

Biventricular VAD versus LVAD for right heart failure

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Introduction

Right ventricular failure (RVF) in the era of left ventricular assist device (LVAD) therapy remains a significant problem. Approximately 6% to 10% of patients with an LVAD will require the implantation of a right ventricular assist device (RVAD) (1) with an additional 15% to 20% requiring prolonged inotropic support for RVF (2,3). Several mechanisms may contribute to RVF post LVAD implantation, most importantly the unloading of the left ventricle and resultant loss of septal contribution to right ventricular (RV) function. In addition, perioperative factors such as myocardial ischemia can further compromise a vulnerable right ventricle. As these factors may lead to rescue implantation of an RVAD, which is associated with increased mortality (4), research should focus on identifying patients that would benefit from preemptive implantation of an RVAD. Here we highlight recent advances in the field, focusing on risk stratification scores, the use of pulmonary vasodilators, the use of biventricular assist devices (BIVAD) versus a total artificial heart (TAH), and the use of a temporary RVAD (tRVAD). We also briefly present recent data on right heart recovery post LVAD using tRVAD support.

Highlights of novel risk scores for RVF post-LVAD

There has been much interest in refining RVF risk scores in the setting of newer imaging modalities and continuous flow devices. Three recent studies on risk stratification for RVF post LVAD stand out. The articles highlight the utility of echocardiographic derived RV strain indices coupled with markers of RV function to provide a superior means of scoring and predicting RVF. These recent scores build on previous methods that combine parameters of right heart function (systolic dysfunction or tricuspid regurgitation

severity); severity of heart failure (cardiac index, temporary mechanical support); end organ dysfunction (hepatic, pulmonary and renal); or other demographic or clinical aspects (Table 1) (5-10). Grant *et al.* (11) examined RV function in 117 patients undergoing continuous flow LVAD implantation. Incorporating RV longitudinal strain, the authors demonstrated that RV free wall strain <9.6% was incremental to the Michigan score (8) in stratifying the risk for RV failure post-LVAD implantation: the area under the curve (AUC) of the Michigan score increased from 0.66 to 0.77 ($P<0.01$) when augmented with RV strain. Finally, the authors noted that neither RV fractional area change (FAC), tricuspid annular plane systolic excursion (TAPSE) nor LV-RV geometry were independent predictors of RVF.

Dandel *et al.* (12) focused on echocardiographic measures of the coupling between RV geometry and afterload, which they referred to as the RV load adaptation index (LAI_{RV}). The LAI_{RV} is derived from the velocity time integral (VTI) of tricuspid regurgitation (cm) multiplied by the end diastolic (ED) RV long axis length (cm) divided by RV ED area (cm^2). Accordingly, patients with aberrant geometry and low afterload have low LAI_{RV} values, whereas patients with preserved RV geometry and maintained afterload have a higher LAI_{RV} . In 205 patients, LAI_{RV} predicted RV failure with an AUC of 0.906. As well, authors confirmed RV longitudinal strain as a relevant parameter for preoperative risk stratification.

Atluri *et al.* (6) devised a new RV risk score (the CRITT score) during the current era of continuous flow devices. The CRITT score includes the five following parameters: central venous pressure >15 mmHg (C), severe RV dysfunction (R), preoperative intubation (I), severe tricuspid regurgitation (T) and tachycardia defined by heart rate >100 bpm (T). The CRITT score attributes a risk varying from 0 to 5,

Table 1 Classification of the independent risk factors for post-LVAD RVF into four categories derived from eight studies

Study	Right ventricular specific	Hemodynamic and support	Hepatorenal function	Others
U Penn score, Fitzpatrick <i>et al.</i> (5)	Severe RVD, RVSWI	CI, SBP	Creat	–
CRITT score, Atluri <i>et al.</i> (6)	Severe RVD, CVP, severe TR	Intubation, tachycardia	–	–
Utah score, Drakos <i>et al.</i> (7)	–	PVR, IABP, inotrope	–	Destination therapy, ACE or ARB, beta blockers, obesity
Michigan score, Matthews <i>et al.</i> (8)	–	Vasopressor	AST, bilirubin, creat	–
Ochiai <i>et al.</i> (9)	Not included in analysis	Circulatory support	–	Non-ischemic cardiomyopathy
Kormos <i>et al.</i> (10)	CVP	Ventilatory support	BUN	–
Grant <i>et al.</i> (11)	Peak strain	*	*	–
Dandel <i>et al.</i> (12)	LAI _{RV} , peak strain, TAPSm, S/L _{ED} , CVP, MPAP	–	–	–

*, Michigan score. LVAD, left ventricular assist device; RVF, right ventricular failure; RVD, right ventricular dysfunction; RVSWI, right ventricular stroke work index; CI, cardiac index; SBP, systemic blood pressure; Creat, creatinine; CVP, central venous pressure; TR, tricuspid regurgitation; PVR, pulmonary vascular resistance; IABP, intra-aortic balloon pump; ACE or ARB, angiotensin-converting enzyme and/or angiotensin II receptor blocker; AST, aspartate aminotransferase; BUN, blood urea nitrogen; LAI_{RV}, load adaptation index; TAPSm, tricuspid lateral annulus peak systolic wall motion velocity; S/L_{ED}, axis ratio, end diastolic short-/long-axis ratio; MPAP, mean pulmonary artery pressure.

with scores of 1 to 2 representing a negative predictive value for RVAD of 93%. The score is in part an extension of the previously published Penn score (5) but has the advantage of incorporating routinely obtained echocardiographic information, imparting the CRITT score with a superior discrimination for RV failure compared to the Michigan score.

Taken together, these recent scoring systems highlight the power and utility of incorporating echocardiographic information to augment invasive hemodynamic and biomarker measurements. While further validation is required, these scoring approaches offer valuable insight into providing a preemptive strategy for RVAD implantation in high risk cohorts.

Highlights of the use of pulmonary vasodilators in patients at risk of RVF

Inhaled nitric oxide or oral sildenafil are often used either peri-operatively or after LVAD implantation in patients deemed high risk for RVF. In a small prospective randomized study, Potapov *et al.* (13) demonstrated that the use of inhaled nitric oxide after LVAD implantation did not decrease the incidence of RVE. In a recent, open-labeled controlled trial

by Tedford *et al.* (14), sildenafil decreased pulmonary vascular resistance and improved hemodynamic indices of right heart function after LVAD implantation when compared to the control group. Although these studies show a desired measurable physiologic effect, the use of either nitric oxide or phosphodiesterase inhibitors does not yet demonstrate a clear benefit with regards to preventing RVF.

Highlights of the surgical management of patients at risk of RVF

Surgical management of patients at risk of RVF is challenging and lends itself to two crucial questions: (I) whether a TAH should be considered instead of a BIVAD; and (II) what is the role of a tRVAD. Kirsch *et al.* (15) recently reported a large multicenter experience in France comparing the use of BIVAD support and a TAH. There was no significant difference between groups in survival while on support. The main difference was the higher incidence of stroke in the patients with BIVAD therapy, with a trend toward increased survival in the TAH group after 90 days attributed to a decreased incidence of neurologic events. However, not all patients at risk of RVF should be considered for permanent

biventricular support.

Advances in the field of tRVADs have allowed devices to be removed within days or weeks as a bridge to RV recovery, or switched to long-term RVAD support if needed. These advances include the use of right atrium to pulmonary artery extracorporeal life support that may be implanted peroperatively and removed percutaneously (16,17). Delayed or unplanned implantation of a tRVAD proves to be an important risk factor for mortality in LVAD recipients (5). Moreover, Takeda *et al.* (18) highlighted the important prognostic value of RV recovery after unplanned tRVAD implantation. In their experience, patients not weaned from unplanned-tRVAD had a 6-month actuarial survival of 13%, whereas patients weaned from unplanned-tRVAD and those who underwent planned BIVAD implantation had a significantly higher survival (62% and 75%, respectively). This study shows that conditions leading to unplanned RVAD support may alter possibilities from RV recovery that significantly decrease early survival after LVAD implantation. Future studies should focus on recognition of perioperative factors impairing RV function and recovery after LVAD implantation.

Other studies demonstrate the potential benefit of early tRVAD use to avoid unplanned RVAD implantation. Lazar *et al.* (19) demonstrated that planned tRVAD implantation in low risk LVAD recipients was a safe approach with a high rate of tRVAD weaning (91.1%). Their results also showed that patients successfully weaned from tRVAD support had similar in-hospital mortality to those requiring isolated left ventricular support.

Conclusions

This review highlights recent advances in the preoperative risk stratification of RVF in patients requiring left ventricular mechanical circulatory support. Such stratification aims to guide planned surgical therapy for RVF including tRVAD, BiVAD or TAH implantation in order to decrease postoperative RVF and mortality associated with rescue therapy. Future studies should validate and improve these models, allowing us to better predict who will need biventricular support, and whether that support should be considered as a bridge to RV recovery, or as a destination RV support therapy.

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