The Texas Heart Institute® Journal

*Perioperative Mechanical Circulatory Support Symposium*

# Early Intraoperative Detection and Management of Right Ventricular Failure After Left Ventricular Assist Device Implantation

Thomas R. Powell, MD[1,2]

[1]Department of Anesthesiology, Division of Cardiovascular Anesthesia and Critical Care Medicine, Baylor College of Medicine, Houston, Texas
[2]Department of Cardiovascular Anesthesiology, The Texas Heart Institute, Houston, Texas

**Keywords:** Right sided heart failure; right ventricular function; left ventricle; ventricular assist device

## Introduction

Left ventricular assist devices (LVADs) have become an increasingly common therapeutic option for patients with advanced heart failure. Unfortunately, the right ventricle is not afforded the same benefit, and right ventricular failure (RVF) is a major cause of morbidity in patients with LVADs. Early intraoperative diagnosis and management of RVF after LVAD implantation is therefore crucial to improve patient outcomes.

## Current Opportunities for Improvement

Right ventricular failure after LVAD implantation is common, occurring in approximately one-third of patients with third-generation LVADs.[1] However, there are significant challenges in the diagnosis and prediction of RVF.

The first problem is the lack of a universally accepted definition and classification for RVF.[2,3] Two leaders in this arena, the Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) and the European Registry for Patients with Mechanical Circulatory Support (EUROMACS), have different definitions for RVF. Furthermore, individual studies, such as the pivotal MOMENTUM-3 trial,[4] may use their own definitions for RVF. The absence of standardized definitions limits reproducibility and hinders valid comparisons of data.[2]

A second challenge is that RVF remains difficult to predict. Numerous clinical, hemodynamic, and echocardiographic parameters have been proposed for prediction of RVF, including elevated central venous pressure (CVP >15 mm Hg), elevated ratio of right-sided to left-sided filling pressures (CVP/pulmonary capillary wedge pressure >0.63), pulmonary artery pulsatility index (<1.85), and various echocardiographic parameters. Various models have been developed with these parameters. Unfortunately, the best prediction models perform little better than a coin toss for predicting RVF when subjected to independent validation.[5]

## Pathophysiology of RVF

Right ventricular failure results from a multitude of factors after LVAD implantation. First, patients presenting for LVAD placement may have preexisting right ventricular (RV) dysfunction. Second, RV contractility is negatively affected by the loss of interventricular independence as soon as the pericardium is opened,[6] by the leftward shift of the interventricular septum (IVS),[7,8] by impairment of the oblique contraction of the IVS due to the physical

**Citation:** Powell TR. Early intraoperative detection and management of right ventricular failure after left ventricular assist device implantation. *Tex Heart Inst J*. 2023;50(4):e238169. doi:10.14503/THIJ-23-8169
**Corresponding author:** Thomas R. Powell, MD, 6720 Bertner Ave, Room O-520, MC 1-226, Houston, TX 77030 (thomas.powell@bcm.edu)

presence of the LVAD inflow cannula,[8] and by ventricular mechanical dyssynchrony,[9] all of which occur with LVAD implantation. Furthermore, increases in systemic cardiac output from the LVAD increase venous return, leading to volume overload of the right ventricle.

The beleaguered RV is also subject to additional perioperative stresses, such as volume loading from blood transfusions to treat anemia and coagulopathy, exposure to cardiopulmonary bypass, air embolism, hypotension leading to hypoperfusion, and ischemic time if aortic cross-clamping is required for concomitant surgical procedures.

## Early Diagnosis and Management of RVF

The intraoperative diagnosis of early RVF should rely on numerous streams of information, including the patient monitor (eg, blood pressure, CVP, and cardiac output); the LVAD console screen (which can provide information about estimated LVAD flows and, in extreme cases of RVF, show suction alarms); and, most importantly, intraoperative transesophageal echocardiography. Clinical signs, such as hypotension with elevated CVP, may be seen in RVF but are nonspecific. Therefore, transesophageal echocardiography becomes the most important tool for assessment of RV function. Unlike diagnostic echocardiographic studies, which show function at a single time point, intraoperative echocardiographic findings are dynamic. The intraoperative transesophageal echocardiography examination should be recursive with a continual assessment and reassessment of RV size and RV function (using parameters such as the tricuspid annular systolic plane excursion, RV fractional area change, and RV s′ velocity) as well as severity of tricuspid regurgitation and position of the IVS.

Initial management of RVF has several facets. The first goal is to optimize preload. This may be achieved with aggressive diuresis, continuous venovenous hemodialysis, and, if the cardiopulmonary bypass cannulas are in place, direct removal of volume to the venous reservoir. Second is augmentation of RV contractility with inotropic agents such as epinephrine, dobutamine, and milrinone. Right ventricular afterload may be reduced by using pulmonary vasodilators, and though evidence for this is only based on case series,[10] this is the author's universal practice. Another modifiable parameter is LVAD pump speed, which can be decreased to improve the position of the IVS. Finally, for severe and/or refractory RVF, several right ventricular assist devices (RVADs) are available. Options for mechanical support of the RV include the Impella RP (Abiomed); the PROTEK Duo (LivaNova); or a centrifugal pump, such as Centrimag (Abbott) or RotaFlow (Getinge), which connects to the right atrium and pulmonary artery. Venoarterial extracorporeal membrane oxygenation is also an option.

### Abbreviations and Acronyms

| | |
|---|---|
| CVP | central venous pressure |
| EUROMACS | European Registry for Patients With Mechanical Circulatory Support |
| INTERMACS | Interagency Registry for Mechanically Assisted Circulatory Support |
| IVS | interventricular septum |
| LVAD | left ventricular assist device |
| RV | right ventricular |
| RVAD | right ventricular assist device |

For patients who have a struggling right ventricle after LVAD implantation, decisions about the necessity and timing of RV mechanical circulatory support as opposed to medical management alone are important. It should be noted that need for RVAD is associated with elevated mortality following LVAD placement,[3] and long-term options are limited. Available guidelines unfortunately do not delineate specific criteria for intraoperative RVAD placement,[10,11] and data supporting 1 approach over another are extremely limited. However, when RVAD support is indicated, guidelines recommend expeditious decision-making to avoid irreversible end-organ complications.[10] Given these considerations, a proposed intraoperative decision algorithm is presented in Figure 1.

## Future Directions

Despite an improvement in our understanding of RVF over the past several decades, it remains a common complication following LVAD implantation and comes with considerable consequences. There is a need for a standardized definition of RVF and improved predictive models that may help with patient selection. Finally, we need improved treatment options for durable biventricular support. Work is ongoing at The Texas Heart Institute in this regard, the results of which this author looks forward to with great anticipation.

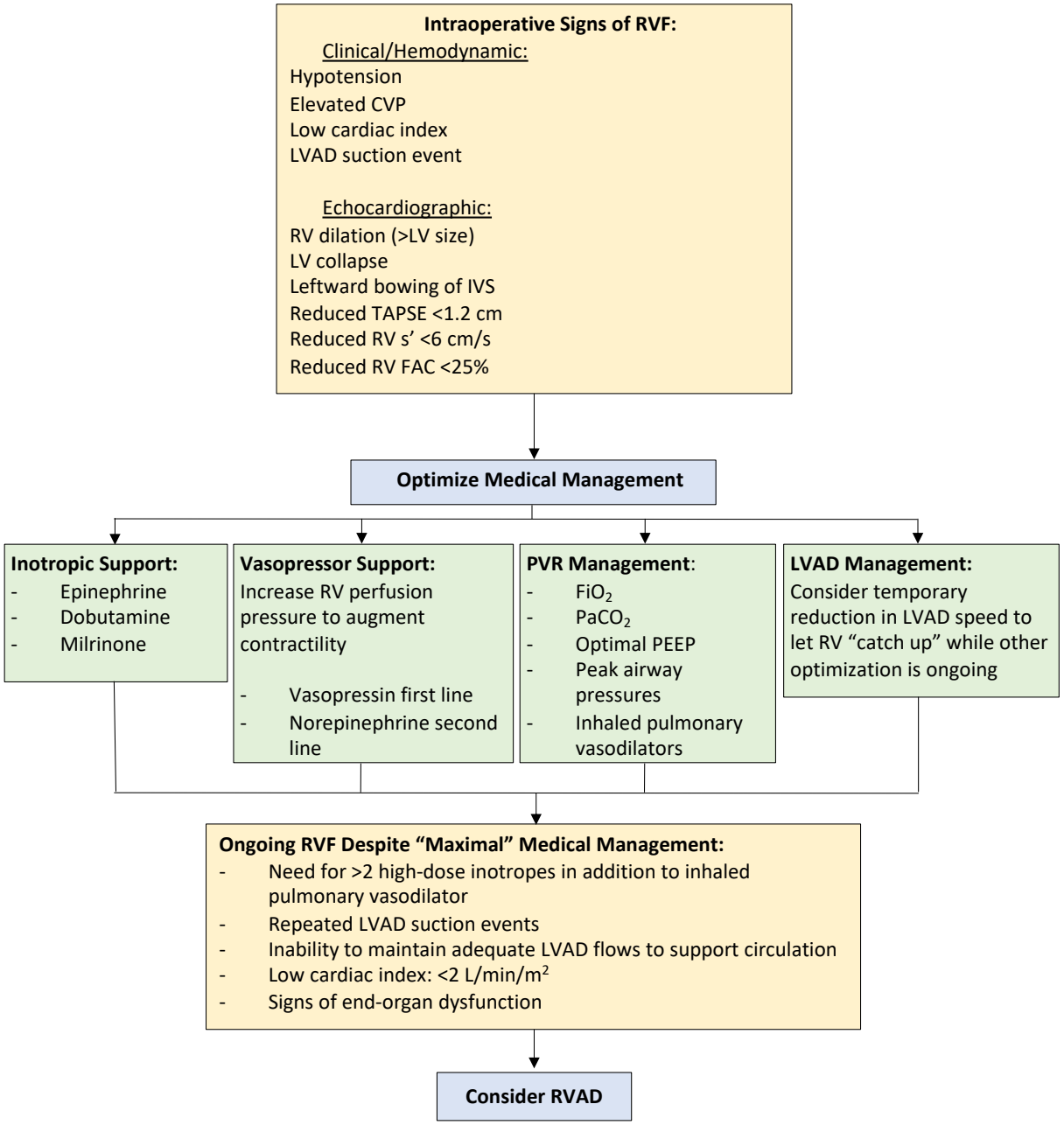


**Fig. 1** Proposed algorithm for intraoperative decision-making for RVF after LVAD implantation.

CVP, central venous pressure; FAC, fractional area change; $FiO_2$, fraction of inspired oxygen; IVS, interventricular septum; LV, left ventricle; LVAD, left ventricular assist device; $PaCO_2$, partial pressure of carbon dioxide; PEEP, positive end-expiratory pressure; RV, right ventricle; RVAD, right ventricular assist device; RVF, right ventricular failure; TAPSE, tricuspid annular systolic plane excursion.

**Published:** 14 July 2023

**Author Contributions:** Thomas R. Powell, MD, was responsible for writing and editing the manuscript. Conceptualization of the topic was done by James M. Anton, MD and José L. Díaz-Gómez, MD, MAS (as part of the MCS conference).

**Conflict of Interest Disclosure:** None.

**Funding/Support:** None.

**Section Editors:** Section Editors: José L. Díaz-Gómez, MD, MAS; James M. Anton, MD.

**Meeting Presentation:** Presented at: 1st Annual Perioperative Mechanical Circulatory Support Symposium & Cutting-Edge Critical Care Echo Workshop; February 24-25, 2023; Houston, TX.

## References

1. Mehra MR, Goldstein DJ, Uriel N, et al. Two-year outcomes with a magnetically levitated cardiac pump in heart failure. *N Engl J Med.* 2018;378(15):1386-1395. doi:10.1056/NEJMoa1800866
2. Frankfurter C, Molinero M, Vishram-Nielsen JKK, et al. Predicting the risk of right ventricular failure in patients undergoing left ventricular assist device implantation: a systematic review. *Circ Heart Fail.* 2020;13(10):e006994. doi:10.1161/circheartfailure.120.006994
3. 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
4. Mehra MR, Naka Y, Uriel N, et al. A fully magnetically levitated circulatory pump for advanced heart failure. *N Engl J Med.* 2017;376(5):440-450. doi:10.1056/NEJMoa1610426
5. Kalogeropoulos AP, Kelkar A, Weinberger JF, et al. Validation of clinical scores for right ventricular failure prediction after implantation of continuous-flow left ventricular assist devices. *J Heart Lung Transplant.* 2015;34(12):1595-1603. doi:10.1016/j.healun.2015.05.005
6. Lampert BC, Teuteberg JJ. Right ventricular failure after left ventricular assist devices. *J Heart Lung Transplant.* 2015;34(9):1123-1130. doi:10.1016/j.healun.2015.06.015
7. Konstam MA, Kiernan MS, Bernstein D, et al. Evaluation and management of right-sided heart failure: a scientific statement from the American Heart Association. *Circulation.* 2018;137(20):e578-e622. doi:10.1161/cir.0000000000000560
8. Houston BA, Shah KB, Mehra MR, Tedford RJ. A new "twist" on right heart failure with left ventricular assist systems. *J Heart Lung Transplant.* 2017;36(7):701-707. doi:10.1016/j.healun.2017.03.014
9. Ramachandran DP, Luo C, Ma TS, Clark JW. Modeling study of the failing heart and its interaction with an implantable rotary blood pump. *Annu Int Conf IEEE Eng Med Biol Soc.* 2011;2011:2403-2409. doi:10.1109/iembs.2011.6090670
10. McGlothlin DP, Granton J, Klepetko W, et al. ISHLT consensus statement: perioperative management of patients with pulmonary hypertension and right heart failure undergoing surgery. *J Heart Lung Transplant.* 2022;41(9):1135-1194. doi:10.1016/j.healun.2022.06.013
11. Bernhardt AM, Copeland H, Deswal A, et al. The International Society for Heart and Lung Transplantation/Heart Failure Society of America Guideline on Acute Mechanical Circulatory Support. *J Heart Lung Transplant.* 2023;42(4):e1-e64. doi:10.1016/j.healun.2022.10.028