Right Heart Failure in Left Ventricular Assist Device Recipients

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The problem with right heart failure following LVAD implantation

Total RVF 20%
- 6% RVAD
- 7% early extended inotropes
- 7% late inotropes

Survival

(N=484)

## Identifying risk for RVF

<table>
<thead>
<tr>
<th></th>
<th>Fukamachi(^1)</th>
<th>Michigan RVFRS(^2)</th>
<th>Kormos(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device Type</strong></td>
<td>Pulsatile</td>
<td>Pulsatile (84%) &amp; cf-LVAD (16%)</td>
<td>cf-LVAD</td>
</tr>
<tr>
<td><strong># of LVAD patients</strong></td>
<td>100</td>
<td>197</td>
<td>484</td>
</tr>
<tr>
<td><strong>RVF Definition</strong></td>
<td>RVAD</td>
<td>RVAD, inotropes, iNO</td>
<td>RVAD, inotropes</td>
</tr>
<tr>
<td><strong>Incidence of RVF</strong></td>
<td>11%</td>
<td>35%</td>
<td>20%</td>
</tr>
<tr>
<td><strong>Incidence RVAD</strong></td>
<td>11%</td>
<td>15%</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Institution</strong></td>
<td>Single center</td>
<td>Single center</td>
<td>Multicenter</td>
</tr>
</tbody>
</table>

### Predictors

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Univariate</th>
<th>Multivariable</th>
<th>Multivariable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RVSWI &lt; 300</td>
<td>Vasopressor support</td>
<td>Ventilator support</td>
</tr>
<tr>
<td></td>
<td>Mean PAP &lt; 40</td>
<td>Bilirubin &gt; 2.0 mg/dL</td>
<td>BUN &gt; 39 mg/dL</td>
</tr>
<tr>
<td></td>
<td>AST</td>
<td>AST &gt; 80 IU/L</td>
<td>RA/PCWP &gt; 0.63</td>
</tr>
<tr>
<td></td>
<td>Creatinine &gt; 2.3 mg/dL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Complex etiology of post-LVAD RV failure

- Chronic
- Intra-op ischemia

RVD

• PRBCs
• TR
• Hepatic/renal congestion

RAP

LVAD & IVS

• High flow

PVR

- CPB
- PRBCs
- Hypoxia
- Acidosis

LV

RV

[Graph showing Stroke Volume vs. Pressure vessel (mmHg)]

McDonald. Curr Opin Card. 2009;24
Severe RV Failure in INTERMACS

Continuous Flow LVAD
N = 2900

- RVAD at time of LVAD Implant
  N = 84 (3%)
    - RVAD: Durable
      N = 5 (6%)
    - RVAD: Temporary
      N = 79 (94%)

- Return to OR for RVAD
  N = 26 (1%)
    - RVAD: Durable
      N = 5 (20%)
    - RVAD: Temporary
      N = 21 (80%)

Kiernan. ISHLT 2012
Implant Dates: June 2006 – September 2009: Bi-VAD Study

Adult Primary BLVAD Implants: n=206
By Continuous Flow Device vs. Pulsatile Flow Device

- Durable/Durable n=160, deaths=56

56%

Event: Death (censored at transplant or explant recovery)

p = .8

Months after Device Implant

Cleveland. J Heart Lung Transplant 2011;30(8):862
Early management:
Outcomes with planned versus delayed BiVAD

Survival until Discharge

- LVAD (N=167) 71%  
- Planned BiVAD (N=71) 51%  
- Delayed BiVAD (N=28) 29%

P = 0.001  
P = 0.054  
P = 0.046

Median time to delayed RVAD 2 days

## Risk Factors for Early RVAD Following LVAD Surgery

Adult Primary Continuous Flow Implants (N=2900)  
Multivariable Logistic Regression (Event=RVAD)

<table>
<thead>
<tr>
<th>Risk Factors (pre-implant)</th>
<th>Odds Ratio</th>
<th>p – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERMACS Patient Profile Level 1</td>
<td>3.11</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>PaPi (per 1 unit larger)</td>
<td>0.71</td>
<td>0.0003</td>
</tr>
<tr>
<td>LVEDD (per 1 mm increase)</td>
<td>0.78</td>
<td>0.01</td>
</tr>
<tr>
<td>RV dysfunction by echo (any)</td>
<td>3.17</td>
<td>0.01</td>
</tr>
<tr>
<td>Primary Diagnosis CAD</td>
<td>1.78</td>
<td>0.03</td>
</tr>
<tr>
<td>Hemoglobin (per 1 gm/dl increase)</td>
<td>0.89</td>
<td>0.03</td>
</tr>
<tr>
<td>Concomitant surgery</td>
<td>1.55</td>
<td>0.03</td>
</tr>
<tr>
<td>INTERMACS Patient Profile Level 2</td>
<td>1.81</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Kiernan. ISHLT 2012
Pulmonary Artery Pulsatility Index

\[ \text{PaPi} = \frac{\text{PA Systolic Pressure} - \text{PA Diastolic Pressure}}{\text{Right Atrial Pressure}} \]
Therapy (Preload, Afterload, Inotropy):
- Diuresis
- Renal Replacement
- Vasodilators
- Inotropes
- IABP/short term MCS
- Vitamin K
- Surgical technique
- ? RCA/LAD revascularization

Goals:
- RA < 15 mmHg
- Euvolemia
- Correction metabolic derangements and end-organ function

Prevention?: Pre-op optimization
Class I (LOE C)

Implants June 2006 – March 2011: RHF Analysis

Adult Primary Continuous Flow Implants N=2900
By Right Heart Failure Level

Event: Right Heart Failure

% Freedom RHF

Mild or Worse Right Heart Failure, n=1284
Moderate or Worse Right Heart Failure, n=398
Severe Right Heart Failure, n=110

Overall p < 0.0001
Readmission rate by cause following LVAD implantation

Hasin (Mayo). JACC 2013;61(2):153
# Impact of Tricuspid Valve Repair at time of LVAD

<table>
<thead>
<tr>
<th></th>
<th>LVAD Only N=81</th>
<th>LVAD + TVR N=34</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCr</td>
<td>1.78 ± 0.8</td>
<td>1.98 ± 0.9</td>
<td>0.32</td>
</tr>
<tr>
<td>BUN</td>
<td>36 ± 21</td>
<td>48 ± 30</td>
<td>0.06</td>
</tr>
<tr>
<td>CVP/PCWP</td>
<td>.57 ± 0.2</td>
<td>0.75 ± 0.3*</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CVP</td>
<td>16 ± 8</td>
<td>19 ± 7</td>
<td>0.09</td>
</tr>
<tr>
<td>Severe TR</td>
<td>33%</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td><strong>OUTCOMES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVAD</td>
<td>10%</td>
<td>3%</td>
<td>0.27</td>
</tr>
<tr>
<td>Inotrope</td>
<td>10d (8,17)</td>
<td>8d (7,12)</td>
<td>0.04</td>
</tr>
<tr>
<td>Post-op renal insuff</td>
<td>39%</td>
<td>21%</td>
<td>0.05</td>
</tr>
<tr>
<td>Hosp LOS</td>
<td>23d (16,46)</td>
<td>19d (14,25)</td>
<td>0.02</td>
</tr>
</tbody>
</table>

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

2196 patients with mod-severe TR--27% TVR

TVR associated with:
• No difference in death or RVAD
• Increased renal failure
• Greater transfusion requirement
• Increased LOS

JHLT 2014
Effect of digoxin on RV function in primary pulmonary hypertension with symptomatic heart failure

### Table 1—Effects of Digoxin on Hemodynamics

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>After Digoxin</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac output, L/min</td>
<td>3.49±1.2</td>
<td>3.81±1.2</td>
<td>0.028</td>
</tr>
<tr>
<td>Heart rate, beats/min</td>
<td>86±14</td>
<td>89±14</td>
<td>NS</td>
</tr>
<tr>
<td>Mean systemic BP, mm Hg</td>
<td>102±10</td>
<td>102±12</td>
<td>NS</td>
</tr>
<tr>
<td>Mean pulmonary artery</td>
<td>60±20</td>
<td>65±23</td>
<td>0.004</td>
</tr>
<tr>
<td>pressure, mm Hg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean right atrial pressure, mm Hg</td>
<td>14±7</td>
<td>13±7</td>
<td>NS</td>
</tr>
<tr>
<td>Mean pulmonary capillary wedge pressure, mm Hg</td>
<td>12±4</td>
<td>13±5</td>
<td>NS</td>
</tr>
<tr>
<td>Pulmonary vascular resistance, U</td>
<td>15.6±9</td>
<td>15.6±9</td>
<td>NS</td>
</tr>
</tbody>
</table>

*NS = not significant.

Class IIb (LOE C)
Effect of PDE-5A inhibition on PVR and RV hemodynamics post LVAD

Tedford (Hopkins). Circ Heart Fail 2008;1:213

Class IIb (LOE C)
Effect of RV pacing on RV function in model of pulmonary hypertension induced RVD

Control

PHTN

RV dP/dt max

+8.5 ± 1.3 %

p < 0.001

RV dP/dt max (mmHg/ms)

baseline
paced

Class IIb (LOE C)

RVSP

+2.7 ± 0.6%

p < 0.01

RV SP (mmHg)

baseline
paced

Conclusions & Future Directions

- RVF post LVAD remains common
- Need multi-disciplinary pre-op evaluation
- Need data/trials investigate operative techniques
- Need trials investigate strategies for management of chronic RVF
- Trials of temporary RV MCS support ongoing pre- and post-LVAD
- Emerging biventricular mechanical support devices