RIGHT HEART FAILURE

Management for Pediatric VADs

**BACKGROUND** We do not have a great solution for long term RV MCS. Progressive RV dysfunction causes end-organ damage; often jeopardizing LVAD and transplant candidacy. RV failure in LVAD pediatric patients has an incidence of up to 50% and is associated with increased mortality on device. Prevention and/ or early identification of RV failure is of utmost importance.

**ACTION REVISED DATE:** 02/18/2020

**OBJECTIVES**

1. To define RV failure
2. To identify and understand risk factors and predictors of RV failure
3. Guidelines for monitoring and evaluation of RV failure
4. Medical and surgical management options and algorithms for treatment of RV failure when it develops

**PROTOCOL**

1. ***Definition of right heart failure after VAD***

**Intermacs/Pedimacs definition:** Symptoms or findings of persistent RV failure characterized by **both** of the following**1**

* *Documentation of elevated central venous pressure (CVP) by:*
* Direct measurement (e.g., right heart cath) with evidence of a CVP or right atrial pressure (RAP) > 16 mmHg in adult sized patients or elevated in a child, **OR**
* Findings of significantly dilated IVC with absence of inspiratory variation by echo, **OR**
* Clinical findings of elevated jugular venous distension at least half way up the neck in an upright adult sized patient.
* *Manifestations of elevated central venous pressure characterized by:*
* Clinical findings of peripheral edema (>2+ either new or unresolved), **OR**
* Presence of ascites or palpable hepatomegaly on physical examination or by diagnostic imaging, **OR**
* Laboratory evidence of worsening hepatic (total bilirubin > 2.0 mg/dl in an adult sized patient) or renal dysfunction (creatinine > 2.0 mg/dl in adults).

 IF the patient meets the definition for right heart failure, the severity of the right heart failure will be graded according to the following scale below. (NOTE: For right heart failure to meet severe or severe acute severity, direct measurement of central venous pressure or right atrial pressure must be one of the criteria)

***Right Heart Failure Severity Grade***

1. **Mild Right Heart Failure**
* **VAD Implant Admission**

 **Patient meets both criteria for RHF plus:**

* Inotropes, inhaled nitric oxide or intravenous vasodilators not continued beyond post-op day 7 following VAD implant
* **Surveillance periods (3 months, 6 months, 12 months and every 6 months thereafter) following VAD implant**

**Patient meets both criteria for RHF plus:**

* No readmissions for RHF since last surveillance period  **AND**
* No inotropes since last surveillance period.
1. **Moderate Right Heart Failure**
* **VAD Implant Admission**

 **Patient meets both criteria for RHF plus:**

* Post-implant inotropes, inhaled nitric oxide or intravenous vasodilators continued beyond post-op day 7 and up to post-op day 14 following VAD implant
* **Surveillance periods (3 months, 6 months, 12 months and every 6 months thereafter) following VAD implant**

 **Patient meets both criteria for RHF plus:**

* Limited to **one (1)** readmission for intravenous diuretics/vasodilators to treat RHF since last surveillance period **AND**
* No inotropes since last surveillance period
1. **Severe Right Heart Failure**
* **VAD Implant Admission**

 **Patient meets both criteria for RHF plus**:

* Central venous pressure or right atrial pressure greater than 16mm Hg **AND**
* Prolonged post-implant inotropes, inhaled nitric oxide or intravenous vasodilators continued beyond post-op day 14 following VAD implant
* **Surveillance periods (3 months, 6 months, 12 months and every 6 months thereafter) following VAD implant**

 **Patient meets both criteria for RHF plus:**

* Need for inotropes at any time since last surveillance period **OR**
* Two (2) or more readmissions for intravenous diuretics/vasodilators to treat RHF since last surveillance period **OR**
* Requiring RVAD support at any time after hospital discharge **OR**
* Death at any time following discharge from the VAD implant hospitalization with RHF as the primary cause.
1. **Severe-Acute Right Heart Failure**
* **VAD Implant Admission**

 **Patient meets both criteria for Right Heart Failure plus:**

* Central venous pressure or right atrial pressure greater than 16 mmHg **AND**
* Need for RVAD at any time following VAD implant **OR**
* Death during the VAD implants hospitalization with RHF as the primary cause.
1. ***Predictors of right heart failure***

**Patient selection and timing of implant appear to be key components to avoiding/preparing for RHF. However no variables exist that can reliably predict right heart failure independently.**

**Data are limited in pediatrics. The largest, a Pedimacs analysis, identified the following factors associated with RHF: 14**

**female gender**

**Intermacs profile 1**

**younger age**

**smaller BSA**

**chemical paralysis during first week post-LVAD**

**pulsatile flow devices.**

**The following associations are from adult RHF risk models that perform only modestly when applied to different adult cohorts and may not be directly applicable to the pediatric population.**

* **Demographic/ clinical10**
	+ Female gender
	+ Prior cardiac surgery
	+ Inotrope dependency or vasopressor use
	+ Need for mechanical ventilation
	+ Extremes of age, lower BSA
	+ Pre-operative circulatory support
	+ Advanced InterMACS profile
* **Biochemical (markers of end organ damage)**
	+ Elevated serum creatinine (> 2 in adults) or elevated for age
	+ Elevated BUN (> 39 in adults) or elevated for age
	+ Elevated AST, INR and total bilirubin (>2.0)
	+ Persistently elevated pro BNP post-implant
* **Echocardiographic2, 3, 4, 5,6**
	+ Severe systolic RV dysfunction
	+ Severe TR
	+ RV fractional area change (RVFAC) measured in apical 4 chamber view using the formula RV end-diastolic area – RV end-systolic area)/ RV end-diastolic area. Impairment in RV function <30%.
	+ RVS – peak longitudinal strain, speckle tracking measures RV contractile function. A peak strain cut off of -9.6% in adults predicts post LVAD RV failure with a specificity of 76% and a sensitivity of 68%. Age based norms exist in Pediatrics.
	+ Tricuspid annular plane systolic excursion (TAPSE). Independent of ventricular geometry. Tricuspid valve annular motion < 7.5 mm in adults, or lower than normal age-related reference values.
	+ Increased RV to LV end-diastolic diameter ratio- poor reproducibility
* **Hemodynamic6,7**
	+ Elevated CVP/ RAP or CVP/ pulmonary capillary wedge pressure > 0.63
	+ Low cardiac index
	+ Lower mean PAP
	+ Elevated PVR

*In adult sized patients can consider*

* + Low RV stroke work index: (Mean PAP – mean RAP)/ stroke volume. < 300 mm/mL/m2. Preload dependent
	+ Lower Pulmonary artery Pulsatility Index (PAPi) : systolic PAP – diastolic PAP)/ CVP in CF-VADs predicts need for RVAD**8**
* **Intra-operative events**
	+ Ischemia from prolonged bypass, blood transfusions, bleeding and shock
	+ Disruption of bypass grafts or coronaries supplying RV
	+ Air embolism
	+ Sub-optimal ventilation, alveolar hypoxia, hyperinflation or atelectasis that increases PVR
	+ Acidosis causing ischemic injury

**3. Evaluation for right heart failure**

To make the diagnosis of right heart failure, the following patient domains must be carefully and frequently monitored and assessed.

**Symptoms –** GI complaints, poor feeding, exercise intolerance

**Physical exam –** Jugular venous distention, Tachypnea, Tachycardia, Holosystolic murmur (TR), Heave, Hepatomegaly, Edema, Ascites, Pleural effusions

**Labs –** transaminases (ALT may be more specific), total/direct bilirubin, BUN, creatinine, cystatin C, BNP or NT-proBNP

**Echo –** RV size, function (*see above* for specific measurements), dilated IVC

**Hemodynamics –** CVP, hypotension, *see above*

**VAD –** Evidence of decreased LVAD preload: decreased pulsatility/flows (CF device) or filling (pulsatile device)

**4. Medical management of right heart failure**

**PREOPERATIVE**

* Perform careful echocardiogram and consider right heart catheterization to assess RV function and for risk assessment. *See above for specifics.*
* Minimize preload – aim for lower CVP with diuresis and fluid restriction.
* Maximize end organ function – timely/earlier referral for LVAD to avoid cardiogenic shock, consider temporary circulatory support for patients in shock to recover end organ function prior to durable LVAD implantation.

**INTRAOPERATIVE**

* Careful myocardial preservation techniques
* Complete deairing to avoid air embolism to the right coronary artery
* Aggressive intraoperative ultrafiltration while on bypass.
* Minimizing crossclamp time
* Minimize transfusions and excessive fluid
* Avoid acidosis, hypercapnia, hypoxemia
* Wean off of bypass on inotropic support, not hypervolemic, stable respiratory status with supplemental oxygen and many centers report to using iNO, especially in the setting of elevated PVR.
* Slow, careful uptitration of LVAD with transesophageal echocardiographic and hemodynamic guidance – keep interventricular septum midline/neutral and rounded if possible. Avoid excessive RPM and significant leftward shift of the septum.
* Consider concomitant tricuspid valvuloplasty in the setting of significant baseline tricuspid regurgitation

**POSTOPERATIVE**

***Minimize preload***

* Fluid restrict (to 1/3 to 2/3 maintenance rate as tolerated). Avoid unnecessary fluid boluses. Diurese aggressively. Aim for CVP <12 or lower as tolerated. Consider renal replacement therapies (ultrafiltration, dialysis) early if fluid overloaded and unresponsive to escalating, high dose diuretics.

***Minimize RV afterload***

* Adequate respiratory support to avoid hypoxemia and hypercapnia. Avoid excessive positive pressure and extubate as soon as clinically feasible.
* Continue/consider iNO. Transition from iNO to sildenafil for chronic therapy, especially in the setting of baseline elevated PVR. Consider additional selective pulmonary vasodilators in select patients with high baseline PVR.

***Maximize RV contractility/output***

* Centers will often use combination of milrinone (inotropy and pulmonary vasodilation) and another inotropic agent (dopamine, epinephrine, dobutamine) for RV support and systemic afterload reduction if needed.
* Wean support carefully while monitoring for symptoms, exam, hemodynamics and end organ function.
* Maintain sinus rhythm, treat arrhythmias, consider pacing for any relative bradycardia to improve RV output.
* Consider digoxin

***Optimize VAD***

* Evidence of decreased LVAD preload (decreased pulsatility in continuous flow devices or decreased filling in pulsatile devices) and decreased LVAD flows/output should raise concern for RV failure in the absence of bleeding/hypovolemia.
* Ensure appropriate VAD settings by echocardiogram: LV decompression while keeping interventricular septum midline/neutral and rounded if possible. Avoid significant leftward shift of the septum. Close attention to tricuspid regurgitation and RV size.
* Low threshold for catheterization, hemodynamic assessment and VAD ramp study to identify optimal settings.

**LATE or CHRONIC RIGHT HEART FAILURE**

* Consider other comorbidities and contributors including obesity, pulmonary stenosis, pulmonary embolism, obstructive sleep apnea, tamponade, device thrombosis, liver/renal dysfunction.
* Obtain hemodynamic catheterization and optimize device as above
* Acute management principles as above

**5. Mechanical circulatory support for right heart failure**

* In the setting of significant RV dysfunction, mechanical RV support should be considered (as early as in the OR) to avoid significant end organ dysfunction and to maximize possibility of RV recovery.
* Elective/planned/earlier RVAD is associated with better long-term survival than emergency RVAD implantation.
* Severe right heart failure despite optimal medical management should prompt consideration for MCS.
* Choice of RVAD device depends on patient size, center experience, device availability and anticipated duration of support. Most commonly used ‘temporary’ devices include paracorporeal CF (Centrimag, Rotaflow) and percutaneous (Impella RP, Protek Duo). Dependent on patient size, potential durable, longer-term options include intrapericardial (HVAD, Heartmate 3), paracorporeal (Berlin Heart, Centrimag) or Total Artificial Heart devices.

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***Disclaimer:*** *The ACTION network is focused on quality improvement efforts such as harmonizing best practice protocols, disseminating them among institutions, and helping centers to improve care practices at the local level. This protocol was developed as a consensus tool for pediatric VAD programs. The information in the protocols are based on center practices, individual opinions, experiences, and, where available, published literature. Centers may choose to adapt this protocol to include in their center-specific protocols with reference to ACTION with the understanding that these are meant as guidelines and not standard of care. (Revised: 02/18/2020)*

References

1. InterMACS Adverse Event Definitoons : Adult and Pediatric patients. Manual of Operations Version 5.0, appendix D. <https://www.uab.edu/medicine/intermacs/images/protocol_5.0/appendix_a/AE-Definitions-Final-02-4-2016.docx>
2. Acute and Long-term effects of LVAD support on right ventricular function in children with pediatric pulsatile ventricular assist devices. Iacobelli R, Di Mofetta A, Brancaccio G, Filippelli S, Natali B, Toscano A, Drago F, Amodeo A. ASIAO Journal 2018;64:91-97
3. Predictors and management of right heart failure after left ventricular assist device implantation. Fida N, Loebe M, Estep J, Guha A. Methodist Debakey Cardiovasc J. 2015 Jan-Mar; 11(1): 18–23.
4. Serial changes in right ventricular systolic function among rejection free children and young adults after heart transplantation. Harrington J, Richmond M, Woldu K, Pasumarti N, Kobsa S, Freud L. J Am Soc Echocardiogr. 2019 Aug; 32(8):1027-1035.
5. Preoperative evaluation and management of right ventricular failure after Left ventricular assist device implantation. Marzec L and Ambardekar A. Seminars in Cardiothoracic and Vascular Anesthesia 2013 17(4)249-261
6. Echocardiographic parameters associated with RV failure after LVAD: a review. Neyer J, Arsanjani R, Moriguchi J, Siegel R, Kobashigawa J J heart Lung Transplant 2016;35:283-293
7. Evaluation and Management of Right-Sided Heart Failure: A Scientific Statement from the American Heart Association. Konstam MA, Kiernan MS, Bernstein D, et al. Circulation. 2018; 137:e578-e622.
8. Pulmonary artery pulsatility index predicts right ventricular failure after left ventricular assist device implantation. Kang G, Ha R, Banerjee D. J Heart LungTransplant2016;35:67–73
9. The risk of right ventricular failure with current continuous-flow left ventricular assist devices. Loforte A, Grigioni F and Marinelli G. Expert Review of Medical Devices, 2017 14:12, 969-983
10. Prevention and Treatment of Right Ventricular Failure During Left Ventricular Assist Device Therapy. Raina A and Patarroyo-Aponte M. *Crit Care Clin*. 2018; 34:439-452.
11. Right ventricular failure after left ventricular assist devices. Lampert BC and Jeffery Teuteberg. J Heart Lung Transplantation 2015;34:1123-1130
12. Right ventricular failure after LVAD implantation: prevention and treatment. Meineri M, Van Rensburg AE and Vegas A. *Best Pract Res Clin Anaesthesiol*. 2012; 26:217-29.
13. Left ventricular assist device implantation with and without concomitant tricuspid valve surgery: a systematic review and meta-analysis. Veen KM, Muslem R, Soliman OI, Caliskan K, Kolff MEA, Dousma D, Manintveld OC, Birim O, Bogers A and Takkenberg JJM. *Eur J Cardiothorac Surg*. 2018;54:644-651.
14. Right heart failure with left ventricular assist device implantation in children: an analysis of the Pedimacs registry database. Simpson, KE, Kirklin JK, Cantor RS, Mehegan M, Lamour JM, Guleserian KJ, Peng DM, and Pahl E. *J Heart Lung Transplant 2020; article in press.*