromise from

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atrial and ventricular tachyarrhythmias, and a rhythm-control strategy may be advisable, achieved medically or through cardioversion. Ventricular tachyarrhythmias should also trigger an investigation into possible preceding ventricular suction events, the detection of which should prompt reevaluation of pump speed and volume status. In addition, subcutaneous implantable cardioverter-defibrillators in particular should be interrogated postoperatively and reprogrammed accordingly to avoid inappropriate shocks that may result from intraoperative lead reorientation.[6]

Left ventricular assist device speed adjustment is another hallmark of postoperative care. The goal is to optimize forward flow and perfusion while simultaneously unloading the left ventricle and optimizing RV performance; the secondary goal is to promote at least intermittent pulsatility to reduce the long-term risk of aortic insufficiency and bleeding diathesis. The initial speed is set intraoperatively under transesophageal echocardiographic guidance to verify a midline interventricular septum and acceptable RV size and function. Thereafter, the speed is serially increased in parallel with inotrope weaning and with regular hemodynamic and echocardiographic assessments to ensure adequate systemic perfusion and RV function. Given that increases in speed both challenge RV function because of increased preload and facilitate RV function through decreased afterload, perhaps the most robust checkmark of tolerance of a new speed is subsequent reassessment of hemodynamics, including central venous pressure measurement, the ratio of central venous pressure to pulmonary capillary wedge pressure, and especially pulmonary arterial saturation. Echocardiographic evaluation of the position of the interventricular septum and right ventricle can further confirm the appropriateness of the speed adjustment. Besides RV function, volume shifts and vasoplegia also frequently compound the immediate postoperative hemodynamic milieu. Hence, the trajectory of speed increments often follows a nonlinear pace and also depends on the rate of postoperative RV recovery.

Abbreviations and Acronyms

LVAD	left ventricular assist device
RVF	right ventricular failure

Common late LVAD complications include infection (31%), gastrointestinal bleeding (13%), and neurologic dysfunction (12%).[7] The leading causes of death include withdrawal of support (19.4%), multiorgan failure (15.8%), heart failure (13.1%), and neurologic dysfunction (12.3%).[7] Late RVF carries substantial morbidity and mortality. Regular outpatient echocardiographic assessments, with or without invasive hemodynamics, are an integral component of minimizing decompensated heart failure and are associated with reduced hospital readmission rates.[8] Table II[9,10] summarizes common late LVAD complications.

TABLE I. 2014 INTERMACS Criteria for Post-LVAD RVF and RVF Severity

INTERMACS post-LVAD RVF definition[a]	Classification right ventricular failure severity[b]
Definition includes both • documentation of increased CVP (CVP >16 mm Hg) or dilated IVC without respiratory variation on echocardiography or clinical finding of elevated JVP at least halfway up the neck; and • manifestation of elevated CVP: clinical finding ≥2 peripheral edema or clinical or imaging finding of ascites or hepatomegaly or laboratory finding of worsening hepatic congestion (total bilirubin >2.0 mg/dL) or kidney dysfunction (creatinine >2.0 mg/dL)	Mild RVF: inotropic support ≤7 d Moderate RVF: inotropic support 8-14 d Severe RVF: inotropic support >14 d Acute severe RVF: need for RVAD support

CVP, central venous pressure; INTERMACS, Interagency Registry for Mechanically Assisted Circulatory Support; IVC, inferior vena cava; JVP, jugular venous pressure; LVAD, left ventricular assist device; RVAD, right ventricular assist device; RVF, right ventricular failure.

[a]Adapted from Hall et al. *Frontiers in Cardiovascular Medicine.* 2022;9:893327. Used under the terms of the Creative Commons CC-BY 4.0 license.
[b]Adapted from LaRue et al. *Journal of Heart and Lung Transplantation.* 36(4), 475-477. Used with permission from *Journal of Heart and Lung Transplantation* (Copyright ©2017). Elsevier Inc. All Rights Reserved.

TABLE II. Summary of the Most Common Late LVAD Complications, With Respective Incidence, Acute Evaluation and Management, and Long-Term Therapeutic Considerations

Complication	Incidence	Acute management	Long-term considerations
Infection	Most common are non-LVAD infections. Most common LVAD-specific infections are driveline related.	Systemic antibiotics Judicious fluid administration in sepsis to avoid decompensated heart failure Ultrasonography, CT, or PET/CT imaging if deeper infection suspected TEE for persistent bacteremia	Diabetes control Diligent driveline care Nutritional optimization
Bleeding	Gastrointestinal is the most common source, with 29%-44% related to arteriovenous malformations.[a]	Anticoagulation reversal for hemodynamically significant blood loss/anemia after ruling out aortic root thrombus Gastrointestinal evaluation	LVAD speed adjustments to promote pulsatility Lack of well-validated medical therapies Despite endoscopy, 25% experience re-bleeds[a]
Stroke	Ischemic and hemorrhagic strokes occur in U-shaped distribution, with the highest prevalence early after LVAD implant, then rising again at 9-12 mo.[b]	Ischemic: assess for endovascular therapy Hemorrhagic: rapid anticoagulation reversal, surgical evaluation, blood pressure control (MAP <110 mm Hg)	LVAD speed adjustments to promote pulsatility Optimization of risk factors: hypertension, bacteremia, pump infection, pump thrombosis

CT, computed tomography; LVAD, left ventricular assist device; MAP, mean arterial pressure; PET/CT, positron emission tomography/computed tomography; TEE, transesophageal echocardiography.

[a]Adapted from Vedachalam S, et al. *World Journal of Gastroenterology.* 2020;26(20): 2550-2558. Used under the terms of the Creative Commons Attribution CC-BY-NC 4.0 license.
[b]Adapted from Frontera et al. *Journal of Heart Lung Transplantation.* 36(6), 673-683. Used with permission from *Journal of Heart and Lung Transplantation* (Copyright ©2017). Elsevier Inc. All Rights Reserved.

Future Directions

In light of the growing presence of patients with LVADs in the health care system, there is no shortage of developments and innovations in this field. Further initiatives to create a streamlined definition and better prediction for postoperative RVF will facilitate preoperative patient selection and optimization. The recently developed EVAHEART2 LVAD (Evaheart, Inc) was engineered in part to target lower rates of postoperative RVF; its safety and efficacy are being evaluated in the ongoing COMPETENCE trial. Finally, BiVACOR (BiVACOR, Inc) is a total artificial heart device that is under development and that may fill the void in the need for durable biventricular support.

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References

1. Varshney AS, DeFilippis EM, Cowger JA, Netuka I, Pinney SP, Givertz MM. Trends and outcomes of left ventricular assist device therapy. *J Am Coll Cardiol.* 2022;79(11):1092-1107. doi:10.1016/j.jacc.2022.01.017
2. Hall SA, Copeland H, Alam A, Joseph SM. The "right" definition for post-left ventricular assist device right heart failure: the more we learn, the less we know. *Front Cardiovasc Med.* 2022;9:893327. doi:10.3389/fcvm.2022.893327
3. LaRue SJ, Raymer DS, Pierce BR, Nassif ME, Sparrow CT, Vader JM. Clinical outcomes associated with INTERMACS-defined right heart failure after left ventricular assist device implantation. *J Heart Lung Transplant.* 2017;36(4):475-477. doi:10.1016/j.healun.2016.12.017
4. Rodenas-Alesina E, Brahmbhatt DH, Rao V, Salvatori M, Billia F. Prediction, prevention, and management of right ventricular failure after left ventricular assist device implantation: a comprehensive review. *Front Cardiovasc Med.* 2022;9:1040251. doi:10.3389/fcvm.2022.1040251

5. Wang TS, Cevasco M, Birati EY, Mazurek JA. Predicting, recognizing, and treating right heart failure in patients undergoing durable LVAD therapy. *J Clin Med.* 2022;11(11):2984. doi:10.3390/jcm11112984
6. Gopinathannair R, Cornwell WK, Dukes JW, et al. Device therapy and arrhythmia management in left ventricular assist device recipients: a scientific statement from the American Heart Association. *Circulation.* 2019;139(20):e967-e989. doi:10.1161/CIR.0000000000000673
7. Yuzefpolskaya M, Schroeder SE, Houston BA, et al. The Society of Thoracic Surgeons Intermacs 2022 annual report: focus on the 2018 heart transplant allocation system. *Ann of Thoracic Surg.* 2023;115(2):311-327. doi:10.1016/j.athoracsur.2022.11.023
8. Imamura T, Jeevanandam V, Kim G, et al. Optimal hemodynamics during left ventricular assist device support are associated with reduced readmission rates. *Circ Heart Fail.* 2019;12(2):e005094. doi:10.1161/CIRCHEARTFAILURE.118.005094
9. Vedachalam S, Balasubramanian G, Haas GJ, Krishna SG. Treatment of gastrointestinal bleeding in left ventricular assist devices: a comprehensive review. *World J Gastroenterol.* 2020;26(20):2550-2558. doi:10.3748/wjg.v26.i20.2550
10. Frontera JA, Starling R, Cho SM, et al. Risk factors, mortality, and timing of ischemic and hemorrhagic stroke with left ventricular assist devices. *J Heart Lung Transplant.* 2017;36(6):673-683. doi:10.1016/j.healun.2016.12.010