Right Heart Failure: The Struggle is Real

Bryan Barrus, MD
Associate Director of Heart Transplantation
University of Rochester
No Financial Disclosures
Objectives:

1. Review early diagnosis and risk factors for right heart failure
2. Discuss targeted therapy for the struggling right ventricle post cardiopulmonary bypass
The Forgotten Chamber
Right Heart Failure

Publications on Right Heart Failure

Pubmed accessed on 4/1/2018: "Right Heart Failure"
Right Ventricle Anatomy is Complex
Right Ventricle Anatomy
The Heart Unraveled
Normal Physiology

- Peristaltic contraction of RV
- Low pulmonary impedance – 1/6th systemic
- Critical septal interdependence – LV contribution 20-40%

Can J Cardiol. 2017 Jan;33(1):61-71
Radiologia 2012;54:231-45
Coronary Blood Flow

- LCA occurs during diastole
- RCA occurs during diastole and systole

Can J Cardiol. 2017 Jan;33(1):61-71
Pathology of RV Failure
Avoid the RV Death Spiral!
Causes of RV Failure

- Afterload
- Preload
- Contractility
- Other
Preload Causes of RV Failure

Too much:
- Tricuspid or pulmonic valve regurgitation
- Anomalous pulmonary venous return
- Atrial septal defect

Too little:
- Tamponade

*Circulation* 2008;117:1717–1731
Afterload Causes of RV Failure

Mechanical:
- Pulmonary stenosis/RVOT obstruction
- PE
- Pulmonary hypertension (some types)

Functional:
- Lung volumes: FRC
- Hypoxia, hypercarbia, acidosis, hypothermia, shivering
- $\alpha$-agonists

Mean PAP = LAP + CO x PVR

Can J Cardiol. 2017 Jan;33(1):61-71
Preload vs Afterload Effect on RV Dilation

Elevated PA pressures: TSG = 20 mmHg

RVESP 60 mmHg
LVESP 80 mmHg

D  Extension of PEVK and N2B unique sequence

Circulation 2008; 117: 171–173
Contractility Causes of RV Failure

Causes:

- RV Infarction
- Arrhythmia
- Cardiomyopathy
- Sepsis
"Double Hit" Phenomenon

"Double-Hit", Rapid Organ System Failure

↑ CVP

↑ RV wall tension, RV dilation

Pericardial Restraint

↓ RV perfusion

↑ RV Afterload

↑ RV Pressure

↓ TSG, IVS shifts left, RV becomes globular

↓ RV CO

↓ LV filling, ↓ LV CO

Systemic hypotension

TR

LV ischemia, ↑ LVEDP

Can J Cardiol. 2017 Jan;33(1):61-71
“Double Hit” Phenomenon

MAP – CVP = Organ Perfusion Pressure

Right-Sided Shock

CO = 2.0, MAP = 60, CVP = 23

Organ perfusion pressure = 37
(low MAP and high CVP)

• Organ perfusion pressure severely reduced
• Renal failure
• Liver failure
• Bowel edema, translocation of bacteria
  • Further ↓ in SBP
• Ascites

Left-Sided Shock

CO = 2.0, MAP = 60, CVP = 8

Organ perfusion pressure = 52
(low MAP but low CVP)

• Relatively preserved end organ perfusion
Clinical Signs of RV Failure

- Hypoxemia
- Signs of systemic congestion
  - JVP, Kussmaul’s sign, peripheral edema, ascites, etc.
- Signs of RV dysfunction
  - 3rd heart sound, TR murmur, hepatic pulse
- Signs of low cardiac output state
  - Hypotension, cool extremities, tachycardia, oliguria, mental status changes
Diagnosis Aids

Echocardiographic findings in RV failure

- Increased RA size
- Large RA and RV
- RV > LV in 4-chamber apical view
- RV wall motion: grade 1 = normal; grade 2 = hypokinetic; grade 3 = akinetic; grade 4 = dyskinetic; grade 5 = aneurysmal
- Septal flattening
- Dilated IVC with no respiratory variation
- Dilated IVC
- RV wall thickness: > 5 mm is hypertrophy; > 10 mm suggests PA pressures near systemic
- McConnell sign in PE (akinesis of mid free wall, normal apical motion)
- Visible clot (PE)
- TAPSE < 16 mm
- RVSP elevated: Bernoulli method using TR velocity using RA pressure
- S' of tricuspid annulus
- RV myocardial performance index
- RV FAC [(EDV – ESV)/EDV]: normal 35%-60%
- Pulmonic flow signal morphology: PH from left heart disease shows normal morphology; late systolic notching indicative of increased PVR; early systolic notching suggests severe PH and RV dysfunction
Diagnosis Aids

Invasive monitoring:

- Incredibly helpful in early diagnosis and management
Can We Predict Post-op RV Failure?

Table 1. Hemodynamic Formulas to Assess Right Ventricular Function

<table>
<thead>
<tr>
<th>Hemodynamic Formulas to Assess RV Function</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
</table>
| Cardiac filling pressures                 | RAP/PCWP | >0.63 (RVF after LVAD)<sup>13</sup>  
>0.86 (RVF in acute MI)<sup>30</sup> |
| PA pulsatility index (PAPI)               | (PASP−PADP)/RAP | <1.85 (RVF after LVAD)<sup>31</sup>  
<1.0 (RVF in acute MI)<sup>32</sup> |
| Pulmonary vascular resistance             | mPAP−PCWP/CO | >3.6 (RVF after LVAD)<sup>15</sup> |
| Transpulmonary gradient                   | mPAP−PCWP | Undetermined<sup>33</sup> |
| Diastolic pulmonary gradient              | PADP−PCWP | Undetermined<sup>33,34</sup> |
| RV stroke work                            | (mPAP−RAP)x  
SV×0.0136 | <15 (RVF after LVAD)<sup>15</sup>  
<10 (RVF after acute MI)<sup>35</sup> |
| RV stroke work index                      | (mPAP−RAP)/SV  
index | <0.3−0.6 (RVF after LVAD)<sup>13,31</sup> |
| PA compliance                             | SV/(PASP−PADP) | <2.5 (RVF in chronic heart failure)<sup>36</sup> |
| PA elastance                              | PASP/SV | Undetermined<sup>37</sup> |

CO indicates cardiac output; LVAD, left ventricular assist device; MI, myocardial infarction; mPAP, mean pulmonary artery pressure; PA, pulmonary artery; PADP, pulmonary artery diastolic pressure; PASP, pulmonary artery systolic pressure; PCWP, pulmonary capillary wedge pressure; RAP, right atrial pressure; RV, right ventricular; RVF, right ventricular failure; and SV, stroke volume.
Defining Right Heart Failure

- No agreed upon definition, particularly after LVAD implant
- INTERMACS definition:
  - CVP >18 mmHg
  - CI < 2.0 in absence of:
    - PCWP/LA pressure >18 mmHg
    - Cardiac tamponade
    - Ventricular arrhythmias
    - Pneumothorax
  - Requires either:
    - RVAD
    - iNO or inotrope therapy ≥14 days

Defining Right Heart Failure

- INTERMACS further divides:
  - Mild - a combination of ≥ 2 signs and symptoms are present but without the need for RVAD or inotropic and/or vasodilator support.
    - Signs and symptoms: CVP > 18 mm Hg, CI < 2.3 L/min/m^2, ascites, moderate to severe peripheral edema, or evidence of high CVP on physical exam or transthoracic echocardiogram.
  - Moderate - inotropes or intravenous or inhaled pulmonary vasodilators are used.
  - Severe - there is a need for RVAD;

Principles of RV Management in the ICU

• General medical principles
• MCS is the only targeted therapy
General Principles

1. Optimize the rate and rhythm
2. Determine the optimum RV filling pressure
3. Maintain RV coronary perfusion
4. Reduce the pulmonary resistance with selective use pulmonary vasodilators
1. Optimize Rate and Rhythm

- Afib and heart block is not tolerated by RV. Early cardioversion is key.

- Higher HR (>80) to decrease distention, TR. This might lead to increased cardiac output.

- Infarction – often associated with bradyarrhythmias. Consider cath if indicated.

- Pace! (but use atrial leads to keep AV synchrony)
2. Determine the Optimum RV Filling

• “Failing RV needs volume loading” – WRONG!

• CVP >10 mmHg (adequate) with echo showing dilated RV can be confounding

• Give small fluid bolus (250 cc), should see 2-5 mmHg in CVP (but still remains <20) and significant improvement in systemic perfusion

• Autotransfusion with the passive leg raise test is an alternative method to determine RV volume responsiveness.
3. Maintain RV Coronary Perfusion

- Failing RV – pressures are high creating LV filling pattern, perfusion during diastole

- Consider vasopressin (no receptors in the pulmonary vasculature), usually need norepinephrine in addition and an inotrope

- Increase the MAP 70-90
  - This will also reposition the interventricular septum more midline, increase TSG
4. Reduce PVR – Non-pharmacologic

- Optimize lungs: Reduce atelectasis and avoid overdistending lungs
  - Optimize PEEP, correct acidosis, low CO2 and high O2
  - Correct ET tube placement (right mainstem can be fatal)
  - PIP <30 cmH2O
- Consider sedation, paralysis, and draining effusions
4. Reduce PVR - pharmacologic

- Avoid intravenous pulmonary vasodilators
- Inhaled vasodilators:
  - Epoprostenol
  - Iloprost
  - Nitric oxide
- Phosphodiesterase inhibitors:
  - Milrinone (can also be inhaled)
  - Sildenafil, tadalafil

- Consider combination therapy
Mechanical Circulation Support

Intra-aortic Balloon Pump
**IABP Evidence**

- 54 patients decompensating prior to LVAD
- Inclusion criteria:
  - Intubation
  - ↑ vasopressors
  - Initiation dialysis
  - Refractory ventricular arrhythmias
  - Worsening acidosis
- 43% Decompensated
- 57% Stabilized

---

**Intra-Aortic Balloon Counterpulsation in Patients with Chronic Heart Failure and Cardiogenic Shock: Clinical Response and Predictors of Stabilization**

Marc A. Sintek, MD
d, Mark Gidewail, MD
d, Brian R. Lindman, MD, MSc
d, Michael Hassell, MD
d, Kory J. Levine, MD, PhD
d, Eric Novak, MS
d, Richard G. Bach, MD
d, Scott C. Silvestry, MD, Douglas L. Mann, MD
d, and Susan M. Joseph, MD
d

1 Cardiovascular Division, Washington University School of Medicine, St. Louis, MO

Impella RP

Benefits of a novel percutaneous ventricular assist device for right heart failure: The prospective RECOVER RIGHT study of the Impella RP device

J Heart Lung Transplant. 2015;34:1549–1560
Protek Duo

- Provides up to 5 LPM support
- Allows incorporation of oxygenator
- 17 patients with RVF (LVAD, Txp)
  - 24% weaned
  - 35% changed to surgical RVAD
  - 41% mortality
Indirect Support – VA ECMO

- Clinical data limited to case series
- Will see decrease in CVP and PA pressures
## Summary of MCS for RVAD Support

### Table 2. Hemodynamic Effects of Acute Right Ventricular Mechanical Circulatory Support Systems for Isolated Right Ventricular Failure or Biventricular Failure

<table>
<thead>
<tr>
<th>RV-AMCS Device</th>
<th>Device Characteristics</th>
<th>Hemodynamic Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Device Characteristics</td>
<td>Flow Range, L/min</td>
</tr>
<tr>
<td></td>
<td>Inflow</td>
<td>Outflow</td>
</tr>
<tr>
<td>Isolated RV failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impella RP</td>
<td>RA</td>
<td>PA</td>
</tr>
<tr>
<td>TH-RVAD or Protek</td>
<td>RA</td>
<td>PA</td>
</tr>
<tr>
<td>VA-ECMO</td>
<td>RA</td>
<td>FA</td>
</tr>
<tr>
<td>Biventricular failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impella RP</td>
<td>RA</td>
<td>PA</td>
</tr>
<tr>
<td>TH-RVAD or Protek</td>
<td>RA</td>
<td>PA</td>
</tr>
<tr>
<td>VA-ECMO</td>
<td>RA</td>
<td>FA</td>
</tr>
<tr>
<td>Biventricular support devices (ie, Impella CP+RP)</td>
<td>RA</td>
<td>PA</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>AO</td>
</tr>
</tbody>
</table>

AMCS indicates acute mechanical circulatory support; AO, aorta; CO, cardiac output; FA, femoral artery; LV, left ventricle; LVEDP, left ventricular end-diastolic pressure; MAP, mean arterial pressure; PA, pulmonary artery; PAP, pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; RA, right atrial; RAP, right atrial pressure; RV, right ventricular; TH-RVAD, TandemHeart right ventricular assist device; VA-ECMO, venoarterial extracorporeal membrane oxygenation; Δ, no change; ↑ or ↓, mild to moderate change; ↑↑ or ↓↓, moderate to significant change; Δ↑, no change or mild increase; and Δ↓, no change or mild decrease.
Durable MCS
Ultimate RV Support

Total Artificial Heart

Human Heart
# TAH Eliminates

<table>
<thead>
<tr>
<th>Types of Support</th>
<th>Native Heart issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Defibrillator</td>
<td>• Ventricular thrombus</td>
</tr>
<tr>
<td>• Pacemaker</td>
<td>• VSDs</td>
</tr>
<tr>
<td>• Balloon pump</td>
<td>• Mechanical valves</td>
</tr>
<tr>
<td>• ECG/arrhythmia monitoring</td>
<td>• Heart/graft preservation</td>
</tr>
<tr>
<td>• Swan-Ganz catheters</td>
<td>• Right heart failure/dysfunction</td>
</tr>
<tr>
<td></td>
<td>• Native valves (aortic/tricuspid insufficiency)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
<th>Medications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CPR</td>
<td>• Anti-arrhythmics</td>
</tr>
<tr>
<td>• Concern with pulmonary pressures</td>
<td>• Beta blockers</td>
</tr>
<tr>
<td>• Device pocket</td>
<td>• Inotropes</td>
</tr>
<tr>
<td>• End organ dysfunction due to low flow and elevated filling pressures</td>
<td>• Immunosuppressives</td>
</tr>
<tr>
<td></td>
<td>• Pulmonary dilators</td>
</tr>
</tbody>
</table>
Upcoming MCS

MVAD?

CAUTION: Investigational device. Exclusively for clinical investigation.
Investigational device to be used by Qualified Investigators Only.
Upcoming MCS

PERKAT
- Based on IABP
- Flows up to 4 LPM
Upcoming MCS

FREED (Free-range Resonant Electrical Electrical Energy Delivery)  
A tether-free Left Ventricular Assist Device (LVAD)

Image Courtesy of Pramod Bonde
Takeaway Message

- Early recognition RVF is key
- Optimize hemodynamics
- Inotropes, pulmonary vasodilators