Right Heart Failure in LVAD patients: Prevention and Management.
Conflict of Interest

• No Financial Disclosures.
Interaction RV and LVAD support

Interplay between LVAD support, combined pre and post capillary HT and RV function

Sparrow JACC HF 2018; 11:e004255
INTERMACS definition of RVF

• Symptoms and Signs of persistent RVF following LVAD implantation characterized by:

• Elevated CVP documented by:
  ○ Right atrial pressure >16 mmHg 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:
  ○ Peripheral edema(>2+)
  ○ Ascites or hepatomegaly on exam or diagnostic imaging
  ○ Laboratory evidence of worsening hepatic (total bilirubin >2.0 mg/dl) or renal dysfunction (creatinine >2.0 mg/dl)
Severity of Post-op RV Failure

<table>
<thead>
<tr>
<th>SEVERITY</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MILD</td>
<td>RHF requiring IV inotropes or vasodilators and/or iNO used for less than 7 days post-implantation</td>
</tr>
<tr>
<td>MODERATE</td>
<td>Persisting RHF requiring IV inotropes or vasodilators and/or iNO used for &gt; 7 days post-implantation but ≤ 14 days post-implantation</td>
</tr>
<tr>
<td>SEVERE</td>
<td>Persisting RHF requiring IV inotropes or vasodilators and/or iNO used for &gt; 14 days post-implantation or implantation of MCS device for RV support at any time.</td>
</tr>
</tbody>
</table>

2.6 fold increase in mortality at 6 months
Clinical outcomes associated with INTERMACS-defined right heart failure after left ventricular assist device implantation

306 pt with less than severe RVD and 139 with severe RVD, St Louis

Severe RVD has profound effect in survival and clinical outcomes

Larue  JHLT 2017
Right Ventricular Failure

- 9-44% incidence in VAD eligible
- 5-20% post-LVAD incidence
- RVF:
  - Increased mortality
  - Multi-system organ failure
  - Coagulopathy
  - Hemorrhage
  - Pulmonary failure
  - Thromboembolic complications

Circ Cardiovasc Imaging 2014
Kalogeropoulos JHLT 2015
Kormos JTCVS 2010
Genovese Ann Thor Surg 2009
Fitzpatrick JHLT 2008
Morgan Ann Thor Surg 2004
Slaughter JHLT 2010
Surgical RVAD’s in the US: Eighth INTERMACS Reports

3.5% CF LVAD require RVAD

J Heart Lung Transplant 2017;36:1080–1086
RV Risk Assessment

- Risk Scores:
  - Michigan
  - Penn BIVAD
  - Penn CRITT
  - Berlin
  - Utah
  - U. Pitt
  - HM II

- Clinical: MV, RF, LVD, INTMCS
- Hemodynamics: CVP, RVSWI, CVP:PCWP, PVR, TPG, PA pressure
- Echo: RV Failure, TAPSE, TR, 3D TEE

Matthews JC JACC 2009
Fitzpatrick JR JHLT 2008
Drakos SGAm J Card 2010
Atluri P Ann Thor Surg 2014
Potapov JHLT 2008
Wang Y JHLT 2012
Kormos JTCVS 2010
Kiernan J Card Failure 2015
Clinical Tools for Assessing Risk for Right Ventricular Failure or Mortality After LVAD Since 2008

<table>
<thead>
<tr>
<th>Publication</th>
<th>First author date</th>
<th>Devices implanted</th>
<th>Components of score</th>
<th>Definition of RV failure</th>
<th>Major findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poirier¹⁸</td>
<td>2008</td>
<td>Pulmonary 50% Continuous 25%</td>
<td>1. Cardiac index 2. RV stroke work index 3. Swan RV dysfunction 4. Peripartum cardiomyopathy 5. Previous cardiac surgery</td>
<td>Need for inotropic support</td>
<td>Sensitivity of 86% and specificity of 88% to predict survival/LVAD support using a cutoff of 0.5 (p&lt;0.001)</td>
</tr>
<tr>
<td>Maharajan²³</td>
<td>2008</td>
<td>Pulmonary 50% Continuous 15%</td>
<td>1. Preoperative right heart failure 2. Swan RV dysfunction 3. Increasing tricuspid regurgitation at discharge or on intensive care</td>
<td>Need for post-operative inotropic support for &gt;14 days, followed by RV failure for &gt;8 weeks, right atrial and/or RV pressure 4. Swan RV dyskinesis</td>
<td>Area under the ROC curve for the risk score was 0.73 ± 0.04</td>
</tr>
<tr>
<td>Doshi⁴</td>
<td>2011</td>
<td>Pulmonary 50% Continuous 14%</td>
<td>1. Preoperative RV failure 2. Increased PRA 3. Dusting therapy 4. Inotropic dependency 5. Obesity</td>
<td>Need for initial inotropic support for &gt;48 hours, RV inotrope &gt;14 days and/or RV device insertion</td>
<td>Area under the ROC curve to predict RV failure was 0.743 ± 0.027</td>
</tr>
<tr>
<td>Kurosaka²⁴</td>
<td>2011</td>
<td>Pulmonary 50% Continuous 15%</td>
<td>1. RV-to-LV end-diastolic diameter (LV/LD) ratio obtained from transesophageal echo</td>
<td>Need for inotropic support &gt;14 days</td>
<td>Area under the ROC curve of 0.742</td>
</tr>
</tbody>
</table>

J HeartLungTransplant 2016;35:283–293
EUROMACs Right Sided-HF Risk Score

Risk score components:

9.5-point risk score (5-item)
- Severe RV dysfunction on semi quantitative echocardiography (2 points)
- Ratio of RA to PCWP ≥ 0.54 (2 points)
- INTERMACS class 1 through 3 (2 points)
- Need of ≥3 inotropic agents (2.5 points)
- Hemoglobin ≤10 g/dL (1 point).

0-2: Low risk
2.5-5: Intermediate risk
> 4: High risk

Includes only the 3 most used CF pumps (HMII, HW, HMIII)
How do we prevent and manage acute perioperative RVF....
Pre-operative Optimization RV

- Diuresis (Lasix Drip/ CVVH, target CVP<15 mmhg)
- Preoperative Inotropic Support (Milrinone preferred over Dobutamine).
- IABP
RV Pre- and Post-Optimization
Preoperative IABP

Intra-Aortic Balloon Pump Use Before Left Ventricular Assist Device Implantation: Insights From the INTERMACS Registry

Despite markers of higher risk in patients with IABP use, we found no significant difference in 30 day outcomes compared to those without. The results suggest that IABP use may mitigate risk of early postoperative adverse outcomes in select patients.

ASAIO Journal 2018; 64:218–224
Intra-and Perioperative Strategies to Prevent/Treat RV Failure

**Surgical Strategies**
- TV Repair
- Minimize CPB
- Avoid bleeding /prevent transfusions
- Delayed chest closure
- Adjust LVAd flow (avoid septal shift)
- RVAD (early implantation)

**Perioperative management**
- Nitric Oxide or inhaled prostacyclin
- TEE monitoring of RVF
- Inotropic support to Maintain systolic BP and avoid vasodilation
  - Milrinone
  - Epinephrine
  - Isoproterenol
- Ventilator strategies
  - Maintain O2 and reduce CO2 (avoid hypercarbia)
Right heart failure and benefits of adjuvant tricuspid valve repair in patients undergoing left ventricular assist device implantation

141 LVAD /69 TVr

Right heart failure and benefits of adjuvant tricuspid valve repair in patients undergoing left ventricular assist device implantation

Tricuspid valve repair is a useful and durable adjuvant procedure for restoring deteriorated right ventricular function in patients requiring LVAD implantation.

Concomitant tricuspid valve surgery during implantation of continuous-flow left ventricular assist devices: A Society of Thoracic Surgeons database analysis.

TVP was associated with an increased risk for postoperative renal failure (RR, 1.53; 95% CI, 1.13–2.08; \( p = 0.0061 \)), dialysis (RR, 1.49; 95% CI, 1.03–2.15; \( p = 0.0339 \)), reoperation (RR, 1.24; 95% CI, 1.07–1.45; \( p = 0.0056 \)), greater total transfusion requirement (RR, 1.03; 95% CI, 1.01–1.05; \( p = 0.0013 \)), and hospital length of stay >21 days (RR, 1.29; 95% CI, 1.16–1.43; \( p < 0.0001 \)). Time on the ventilator and intensive care unit length of stay were also significantly prolonged for the LVAD +TVp group.

The Journal of Heart and Lung Transplantation, Vol 33, No 6, June 2014
Continuous Flow Left Ventricular Assist Device Implant Significantly Improves Pulmonary Hypertension, Right Ventricular Contractility, and Tricuspid Valve Competence

Conclusion: Continuous flow LVAD implant improves pulmonary hypertension, RV function, and tricuspid regurgitation. TR may be managed non-operatively during CF LVAD implant.

J CARD SURG ATLURI, ET AL. 771 2013;28:770–775
Inhaled nitric oxide after left ventricular assist device implantation: A prospective, randomized, double-blind, multicenter, placebo-controlled trial

105 patients randomized to receive 40ppm NO vs placebo at time of weaning from bypass

Use of iNO at 40 ppm given before separation from CPB did not reach statistical significance for the primary end point of reduction in RVD incidence. No statistically significant difference was found for secondary variables, including time on mechanical ventilation, ICU or hospital stay, and the need for RVAD after LVAD placement.

Table 5  Primary and Secondary Outcome Measures in the Intent-to-Treat Population

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>iNO</th>
<th>Placebo</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of total (%)</td>
<td>7/73 (9.6)</td>
<td>12/77 (15.6)</td>
<td>0.330</td>
</tr>
<tr>
<td>95% CI</td>
<td>2.8–16.3</td>
<td>7.5–23.7</td>
<td></td>
</tr>
<tr>
<td>Males, No. (%)</td>
<td>7/64 (10.9)</td>
<td>7/65 (10.8)</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>Females, No. (%)</td>
<td>0/9 (0.0)</td>
<td>5/12 (41.7)</td>
<td>0.045</td>
</tr>
<tr>
<td>PVR &lt;270.5 dyne/sec/cm²</td>
<td>6/51 (11.8)</td>
<td>6/48 (12.5)</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>PVR ≥270.5 dyne/sec/cm²</td>
<td>1/7 (14.3)</td>
<td>5/7 (71.4)</td>
<td>0.103</td>
</tr>
<tr>
<td>Days on mechanical ventilation</td>
<td>70</td>
<td>67</td>
<td>0.077</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>5.37 (7.72)</td>
<td>11.10 (24.81)</td>
<td></td>
</tr>
<tr>
<td>Median (range)</td>
<td>2.0 (1–30)</td>
<td>3.0 (0–160)</td>
<td></td>
</tr>
<tr>
<td>No. of ICU days</td>
<td>60</td>
<td>58</td>
<td>0.630</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>20.52 (32.31)</td>
<td>19.90 (24.38)</td>
<td></td>
</tr>
<tr>
<td>Median (range)</td>
<td>11.0 (3–194)</td>
<td>9.0 (3–115)</td>
<td></td>
</tr>
<tr>
<td>No. of total hospital days</td>
<td>58</td>
<td>58</td>
<td>0.979</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>40.57 (32.19)</td>
<td>40.76 (29.41)</td>
<td></td>
</tr>
<tr>
<td>Median (range)</td>
<td>32.0 (11–194)</td>
<td>31.5 (10–156)</td>
<td></td>
</tr>
<tr>
<td>Quantity of blood products used</td>
<td>73</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Mean, ml (SD)</td>
<td>4,232 (4,675)</td>
<td>4,885 (7,760)</td>
<td>0.226</td>
</tr>
<tr>
<td>Patients requiring RTR, No. (%)</td>
<td>19/71 (27.0)</td>
<td>8/70 (11.4)</td>
<td>0.037</td>
</tr>
<tr>
<td>Non-survival at Day 28, No. (%)</td>
<td>8/71 (11.3)</td>
<td>8/70 (11.4)</td>
<td>0.924</td>
</tr>
<tr>
<td>Patients needing RVAD by Day 28, No. (%)</td>
<td>4/71 (5.6)</td>
<td>7/70 (10.0)</td>
<td>0.468</td>
</tr>
</tbody>
</table>

J Heart Lung Transplant 2011;30:870–8
Surgical Temporary Mechanical RV Support Options

Sternotomy/Thoracotomy

Centrifugal Pump RVAD

☆FDA approved for RV support
Percutaneous Temporary RV Support Options

- Impella RP *
- Tandem Heart-Protek-Duo Cann**.
- ECMO***

*FDA Approval for RV support
** FDA Approval for Circulatory Support 6h
*** FDA Approval for Circulatory Support 6h
Early, Planned Institution of Biventricular Mechanical Circulatory Support Results in Improved Outcomes Compared to Delayed Conversion of LVAD to BiVAD

167 LVAD alone, 71 Planned BIVAD and 28 delayed BIVAD (PVADS)
Similar patient characteristics in the BIVAD group

When patients at risk for isolated LVAD support failure are identified, proceeding directly to BiVAD implantation is advised, as early institution of biventricular support results in dramatic improvement in survival

J Thorac Cardiovasc Surg. 2009 April ; 137(4): 971–977

STS/EACTS Latin America Cardiovascular Surgery Conference 2018
Outcome of unplanned right ventricular assist device support for severe right heart failure after implantable left ventricular assist device insertion.
Clinical experience with Centrimag temporary right ventricular mechanical circulatory support

<table>
<thead>
<tr>
<th>Variable</th>
<th>PCCS (n = 13, %)</th>
<th>CTx (n = 25, %)</th>
<th>LVAD (n = 42, %)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adverse event</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>2 (20)</td>
<td>9 (36)</td>
<td>10 (30)</td>
<td>.52</td>
</tr>
<tr>
<td>Major infection</td>
<td>8 (62)</td>
<td>13 (52)</td>
<td>23 (55)</td>
<td>.85</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>5 (58)</td>
<td>10 (40)</td>
<td>21 (50)</td>
<td>.64</td>
</tr>
<tr>
<td>Stroke/encephalopathy</td>
<td>1 (8)</td>
<td>3 (12)</td>
<td>9 (21)</td>
<td>.54</td>
</tr>
<tr>
<td>Air embolism</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td>.65</td>
</tr>
<tr>
<td>Causes of early death</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSOF/sepsis</td>
<td>1 (8)</td>
<td>5 (20)</td>
<td>3 (7)</td>
<td>.25</td>
</tr>
<tr>
<td>LV failure</td>
<td>1 (8)</td>
<td>1 (4)</td>
<td>0 (0)</td>
<td>.22</td>
</tr>
<tr>
<td>Stroke</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>-</td>
</tr>
<tr>
<td>Care withdrawn</td>
<td>5 (58)</td>
<td>1 (4)</td>
<td>4 (10)</td>
<td>.01</td>
</tr>
<tr>
<td>Causes of late death</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>-</td>
</tr>
<tr>
<td>Care withdrawn</td>
<td>1 (8)</td>
<td>1 (4)</td>
<td>4 (10)</td>
<td>.71</td>
</tr>
</tbody>
</table>

Risk factors for weaning RVAD

Centrimag Central cann.

J.Thorac Cardiovasc Surg 2018;156:1885-91
Conclusions: Temporary right ventricular mechanical support remains an effective treatment strategy after left ventricular assist device placement with immediate support resulting in superior short-term survival. Caution should be applied in postcardiotomy cardiogenic shock when weaning and survival are poor. Overall survival outcomes have remained relatively static over time.

J.Thorac Cardiovasc Surg 2018;156:1885-91
TandemHeart RVAD (TH pump and Dual Lumen Cannula)

Placement under fluoroscopy using One flow directed PA catheter and COOK®.035 Lunderquist® guidewire used to advance the Cannula

PROTEK-DUO Cannula
29 and 31 FR
Outcomes with the Tandem Protek Duo Dual-Lumen Percutaneous Right Ventricular Assist Device

Complications occurred in 6 (35%):

- 1 pt epistaxis and hematemesis.
- 1pt had injury to left internal jugular due to inability to advance the catheter past the RV due to tortuous anatomy.
- 2 intracranial bleeds
- 2 bleeding at the catheter insertion site after placement.

Two-center experience using the TPD in 17 patients with right ventricular (RV) failure (12 of whom were post-left ventricular assist device (LVAD) implantation)

Complications occurred in 6 (35%):
Impella RP: Percutaneous Device

- 3D catheter-based percutaneous VAD (22 Fr pump mounted on a 11 Fr catheter)
- Treatment: RV dysfunction
- Flow: > 4 L/min at 33000 rpm
- Duration of support: up to 14 days
- Pump Inflow: Inferior Vena Cava (IVC)
- Pump Outflow: Pulmonary Artery (PA)
- Anticoagulation: ACT ~ 160-180 sec

- Axial Flow pump (22 Fr)
- Catheter based (11Fr)
- IVC implant
- RPM up to 33000.
### RECOVER Trial: Patient Outcomes and Adverse Events

**Primary End Points**

<table>
<thead>
<tr>
<th>Event</th>
<th>All patients (N = 30)</th>
<th>Cohort A (n = 18)</th>
<th>Cohort B (n = 12)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alive at 30 Days</td>
<td>73.3 (22)</td>
<td>83.3 (15)</td>
<td>58.3 (7)</td>
<td>0.129</td>
</tr>
<tr>
<td>Discharge</td>
<td>70.0 (21)</td>
<td>77.8 (14)</td>
<td>58.3 (7)</td>
<td>0.255</td>
</tr>
<tr>
<td>30 days/discharge/next therapy</td>
<td>73.3 (22)</td>
<td>83.3 (15)</td>
<td>58.3 (7)</td>
<td>0.129</td>
</tr>
<tr>
<td>180 days</td>
<td>70.0 (21)</td>
<td>77.8 (14)</td>
<td>58.3 (7)</td>
<td>0.255</td>
</tr>
</tbody>
</table>

**Secondary End Points**

<table>
<thead>
<tr>
<th>Safety end points</th>
<th>All patients (N = 30)</th>
<th>Cohort A (n = 18)</th>
<th>Cohort B (n = 12)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>26.7 (8)</td>
<td>16.7 (3)</td>
<td>41.7 (5)</td>
<td>0.129</td>
</tr>
<tr>
<td>Major bleeding</td>
<td>60.0 (18)</td>
<td>55.6 (10)</td>
<td>66.7 (8)</td>
<td>0.563</td>
</tr>
<tr>
<td>Device access site</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative</td>
<td>3.3</td>
<td>0.0</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Transfusion with no overt bleeding</td>
<td>36.7</td>
<td>33.3</td>
<td>41.7</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>16.7</td>
<td>22.2</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>Hemolysis</td>
<td>13.3 (4)</td>
<td>16.7 (3)</td>
<td>8.3 (1)</td>
<td>0.511</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td></td>
</tr>
<tr>
<td>Tricuspid and pulmonary valve dysfunction</td>
<td>3.3 (1)</td>
<td>5.6 (1)</td>
<td>0.0 (0)</td>
<td>0.406</td>
</tr>
</tbody>
</table>

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Flows and Hemodynamics

FLOW BY COHORT

- **ALL**: N=27
- **COHORT A**: N=16
- **COHORT B**: N=11

AVERAGE PUMP FLOW (L/min)

CARDIAC INDEX

- **PRE SUPPORT**: N=30
- **ON SUPPORT**: N=28
- **POST SUPPORT**: N=17

AVERAGE CARDIAC INDEX (L/min/m²)

P<0.0001

CENTRAL VENOUS PRESSURE

- **PRE SUPPORT**: N=30
- **ON SUPPORT**: N=27
- **POST SUPPORT**: N=25

AVERAGE CVP (mmHg)

P<0.0001

P=0.515
Summary

- The presence of acute severe RV failure is associated with increased risk of mortality and morbidity.

- Preoperative, intraoperative and postoperative management are key to prevent and avoid progression of RVF and may be critical to prevent poor outcomes.

- There is an increasing number of surgical and percutaneous RVAD options that seem to be efficacious and safe, but timing implantation seems to be a critical step to prevent progression to MOF.
THANK YOU
Post-Operative/ICU Management

- Bleeding
- Nitric Oxide
- Inotropes
- Maintain MAP
- Watch CVP/PA ratio – go to RVAD early if any doubts
- Role of Pump Speed? – Don’t know, do not over pump