Role of the Right ventricle in the evaluation for VAD

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Disclosure

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Second INTERMACS annual report

Table 7 Causes of Death in 1092 Primary LVAD Patients (INTERMACS: June 2006–March 2009)

<table>
<thead>
<tr>
<th>Primary cause of death</th>
<th>Early (≤1 mon)</th>
<th>Later (&gt;1 mon)</th>
<th>Total (N = 191)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 69)</td>
<td>%</td>
<td>(n = 122)</td>
</tr>
<tr>
<td>Cardiac failure³</td>
<td>21</td>
<td>30.4</td>
<td>21</td>
</tr>
<tr>
<td>Infection</td>
<td>6</td>
<td>8.7</td>
<td>25</td>
</tr>
<tr>
<td>CNS event</td>
<td>8</td>
<td>11.6</td>
<td>19</td>
</tr>
<tr>
<td>Multorgan failure</td>
<td>11</td>
<td>15.9</td>
<td>9</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>4</td>
<td>5.8</td>
<td>6</td>
</tr>
<tr>
<td>Bleeding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleeding</td>
<td>1</td>
<td>1.4</td>
<td>4</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
</tr>
<tr>
<td>Surgical</td>
<td>5</td>
<td>7.2</td>
<td>1</td>
</tr>
<tr>
<td>Device failure</td>
<td>0</td>
<td>0.0</td>
<td>9</td>
</tr>
<tr>
<td>Renal failure</td>
<td>3</td>
<td>4.3</td>
<td>3</td>
</tr>
<tr>
<td>Hepatic failure</td>
<td>2</td>
<td>2.9</td>
<td>1</td>
</tr>
<tr>
<td>Malignancy</td>
<td>0</td>
<td>0.0</td>
<td>2</td>
</tr>
<tr>
<td>Arterial embolism</td>
<td>0</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>Cardiac tamponade</td>
<td>1</td>
<td>1.4</td>
<td>0</td>
</tr>
<tr>
<td>Post-explant failure to recover</td>
<td>0</td>
<td>0.0</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>10.1</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>69</td>
<td>100.0</td>
<td>122</td>
</tr>
</tbody>
</table>

CNS, central nervous system; INTERMACS, Interagency Registry For Mechanical Circulatory Support; LVAD, left ventricular assist device.
³Cardiac failure includes right ventricular failure and ventricular tachycardia/ventricular fibrillation.
Right ventricular failure

- **RV failure** is the leading cause of mortality after L-VAD implantation because
  - Increased peri-operative mortality
  - Prolonged length of stay
  - Worse survival (even after HTx)
  - Liver-gastrointestinal and renal congestion
    - Coagulopathy, altered drug metabolism, malnutrition, diuretic resistance, poor QoL
- Right heart failure occurs frequently after LVAD implantation (**up to 10-44 % of patients**)

Dang NC et al. J Heart Lung Transplant 2006; 25: 1
Baumwol J et al, JHLT 2011;30:888
<table>
<thead>
<tr>
<th>INTERMAC</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagnostic criteria for RV failure</strong></td>
<td>Symptoms and signs of persistent right ventricular dysfunction, central venous pressure (CVP) &gt; 18 mmHg with a cardiac index (CI) &lt; 2.01/min.m². In the absence of elevated left atrial/pulmonary capillary wedge pressure &gt; 18 mmHg, tamponade, ventricular arrhythmias or pneumothorax.</td>
</tr>
<tr>
<td><strong>Severity scale</strong></td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>Need for RVAD</td>
</tr>
<tr>
<td>Moderate</td>
<td>Need for inotrope or intravenous or inhaled pulmonary vasodilator (e.g. prostaglandin E or inhaled nitric oxide)</td>
</tr>
<tr>
<td>Mild</td>
<td>Meets 2 of the 4 clinical criteria listed below</td>
</tr>
<tr>
<td></td>
<td>- CVP &gt; 18 mmHg or mean RA pressure &gt; 18 mmHg</td>
</tr>
<tr>
<td></td>
<td>- CI &lt; 2.3 l/min/M² (using a pulmonary artery catheter)</td>
</tr>
<tr>
<td></td>
<td>- Ascites or evidence of moderate to worse peripheral edema</td>
</tr>
<tr>
<td></td>
<td>- Evidence of elevated CVP by echo (dilated inferior vena cava without collapse), physical exam (signs of increased jugular venous pressure)</td>
</tr>
</tbody>
</table>

Holman WL, Circ 2012;126:1401
**Right ventricular function**

- **Evaluation of the RV** is difficult because of its:
  - complex anatomical structure
  - Contractility pattern
- The **function of the RV** can be easily affected by:
  - preload
  - afterload
  - **Ventricular interdependence**: (systolic>IVS, diastolic>pericardium)
    - 20-40% of RV output results from LV contraction

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Ho YS, Nihoyannopoulos P. Heart 2006;92:2
Pulmonary hypertension in left heart failure

Left Heart Disease
- HFrEF
  - Diastolic Dysfunction
  - Mitral Regurgitation
- Valvular Heart Disease
  - LV Hypertrophy
  - Diastolic Dysfunction
- HFrpEF
  - Diastolic Dysfunction

Acute
- Increased Left Atrial Pressure
- Backward hemodynamic effects
- Hydrostatic pressure in pulmonary capillaries

Chronic
- Mechanical injury
- Edema
- Alveolar-capillary unit injury & edema
- Alveolar-capillary stress failure
- Reversible
  - ET-1 & NO release imbalance
  - Neurohormonal activation (Ang II)
  - Inflammation (TNF-α)
- Alveolar-capillary membrane remodeling
- Extracellular matrix thickening
- Irreversible
  - Medial hypertrophy of SMC
  - Genes
  - Pulmonary vein arterialization
  - Medial hypertrophy of SMC
  - Internal elastic lamina
  - External elastic lamina

Inflammatory markers
- Proteases
- Proteins
- Red blood cells
<table>
<thead>
<tr>
<th>Clinical Classification Group</th>
<th>Characteristics of arteriopathy</th>
<th>Histological examples</th>
</tr>
</thead>
</table>
| 1. Pulmonary arterial hypertension 'Pulmonary veno-occlusive disease or pulmonary capillary hemangiomatosis | • Medial hypertrophy  
• Muscularization of arterioles  
• Cellular proliferation of intima layer  
• Concentric laminar intimal fibrosis  
• Plexiform lesions  
• Fibrinoid necrosis | ![Histological example 1]![Histological example 2]![Histological example 3] |
| 2. PH due to left heart disease | • Medial hypertrophy  
• Muscularization of arterioles and veins  
• Non-obstructive intimal fibrosis  
• Moderate intima fibrosis veins | ![Histological example 1]![Histological example 2]![Histological example 3] |
| 3. PH due to lung disease or hypoxia | • Large arteries mostly normal  
• Medial hypertrophy  
• Muscularization of arterioles  
• Similar changes to lesser extent in small pulmonary veins | ![Histological example 1]![Histological example 2]![Histological example 3] |
| 4. Chronic Thromboembolic PH (CTEPH) | • Mild medial hypertrophy  
• Eccentric intimal fibrosis  
• Recanalization of lumen  
• Recent thrombi rare | ![Histological example 1]![Histological example 2]![Histological example 3] |
| 5. PH with unclear multifactorial mechanisms | • Muscularization of arterioles and veins (fibrotic lung disease, tumors)  
• Non-obstructive intimal fibrosis (fibrotic lung disease, tumors)  
• Vascular granulomas (sarcoidosis, tuberculosis)  
• Enlargement of bronchial arteries (bronchiectasis) | ![Histological example 1]![Histological example 2]![Histological example 3] |

Adapted from Wagenvoort and Mooi
Impact of LVAD on RV function

- Despite the **acute** RV afterload reduction with L-VAD support and the **initial rise of RV contractility**, RVEF usually **declines gradually** due to:
  - Excessive unloading and change in LV geometry
    - **shifting of the septum** to the left → reduced septal contribution to RV contraction and
    - **TR worsening** (Increased venous return → TV tethering + leftward-shifted septum)
  - **intrinsic impairment of RV contractility**
    - due to the **susceptibility of the RV** during cardiopulmonary bypass
    - Increased venous return to a myopathic RV
    - **Tachyarrhythmias** (esp. Atrial/ventricular fibrillation)

Barbobe A et al. Circulation 2001;104:670
Klotz S et al. J Heart Lung Transplant 2005;24:1195
Reversibility of STRUCTURAL “FIXED” changes in the pulmonary vasculature

- 145 pts
  - 89 reversible PHTN
  - 59 FIXED PHTN (Dob, iloprost for 4 days)

- FIXED PHTN
  - mPAP > 25 mmHg
  - PVR > 2.5 WU
  - TPG > 12

- Continuous flow LVAD (Berlin Incor, HM II)
LATE RV failure

- 336 pts with LVAD

**Definition**
- Hospitalization for medical or surgical therapy for RVF after the index hospital discharge

- 11% developed LATE RVF @ median of 99 days after discharge

**Predictors for LATE RVF**
- Diabetes mellitus
- BMI > 29
- Urea nitrogen > 41 mg/dl

*Figure: Survival analysis of non-RHF and RHF patients with p = 0.016.*

Takeda K, JHLT 2015
**RV DIMENSIONS**

<table>
<thead>
<tr>
<th>(RVD1)</th>
<th>2.0-2.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>(RVD2)</td>
<td>2.7-3.3</td>
</tr>
<tr>
<td>(RVD3)</td>
<td>7.1-7.9</td>
</tr>
</tbody>
</table>

**RVOT-SF**

<table>
<thead>
<tr>
<th>RVOT1</th>
<th>2.5-2.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVOT2</td>
<td>1.7-2.3</td>
</tr>
<tr>
<td>PA1</td>
<td>1.5-2.1</td>
</tr>
</tbody>
</table>

**TAPSE**

20 mm ~ EF 50%

**RV FAC (%)** 35-60 %

(ED area) – (ES area) / (ES area)

**RV-MPI** < 0.4
Echocardiography in predicting RV Failure

- TAPSE < 7.5 mm (spec 91%, but 46% sens)
- RV fractional area change (RV-FAC) < 24%
- RV short/long axis >0.6 and severe TR (>3+)
- Increased RV-to-LV end-diastolic diameter >0.75 (TTE, CF LVAD)

LV parameters
- Smaller LVEDd, greater LVEF and greater LA diameter/LVEDd

Puwanant, JHLT 2008;27:1102
Potapov, LHLT 2008;27:1275
Vivo, JHLT 2013
Kato TS, Am J Card 2012
Combination of LV and RV echo indices for RV Failure prognosis

- LV e' wave velocity ≥ 18.5
- RV diastolic diameter ≥ 50 mm

Aissaoui N, Arc Cardiovasc Dis 2015
RV mechanics - Speckle tracking
## Echocardiography in predicting RV Failure

<table>
<thead>
<tr>
<th>Pts</th>
<th>VAD type</th>
<th>RVF incidence</th>
<th>Risk factors</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>117</td>
<td>continuous</td>
<td>40 %</td>
<td>RV free wall peak longitudinal strain of &lt; -9.6%</td>
<td>Grant, JACC 2012</td>
</tr>
<tr>
<td>10</td>
<td>continuous</td>
<td>30 %</td>
<td>Depressed free wall RV longitudinal strain (-11 %)</td>
<td>Cameli, JHLT 2013</td>
</tr>
</tbody>
</table>
Predictors of RV failure/ need for R-VAD after LVAD implantation

- Female gender
- Nonischemic HF
- Prior cardiac surgery
- Need for IABP
- Inotrope dependency-vasopressor use
- Need for mechanical ventilation
- Elevated CVP, Low mean PA pressure
- Low RV-stroke work index
- Biochemical
  - Creatinine, BUN, Bili, SGOT/SGPT, neutrophil gelatinase-associated lipocalin (NGAL)

Lampert BC, JHLT 2015;34:1123
Dang NC et al. J Heart Lung Transplant 2006;25:1
Fukamachi K et al. Ann Thorac surg 1999;68:2181
Ochiai Y et al. Circulation 2002;106:1198
Pronschinske, JHLT 2014
### Prediction scores of RV failure

<table>
<thead>
<tr>
<th>Study</th>
<th>Patients</th>
<th>RVF Definition and Rate</th>
<th>Multivariable Predictors</th>
<th>Echocardiographic RV Parameters Considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan RV Failure Risk Score (2008)</td>
<td>197 LVADs</td>
<td>Need for RVAD</td>
<td>Preoperative vasopressors (4 pts)</td>
<td>RV systolic function (visual semiquantitative)</td>
</tr>
<tr>
<td></td>
<td>28 continuous-flow</td>
<td>Need for inotropes</td>
<td>AST ≥80 IU/L (2 pts)</td>
<td>TR (visual semiquantitative)</td>
</tr>
<tr>
<td></td>
<td>94% BTT</td>
<td>RVF rate: 35%</td>
<td>Bilirubin ≥2.0 mg/dL (2.5 pts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Creatinine ≥2.3 mg/dL (3 pts)</td>
<td></td>
</tr>
<tr>
<td>Penn RVAD Risk Score (2008)</td>
<td>266 LVADs</td>
<td>Need for RVAD</td>
<td>Cardiac index ≤2.2 L/min per square meter</td>
<td>RV systolic function (visual semiquantitative)</td>
</tr>
<tr>
<td></td>
<td>6 continuous-flow</td>
<td>Included ITT RVAD</td>
<td>RSVWI ≤0.25 mm Hg×L/m²</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RVF rate: 37%</td>
<td>Severe RV dysfunction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Creatinine ≥1.9 mg/dL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prior cardiac surgery</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Systolic BP ≤96 mm Hg</td>
<td></td>
</tr>
<tr>
<td>Utah RV Risk Score (2010)</td>
<td>175 LVADs</td>
<td>Need for RVAD</td>
<td>DT indication (3.5 pts)</td>
<td>Right atrial area</td>
</tr>
<tr>
<td></td>
<td>25 continuous-flow</td>
<td>Need for inotropes</td>
<td>IABP (4 pts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>58% BTT, 42% DT</td>
<td>Need for inhaled NO</td>
<td>PVR (1–4 pts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RVF rate: 44%</td>
<td>Inotrope dependency (2.5 pts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Obesity (2 pts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ACEI or ARB use (−2.5 points)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>β-blocker use (2 pts)</td>
<td></td>
</tr>
<tr>
<td>Kormos (2010)</td>
<td>484 LVADs</td>
<td>Need RVAD</td>
<td>CVP/PCWP &gt;0.63 (OR, 2.3)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>All continuous-flow</td>
<td>Need for inotropes</td>
<td>Need for preoperative ventilator support (OR, 5.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RVF rate: 20.2%</td>
<td>BUN &gt;39 mg/dL</td>
<td></td>
</tr>
<tr>
<td>Pittsburgh Decision Tree (2012)</td>
<td>183 LVADs</td>
<td>Need for RVAD</td>
<td>Age, heart rate, transpulmonary gradient; right atrial pressure; INR, white blood cell count, ALT, number of inotropic agents</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>40 continuous-flow</td>
<td>RVF rate: 15%</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>CRITT (2013)</td>
<td>167 LVADs, all continuous-flow</td>
<td>Need for BIVAD</td>
<td>CVP &gt;15 mm Hg (C)</td>
<td>RV systolic function (visual semiquantitative)</td>
</tr>
<tr>
<td></td>
<td>51 BiVADs</td>
<td>RVF rate: 23%</td>
<td>Severe RV dysfunction (R)</td>
<td>Severe TR (T)-Heart rate &gt;100 (tachycardia [T])</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Preoperative intubation (I)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Severe TR (T)-Heart rate &gt;100 (tachycardia [T])</td>
<td></td>
</tr>
</tbody>
</table>
Are RV scores useful?

- **Fitzpatrick’s score**
  - CI, RV SW index, creatinine, previous cardiac surgery, systolic BP, RV dysfunction

- **Drakos’s score**
  - Destination th, IABP, PVR, inotrope dependency, obesity, ACEi/ARB, b-blocker

- **Matthew’s score**
  - Vasopressors, SGOT/Bilirubin, creatinine/renal replacement therapy

Pettinari, Eur J card-Thorac Surg 2011
Pt #1
Conclusions

- MCS is the therapy of choice in pts with end stage heart failure, esp as BTT or DT
- LVAD survival is better than BIVAD
- Right heart dysfunction is universal
- Right heart failure is avoidable (pretreatment!)
- DON’T leave OR with inadequate hemodynamics, leave the chest open or place RVAD if necessary
Mechanisms for RVF after LVAD

RV RVD
- Chronic
- Intra-op ischemia

RV Failure
- ↑RAP

LVAD-IVS
- High flow
- CPB
- PRBCs
- Hypoxia
- Acidosis

PVR
- PRBCs
- Hepatic-renal congestion
Diastolic HF and MCS

- Implantation of L-VAD alone increases the risk of RV failure (both ventricles affected!)
- MCS only as BTT
- MCS results in children better than in adults
- Use MCS early (before MOF develops)
- Inflow cannula in LV apex associated with thrombus formation
- **Adults** → TAH (Cardiowest)
  - **Children** → maybe only L-VAD (if RV not severely affected) or BiVAD Thoratec/BerlinExcor (BSA!)
Excessive LV unloading

- Normal RV
- RV failure
L-VAD or Bi-VAD?
43 yo, F, RCM
→ BiVAD
→ Inflow cannula reposition
51, F, Arrhythmogenic Right Ventricular Dysplasia
→ BiVAD
→ Inflow cannula malapposition
The problem with RVF after LVAD

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

Survival Curve

- No RVF: 78%
- RVF: 59%

Kormos, J Thor Cardiovas Surg 2010;39:1316
32 yo, acute graft failure 6 years post HTX, No recovery with Levitronix/ECMO → Bi-VAD
Acute RV dysfunction after VAD/HTx
→ Levitronix
Heart failure is characterized by an enlarged heart with decreased ability to pump.

**VENTRICULAR REMODELING**

- Alterations in myocyte biology
  - Myocyte loss
- Myocardial changes
  - Alterations in extracellular matrix
- Alterations in LV chamber geometry

These changes are directly related to deterioration of LV performance and an increase of mortality and morbidity.
Prognostic significance of echocardiographic diastolic dysfunction measures

<table>
<thead>
<tr>
<th>Modality</th>
<th>Patient Population</th>
<th>Cutoff Values</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral inflow Doppler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/A</td>
<td>2,671 elderly patients, no CVD</td>
<td>&lt;0.7 or &gt;1.5</td>
<td>Incident HF</td>
</tr>
<tr>
<td>E/A</td>
<td>1,839 hypertensive patients</td>
<td>Age- and heart rate-adjusted ratio below median</td>
<td>Cardiovascular events*</td>
</tr>
<tr>
<td>E/A</td>
<td>3,008 Native Americans</td>
<td>&lt;0.6 or &gt;1.5</td>
<td>Death or cardiac death</td>
</tr>
<tr>
<td>DT</td>
<td>110 patients, EF &lt;50%, no CAD</td>
<td>&lt;115 ms, persisting after 3 months’ HF treatment</td>
<td>Death or transplant at 4 yrs</td>
</tr>
<tr>
<td>Peak E</td>
<td>2,671 elderly, no CVD</td>
<td>Continuous</td>
<td>Incident HF</td>
</tr>
<tr>
<td>DT</td>
<td>571 patients post-AMI</td>
<td>&lt;130 ms</td>
<td>Death at 4 yrs</td>
</tr>
<tr>
<td>DT</td>
<td>79 HF patients, no CAD</td>
<td>&lt;115 ms</td>
<td>Death or transplant</td>
</tr>
<tr>
<td>M-mode IVRT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary vein Doppler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV AR dur – MV A dur</td>
<td>145 LV dysfunction patients</td>
<td>≥30 ms</td>
<td>Cardiac death or hospital stay</td>
</tr>
<tr>
<td>S/D</td>
<td>115 patients, EF &lt;45%</td>
<td>&lt;1</td>
<td>HF hospital readmission or HF death at 1 yr</td>
</tr>
<tr>
<td>Tissue Doppler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/E'</td>
<td>250 patients post-AMI</td>
<td>&gt;15</td>
<td>Death</td>
</tr>
<tr>
<td>E/E'</td>
<td>45 patients, NYHA functional class III or IV HF</td>
<td>Continuous</td>
<td>Predictor of NYHA functional class, HF hospital stay, cardiac death</td>
</tr>
<tr>
<td>E/E'</td>
<td>130 chronic HF patients</td>
<td>&gt;12.5</td>
<td>Composite: cardiac death, HF hospital stay, urgent transplant</td>
</tr>
<tr>
<td>E/E'</td>
<td>110 patients hospitalized with HF</td>
<td>≥15</td>
<td>Cardiac death or hospital readmission for HF</td>
</tr>
<tr>
<td>E', E/E'</td>
<td>518 patients referred for echocardiography</td>
<td>E' &lt;3 or 3–5 cm/s, E/E' &gt;20</td>
<td>Cardiac death</td>
</tr>
<tr>
<td>Systolic mitral annular velocity</td>
<td>185 patients, EF &lt;45%</td>
<td>Continuous</td>
<td>Death or transplant</td>
</tr>
<tr>
<td>LA volume</td>
<td>1,375 elderly patients with preserved EF</td>
<td>≥32 ml/m²</td>
<td>Incident HF</td>
</tr>
<tr>
<td>Flow propagation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E/Vp</td>
<td>67 post-MI patients</td>
<td>E/Vp ≥1.5</td>
<td>Death and HF readmission</td>
</tr>
<tr>
<td>Vp</td>
<td>125 post-MI patients</td>
<td>Vp &lt;45 cm/s</td>
<td>Cardiac death</td>
</tr>
</tbody>
</table>

*New onset event — myocardial infarction, sudden cardiac death, unstable angina, revascularization, stroke/transient ischemic attack, hospital stay for heart failure (HF), symptomatic aorto-iliac disease, end-stage renal disease.
A — atrial filling velocity; AMI — acute myocardial infarction; CAD — coronary artery disease; CVD — cardiovascular disease; D — diastolic pulmonary vein wave; DT — deceleration time of E-wave; E — early diastolic filling velocity; E’ — tissue Doppler early filling velocity; EF — ejection fraction; IVRT — Interventricular relaxation time; LA — left atrium; LV — left ventricle; MV A dur — mitral valve atrial wave duration; NYHA — New York Heart Association; PV AR dur — pulmonary vein atrial reversal duration; S — systolic pulmonary vein wave; Vp — flow propagation velocity slope.
ECHO evaluation during MCS

PREOPERATIVE
- PFO, ASD, VSD
- LAA - LV thrombi
- Valve disease (AR, MS)
- Ao Ascendens
- LV function
- RV function

INTRAOPERATIVE
- De-airing
- LV/LA inflow cannula position
- LV unloading
- RV function

POSTOPERATIVE
- Tamponade
- Inflow cannula position
- LV unloading
- RV function

MYOCARDIAL RECOVERY
- WEANING
LONG-TERM USE OF A LEFT VENTRICULAR ASSIST DEVICE FOR END-STAGE HEART FAILURE


Table 1. Base-Line Characteristics of the Patients.*

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>MEDICAL-THERAPY GROUP (N=61)</th>
<th>LVAD GROUP (N=68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>68±8.2</td>
<td>66±9.1</td>
</tr>
<tr>
<td>Male sex (%)</td>
<td>82</td>
<td>78</td>
</tr>
<tr>
<td>Ischemic cause of heart failure (%)</td>
<td>69</td>
<td>78</td>
</tr>
<tr>
<td>Left ventricular ejection fraction (%)</td>
<td>17±4.5</td>
<td>17±5.2</td>
</tr>
<tr>
<td>Blood pressure (mm Hg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>103±17</td>
<td>101±15</td>
</tr>
<tr>
<td>Diastolic</td>
<td>62±11</td>
<td>61±10</td>
</tr>
<tr>
<td>Pulmonary-capillary wedge pressure (mm Hg)</td>
<td>24±7.4</td>
<td>25±9.9</td>
</tr>
<tr>
<td>Cardiac index (liters/min/m²)</td>
<td>2±0.61</td>
<td>1.9±0.99</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>84±15</td>
<td>84±16</td>
</tr>
<tr>
<td>Pulmonary vascular resistance (Wood units)</td>
<td>3.2±1.8</td>
<td>3.4±1.8</td>
</tr>
<tr>
<td>Serum sodium (mmol/liter)</td>
<td>135±5.8</td>
<td>135±5.4</td>
</tr>
<tr>
<td>Serum creatinine (mg/dl)†</td>
<td>1.8±0.66</td>
<td>1.7±0.65</td>
</tr>
<tr>
<td>Concomitant medications (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digoxin</td>
<td>85</td>
<td>87</td>
</tr>
<tr>
<td>Loop diuretics</td>
<td>97</td>
<td>96</td>
</tr>
<tr>
<td>Spironolactone</td>
<td>39</td>
<td>34</td>
</tr>
<tr>
<td>ACE inhibitors</td>
<td>51</td>
<td>62</td>
</tr>
<tr>
<td>A II antagonists</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Amiodarone</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>Beta-blockers</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Intravenous inotropic agents</td>
<td>72</td>
<td>65</td>
</tr>
<tr>
<td>NYHA class</td>
<td>1V</td>
<td>1V</td>
</tr>
<tr>
<td>Quality of life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minnesota Living with Heart Failure score SF-36</td>
<td>75±17</td>
<td>75±18</td>
</tr>
<tr>
<td>Physical function</td>
<td>18±19</td>
<td>19±19</td>
</tr>
<tr>
<td>Emotional role</td>
<td>25±38</td>
<td>33±42</td>
</tr>
<tr>
<td>Beck Depression Inventory</td>
<td>16±8</td>
<td>19±9</td>
</tr>
</tbody>
</table>

Survival by treatment group with LV assist device versus Medical therapy

No. at Risk
LV assist device: 68 38 22 11 5 1
Medical therapy: 61 27 11 4 3 0

Months

Graph showing survival rates over time for LV assist device and Medical therapy.
Etiology of HF (1)
Etiology of HF (2)
Figure 2
Diastolic Filling Parameters and the Prediction of Normal Versus Elevated Filling Pressure

**A**
Prediction of Filling Pressures in Preserved and Reduced EF
Tissue Doppler and Flow Propagation

- **E/E’ < 8**
  - E/Vp < 1.4
  - NL LA size
    - (PVARp<Adr-Adr) < 0
    - Valsalva Δ E/A < 0.5
    - DT < 175

- **E/E’ > 9.14**
  - E/Vp > 1.5-1.9
  - ↑ LA size
    - (PVARp<Adr-Adr) > 30
    - Valsalva Δ E/A > 0.5

- **E/E’ > 15**
  - E/Vp > 2

**B**
Prediction of Filling Pressures and Stratification of Diastolic Dysfunction in Reduced LVEF
Mitrail Inflow and PV Flow

- **E/A < 1**
  - DT > 200
  - “Abnormal Relaxation”
  - Normal Filling Pressures
  - ↑ Filling Pressures

- **E/A > 1**
  - DT < 200
  - “Pseudonormal”
  - ↑ Filling Pressures

- **E/A > 2**
  - DT < 150
  - IVRT < 70
  - “Restrictive”
  - ↑↑ Filling Pressures

**PW-Doppler**

- **Normal**
  - DT 140-240 ms
  - E/A 0.75-1.5

- **Grade 1**
  - DT > 240 ms
  - E/A < 0.75

- **Grade 2**
  - DT 140-240 ms
  - E/A 0.75-1.5

- **Grade 3**
  - DT < 140 ms
  - E/A > 1.5

**Color M-mode**

- **Vp > 0.45**
- **Vp ≤ 0.45**
- **Vp ≤ 0.45**
- **Vp ≤ 0.45**

**Tissue Doppler**

- **Normal**
  - E/e’ < 15

- **Moderately Increased**
  - E/e’ ≥ 15

- **Severely Increased**
  - E/e’ ≥ 15

**LA pressure**

- **Normal**
- **Normal**
- **Moderately Increased**
- **Severely Increased**
Intracardiac thrombi
### The Onassis CSC experience (since 2/2003)

#### Results

<table>
<thead>
<tr>
<th>Implants</th>
<th>BiV AD</th>
<th>LV AD</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>48(Bi)</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>8</td>
<td>3(Bi)</td>
</tr>
<tr>
<td></td>
<td>83</td>
<td>33</td>
<td>83</td>
</tr>
</tbody>
</table>

- **Implants**: 83 VADs (78 pts)
- **37 HTx**
- **21 on support**
- **21 dead**

**TOTAL**: 83 (51+32)
Left Ventricular Support

Biventricular Support
Mechanical Circulatory Support

DESTINATION THERAPY

BTR
- Recovery of myocardial function expected
  (myocarditis, RV failure after LVAD implantation...)

BTT
- Listed patients for HTx
- Low-Output Syndrome
  (inotropically dependent, failure to wean within 7 days) ± IABP
- Pending multiorgan failure

Weaning/VAD removal
54 pts, retrospective study

Results

- **RV failure group** had
  - sign. higher short/long axis of the RV
  - TR grade 3+ to 4+

**Table 6. Results of Logistic Regression Analysis**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OR</th>
<th>Confidence interval</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/L axis of RV</td>
<td>4.4</td>
<td>1.4–13.7</td>
<td>0.011</td>
</tr>
<tr>
<td>TI III-IV</td>
<td>4.7</td>
<td>1.26–17.65</td>
<td>0.012</td>
</tr>
<tr>
<td>CVP</td>
<td>1.24</td>
<td>1.04–1.47</td>
<td>0.019</td>
</tr>
<tr>
<td>SAPS II</td>
<td>1.14</td>
<td>1.01–1.28</td>
<td>0.03</td>
</tr>
<tr>
<td>Inotropic score</td>
<td>1</td>
<td>0.99–1.12</td>
<td>0.57</td>
</tr>
<tr>
<td>CI</td>
<td>0.25</td>
<td>0.056–1.12</td>
<td>0.069</td>
</tr>
<tr>
<td>SVR</td>
<td>1</td>
<td>1–1.01</td>
<td>0.05</td>
</tr>
<tr>
<td>CrP</td>
<td>1.12</td>
<td>1–1.26</td>
<td>0.048</td>
</tr>
<tr>
<td>NT-proBNP</td>
<td>1</td>
<td>1–1.002</td>
<td>0.1</td>
</tr>
<tr>
<td>INR</td>
<td>1.37</td>
<td>0.53–3.52</td>
<td>0.051</td>
</tr>
</tbody>
</table>

**Tricuspid incompetence grade III or IV**

- **Yes**
  - Three of four criteria apply:
    - S/L axis > 0.8
    - RVEDD > 39 mm
    - RA > 50 mm
    - RVEF < 30%
  - PVR > 4 Wood units
  - Yes
    - BVAD or TAH
  - No
    - LVAD Implantation

- **No**
# The echocardiographic assessment of the right ventricle: what to do in 2010?

Ruxandra Juncu1, Sorin Giuca1,2, André La Gerche2, Simona Vasile1, Carmen Ginhina1, and Jens-Uwe Voigt2

1Department of Cardiology, University of Medicine and Pharmacy Carol Davila, Bucharest, Romania, and 2Department of Cardiology, Catholic University Louvain, Louvain, Belgium

## Table 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal values (range or mean ± SD)</th>
<th>Clinical significance</th>
<th>Limitations</th>
<th>Source</th>
<th>Population size</th>
<th>Population age (range or mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV E/E' (m/s)</td>
<td>10 ± 5</td>
<td>Diagnosis of patients with ARVC/D</td>
<td>Risk of erroneous measurement in suboptimal sections</td>
<td>Rolke et al.51</td>
<td>41</td>
<td>19–46</td>
</tr>
<tr>
<td>RV E/A (m/s)</td>
<td>2.0 ± 1</td>
<td>Diagnosis of patients with ARVC/D and RV pressure overload</td>
<td>Risk of erroneous measurement in suboptimal sections</td>
<td>Rolke et al.51</td>
<td>41</td>
<td>19–46</td>
</tr>
<tr>
<td>RV E/A index</td>
<td>0.75 ± 0.5</td>
<td>Evaluation of patients with right ventricular failure</td>
<td>Same as measuring diameter Must be used in combination with RV inflow functional parameters</td>
<td>Undoplat et al.45</td>
<td>20</td>
<td>46 ± 12</td>
</tr>
<tr>
<td>LV size (mm)</td>
<td>40 ± 10</td>
<td>Evaluation of patients with right ventricular failure</td>
<td>Same as measuring diameter Must be used in combination with RV inflow functional parameters</td>
<td>Undoplat et al.45</td>
<td>20</td>
<td>46 ± 12</td>
</tr>
<tr>
<td>RV wall thickness (mm)</td>
<td>3 ± 5</td>
<td>Diagnosis of RV hypertrophy</td>
<td>Variability in measurement owing to interobserver variability</td>
<td>Frede et al.50</td>
<td>23</td>
<td>17–58</td>
</tr>
<tr>
<td>RV inflow E/E' (m/s)</td>
<td>2.0 ± 1</td>
<td>Diagnosis of RV dysfunction</td>
<td>Variability in measurement owing to interobserver variability</td>
<td>Lopez-Candales et al.52</td>
<td>82</td>
<td>50 ± 16</td>
</tr>
<tr>
<td>RV E/A (m/s)</td>
<td>1.0 ± 1</td>
<td>Evaluation of patients with right ventricular failure</td>
<td>Same as measuring diameter Must be used in combination with RV inflow functional parameters</td>
<td>Undoplat et al.45</td>
<td>20</td>
<td>46 ± 12</td>
</tr>
<tr>
<td>RV E/A index</td>
<td>0.50 ± 0.25</td>
<td>Evaluation of patients with right ventricular failure</td>
<td>Same as measuring diameter Must be used in combination with RV inflow functional parameters</td>
<td>Undoplat et al.45</td>
<td>20</td>
<td>46 ± 12</td>
</tr>
</tbody>
</table>

## Table 2 Continued

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal values (range or mean ± SD)</th>
<th>Clinical significance</th>
<th>Limitations</th>
<th>Source</th>
<th>Population size</th>
<th>Population age (range or mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV MPI</td>
<td>0.28 ± 0.04</td>
<td>Not limited by RV geometry</td>
<td>Pseudonormalization in the setting of increased atrial pressure</td>
<td>Tiel et al.54</td>
<td>37</td>
<td>43 ± 13</td>
</tr>
<tr>
<td>Evaluation of patients with congenital heart disease and pulmonary hypertension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prognostic value in pulmonary hypertension</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NA (m/s²)</td>
<td>18 ± 0.24</td>
<td>Relatively load-independent</td>
<td>Not limited by RV geometry</td>
<td>Evaluation of patients with congenital heart disease</td>
<td>Further clinical validation still needed</td>
<td>Vogel et al.74</td>
</tr>
<tr>
<td>S (cm²)</td>
<td>Base: 12.64</td>
<td>Simple measure</td>
<td>Diagnosis of patients with RV myocardial infarction</td>
<td>Further clinical validation still needed</td>
<td>Angle dependency</td>
<td>Makini et al.23</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>Base: 19 ± 6</td>
<td>Offers information about regional function</td>
<td>Evaluation of patients with RV myocardial infarction</td>
<td>Further clinical validation still needed</td>
<td>Angle dependency of the measurement (for TD)</td>
<td>Kovalski et al.34</td>
</tr>
<tr>
<td>Strain rate (Vs)</td>
<td>Base: 1.5 ± 0.4</td>
<td>Offers information about regional function</td>
<td>Evaluation of patients with RV myocardial infarction</td>
<td>Further clinical validation still needed</td>
<td>Same as strain</td>
<td>Kovalski et al.34</td>
</tr>
<tr>
<td>E (m/s²)</td>
<td>41 ± 11</td>
<td>Evaluation of RV diastolic function</td>
<td>High variability with respiration</td>
<td>Undoplat et al.77</td>
<td>255</td>
<td>22–89</td>
</tr>
<tr>
<td>A (m/s²)</td>
<td>31 ± 10</td>
<td>Evaluation of RV diastolic function</td>
<td>Same as E wave</td>
<td>Undoplat et al.79</td>
<td>255</td>
<td>22–89</td>
</tr>
<tr>
<td>E' (m/s²)</td>
<td>Base: 14.3 ± 3.5</td>
<td>Evaluation of RV diastolic function</td>
<td>Angle dependency of the measurement</td>
<td>Undoplat et al.79</td>
<td>255</td>
<td>22–89</td>
</tr>
<tr>
<td>E' (m/s²)</td>
<td>Base: 14.3 ± 3.5</td>
<td>Evaluation of RV diastolic function</td>
<td>Angle dependency of the measurement</td>
<td>Undoplat et al.79</td>
<td>255</td>
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<td>Angle dependency of the measurement</td>
<td>Undoplat et al.79</td>
<td>255</td>
<td>22–89</td>
</tr>
</tbody>
</table>
Right ventricular function

- **Semiquantitative evaluation** includes visual estimation of
  - RV size
  - Severe TR
  - RV longitudinal contractility

---

**Table 6 Evaluating Right-Heart Function**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desirable valuea</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVSWI</td>
<td>&gt;300 mm Hg × ml/m²</td>
</tr>
<tr>
<td>Central venous pressure</td>
<td>&lt;15 mm Hg</td>
</tr>
<tr>
<td>Tricuspid regurgitation</td>
<td>Minimal to moderate</td>
</tr>
<tr>
<td>Pulmonary vascular resistance</td>
<td>&lt;4 Woods units</td>
</tr>
<tr>
<td>Transpulmonary gradient</td>
<td>&lt;15 mm Hg</td>
</tr>
<tr>
<td><strong>RV size</strong></td>
<td></td>
</tr>
<tr>
<td>RVEDV</td>
<td>&lt;200 ml</td>
</tr>
<tr>
<td>RVESV</td>
<td>&lt;177 ml</td>
</tr>
</tbody>
</table>

Need for pre-op ventilator support None

PVR, pulmonary vascular resistance; RV, right ventricle; RVEDV, right ventricular end-diastolic volume; RVESV, right ventricular end-systolic volume; RVSWI, right ventricular stroke work index.

aThese are conservative desired values indicating the least risk, and are not absolute cutoffs; pulmonary vascular resistance and transpulmonary gradient will typically be reduced during left ventricular assist device support.
Predictors of Post-LVAD RV failure

- **Clinical**
  - Pre-implant mechanical ventilation
  - Pre-implant renal/hepatic dysfunction

- **Hemodynamic**
  - High RA, low PA
  - CVP:PCW >0.63
  - RV-SW index < 300 mmHg x ml/m2

- **Echocardiographic**
  - RV size/function
  - TR
  - TAPSE
  - RV strain
Treatment Overview of HEART FAILURE

**Stage A**
High risk with no symptoms

**Stage B**
Structural heart disease, no symptoms

**Stage C**
Structural disease, previous or current symptoms

**Stage D**
Refractory symptoms requiring special intervention

- Hospice
- VAD, transplantation

- Inotropes
- Aldosterone antagonist, nesiritide
- Consider multidisciplinary team
- Revascularization, mitral-valve surgery
- Cardiac resynchronization if bundle-branch block present
- Dietary sodium restriction, diuretics, and digoxin
- ACE inhibitors and beta-blockers in all patients
- ACE inhibitors or ARBs in all patients; beta-blockers in selected patients
- Treat hypertension, diabetes, dyslipidemia; ACE inhibitors or ARBs in some patients
- Risk-factor reduction, patient and family education
RV failure during/after LV support (1)

- The **output** of the **native RV** determines the preload of the LVAD → ↓ in RV function will translate into a reduction of LVAD output.

- The **decision of implanting an RVAD** (ECMO, VAD) is most often needed when **CPB is discontinued**, because most pts receiving an RVAD do so just after LVAD implantation or later on the same day.

**Right Ventricle**

**Pulmonary Arteries**

**Normal**
- Thin RV
- Healthy PA endothelium
- Thin walled-relaxed PAs
- Large capillary network
- Normal CO
- Normal PVR
- Normal perfusion

**Compensation**
- Hypertrophied RV
- Abnormal PA endothelium
- Constricted-stiff PAs
- Loss of microvessels
- Normal CO
- Mild increase in PVR
- Moderate decrease in perfusion

**Failure**
- Dilated RV
- Cell proliferation in the PA wall
- Obliterative PA remodeling
- Severe decrease in CO
- Severe increase in PVR
- Severe decrease in perfusion
Risk Score Derived from Pre-operative Data Analysis Predicts the Need for Biventricular Mechanical Circulatory Support

J. Raymond Fitzpatrick III, MD, John R. Frederick, MD, Vivian M. Hsu, MD, Elliott D. Kozin, BA, Mary Lou O’Hara, MSN, Elan Howell, BSN, Deborah Dougherty, BSN, Ryan C. McCormick, BS, Carine A. Laporte, BA, Jeffrey E. Cohen, BA, Kevin W. Southerland, BS, Jessica L. Howard, BS, Mariell L. Jessup, MD, Rohinton J. Morris, MD, Michael A. Acker, MD, and Y. Joseph Woo, MD

Background: Right ventricular (RV) failure after left ventricular assist device (LVAD) placement is a serious complication and is difficult to predict. In the era of destination therapy and the total artificial heart, predicting post-LVAD RV failure requiring mechanical support is extremely important.

Methods: We reviewed patient characteristics, laboratory values and hemodynamic data from 266 patients who underwent LVAD placement at the University of Pennsylvania from April 1995 to June 2007.

Results: Of 266 LVAD recipients, 99 required RV assist device (BiVAD) placement (37%). We compared 36 parameters between LVAD (n = 167) and BiVAD patients (n = 99) to determine pre-operative risk factors for RV assist device (RVAD) need. By univariate analysis, 23 variables showed statistically significant differences between the two groups (p ≤ 0.05). By multivariate logistic regression, cardiac index ≤2.2 liters/min/m² (odds ratio [OR] 5.7), RV stroke work index ≤0.25 mm Hg · liter/m² (OR 5.1), severe pre-operative RV dysfunction (OR 5.0), pre-operative creatinine ≥1.9 mg/dl (OR 4.8), previous cardiac surgery (OR 4.5) and systolic blood pressure ≤96 mm Hg (OR 2.9) were the best predictors of RVAD need.

Conclusions: The most significant predictors for RVAD need were cardiac index, RV stroke work index, severe pre-operative RV dysfunction, creatinine, previous cardiac surgery and systolic blood pressure. Using these data, we constructed an algorithm that can predict which LVAD patients will require RVAD with >80% sensitivity and specificity. J Heart Lung Transplant 2008;27:1286–92. Copyright © 2008 by the International Society for Heart and Lung Transplantation.
The Right Ventricular Failure Risk Score
A Pre-Operative Tool for Assessing the Risk of Right Ventricular Failure in Left Ventricular Assist Device Candidates

Jennifer Cowger Matthews, MD,* Todd M. Koelling, MD,* Francis D. Pagani, MD, PhD†
Keith D. Aaronson, MD, MS*"
PULMONARY CIRCULATION

Superimposed components:
- Vasoconstriction
- NO availability ↓
- Desensitisation to NP-induced vasodilation
- Arteriolar remodeling
- Venous congestion
- Metabolic factors
- Inflammatory cells

Pulmonary vascular disease (i.e. remodeling)

Passive backward transmission of left-sided filling pressures

RIGHT HEART
- RV failure

LEFT HEART
- Loss of LA compliance (exercise increased)
- Mitral regurgitation
- Systolic/diastolic LV dysfunction

Source: Eur Heart J © 2016 Oxford University Press
RV failure is avoidable

- Increased RV afterload
- Imperfect protection
- Unreliable-chaging preload
- Unstable vasculator tone
- Hypthermia
- Transfusion
- LV filling-balancing septum
# Prediction of RV Dysfunction

## Speckle Tracking

## Echocardiographic Risk Factor for RV Failure

<table>
<thead>
<tr>
<th>Echocardiographic Variable</th>
<th>No RV Failure</th>
<th>RV Failure</th>
<th>OR (95% CI)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV end-diastolic dimension (cm)</td>
<td>7.0 ± 1.0</td>
<td>6.9 ± 1.1</td>
<td>0.86 (0.58–1.27)</td>
<td>0.45</td>
</tr>
<tr>
<td>LV ejection fraction (%)</td>
<td>15 (10 to 20)</td>
<td>15 (10 to 25)</td>
<td>1.01 (0.93–1.11)</td>
<td>0.75</td>
</tr>
<tr>
<td>Mitral regurgitation (moderate to severe)</td>
<td>33/62 (53)</td>
<td>24/44 (55)</td>
<td>1.03 (0.70–1.52)</td>
<td>0.89</td>
</tr>
<tr>
<td>Subjective RV dysfunction (moderate to severe)</td>
<td>19/63 (30)</td>
<td>22/43 (51)</td>
<td>1.56 (1.04–2.34)</td>
<td>0.03</td>
</tr>
<tr>
<td>Tricuspid regurgitation (moderate to severe)</td>
<td>21/61 (34)</td>
<td>16/44 (36)</td>
<td>1.04 (0.69–1.56)</td>
<td>0.84</td>
</tr>
<tr>
<td>Lateral RV peak longitudinal strain (%)</td>
<td>−12.2 (−9.5 to 14.9)</td>
<td>−9.0 (−7.3 to 11.4)</td>
<td>0.84 (0.75–0.92)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RV fractional area change (%)</td>
<td>22.1 ± 8.4</td>
<td>19.4 ± 8.7</td>
<td>0.96 (0.92–1.01)</td>
<td>0.09</td>
</tr>
<tr>
<td>RVEDD-to-LVEDD ratio</td>
<td>0.72 ± 0.15</td>
<td>0.74 ± 0.17</td>
<td>2.75 (0.24–33.8)</td>
<td>0.42</td>
</tr>
<tr>
<td>Tricuspid annular systolic excursion (cm)</td>
<td>1.32 ± 0.29</td>
<td>1.22 ± 0.25</td>
<td>0.26 (0.06–1.05)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Grant ADM et al. JACC 2012;60:521-8
Considering RV geometry and velocity of contraction before LVAD implantation.