Right Ventricular Failure and Biventricular Support Strategies

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KEYWORDS

• Circulatory support devices • Heart failure • Right ventricular failure • BVAD • Total artificial heart

KEY POINTS

- Adequate assessment of right ventricle (RV) before left ventricular assist device surgery is crucial.
- Perioperative management of RV dysfunction is imperative.
- Various temporary and permanent surgical options for RV support are discussed within this article.

INTRODUCTION

Left ventricular assist devices (LVADs) play a vital role in management of patients with end-stage heart failure. Some degree of right ventricular (RV) dysfunction can be observed in most patients with advanced heart failure assessed for LVAD implantation. It has been reported that RV failure (RVF) complicates 10% to 40% of LVAD implants.[1–5] The common working definition of RVF is described by Interagency Registry for Mechanically Assisted Circulatory Support (INTERMACS) as persistent signs and symptoms of RV dysfunction requiring placement of an RV assist device (RVAD), or the use of prolonged intravenous inotropic agents or nitric oxide after an LVAD (**Table 1**).[6] The development of RVF that requires RVAD support in LVAD recipients is associated with high mortality irrespective of the timing of device insertion.[6,7] As per the latest INTERMACS report, the need for RVAD support at the time of original operation is the foremost contributor to early mortality with nearly a fourfold increased risk of death.[8]

Two forms of RVF after LVAD implantation have been described: early and late RVF. The mechanism of early RVF in patients with an LVAD is multifactorial; increased venous return to the RV due to higher cardiac output from the LVAD, excessive leftward shift of the interventricular septum with continuous-flow (CF) LVADs, may also decrease septal contribution to RV contraction[9] leading to RVF.[10] Excessive perioperative volume resuscitation may also exacerbate RV dilation, and causes tricuspid valve incompetence and RVF.[11] Finally, atrial and ventricular tachyarrhythmias occur in more than 20% of patients with an LVAD and double the risk of RVF.[12,13]

The other form of RVF that is an increasingly recognized clinical phenomenon is late RVF (occurring >30 days after LVAD implantation). Recent studies have reported incidence rates of late right heart failure (RHF) of 8% to 11%, and have variably shown elevated central venous pressure/pulmonary artery pressure, HeartMate risk score, diabetes, and worse kidney function to be weakly associated with late RVF.[14,15] The pathophysiology of late RHF is controversial and remains poorly elucidated, but is associated with failure to thrive after LVAD implant.[7]

PERIOPERATIVE ASSESSMENT OF THE RIGHT VENTRICULAR FUNCTION

Important clues to assess RVF can be seen based on clinical examination, including the severity and

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Table 1
Interagency registry for mechanically assisted circulatory support definition of right ventricular failure

RVF definition	Symptoms or findings of persistent RVF characterized by *both* of the following: • Elevated CVP documented by the following: ◦ Right atrial pressure >16 mm Hg on right heart catheterization ◦ Significantly dilated inferior vena cava with no inspiratory variation on echocardiography ◦ Elevated jugular venous pressure • Manifestations of elevated CVP characterized by the following: ◦ Peripheral edema (≥2+) ◦ Ascites or hepatomegaly on examination or diagnostic imaging ◦ Laboratory evidence of worsening hepatic (total bilirubin >2.0 mg/dL) or renal dysfunction (creatinine >2.0 mg/dL)
Severity scale	
Mild	Patient meets *both* criteria for RVF plus the following: • Postimplant inotropes, inhaled nitric oxide, or intravenous vasodilators not continued beyond postoperative day 7 after VAD implant AND • No inotropes continued beyond postoperative day 7 after VAD implant
Moderate	Patient meets *both* criteria for RVF plus the following: • Postimplant inotropes, inhaled nitric oxide, or intravenous vasodilators continued beyond postoperative day 7 and up to postoperative day 14 after VAD implant
Severe	Patient meets *both* criteria for RVF plus the following: • CVP or right atrial pressure >16 mm Hg AND • Prolonged postimplant inotropes, inhaled nitric oxide, or intravenous vasodilators continued beyond postoperative day 14 after VAD implant
Severe-acute	Patient meets *both* criteria for RVF plus the following: • CVP or right atrial pressure >16 mm Hg AND • Need for RVAD at any time after VAD implant OR • Death during VAD implants hospitalization with RVF as primary cause

Abbreviations: CVP, central venous pressure; RVAD, right ventricular assist device; RVF, right ventricular failure; VAD, ventricular assist device.

From Lampert BC, Teuteberg JJ. Right ventricular failure after left ventricular assist devices. J Heart Lung Transplant 2015;34(9):1124; with permission.

extent of lower extremity edema, ascites, hepatomegaly, liver enlargement, and scleral icterus. Further, laboratory and imaging studies to evaluate a patient before support with an LVAD include right heart catheterization, cardiac echocardiography, and blood tests. Blood tests include studies to determine nutritional status (serum protein, albumin and pre-albumin levels), renal function (serum blood urea nitrogen and creatinine levels) and hepatic function (prothrombin time/international normalized ratio (INR), total bilirubin, model of end-stage liver disease score, serum aspartate aminotransferase). A right atrial pressure (RAP) ≥18 mm Hg and a high RAP relative to the pulmonary capillary wedge pressure (PCWP, >0.63) are clues regarding the severity of RV impairment. Another important parameter is the RV stroke work index (RVSWI), which is a measurement of RV function: RVSWI = (mean PAP – mean RAP) × (Cardiac Index/Heart rate).[2,16,17] A low RVSWI has been associated with increased risk for severe RV failure requiring RVAD implantation.[18] Apart from the previously mentioned parameters, the main echocardiographic parameters that correlate with RVF after LVAD implantations are outlined in **Box 1**.[19]

Despite many publications, precise characterization of patients with significant RVF requiring biventricular support has not been described and continues to be center and physician specific. Multiple groups have identified preoperative risk factors and scores for post-LVAD RVF; however, no uniform predictors have yet been widely accepted. These risk scores typically were developed by small single-center studies with various definitions of RVF, leading to inconsistent predictors and no single model dependably forecasting RVF. Furthermore, most were developed in