I have no conflicts of interest or financial disclosures to report

Goals and Objectives
1. Review right ventricle anatomy and function
2. Discuss the pathophysiology of right ventricular failure
3. Review the echocardiographic evaluation of the right ventricle
4. Identify risk factors for RV failure
5. Discuss management strategies for RV failure

Case Study
- 54 y male presents with severe mitral regurgitation
  - PMH: CHF exacerbations requiring admissions 3 times over 1 year
  - TTE: Bileaflet redundancy with severe MR, dilated LA, LV func 45%, estimated PASP 58

  - Reluctant to have surgery and has resisted in the past, now willing

Right Ventricle Anatomy
- Complex shape
- Right Ventricle divided into 3 main anatomic areas
  - Smooth muscular inflow (body or sinus)
  - Trabecular apical region
  - Outflow area (infundibulum or conus)

Right Ventricle Normal Function
- Larger than the RV by EDV
- Lower ejection fraction than LV by 10-15%
  - Lower end of normal values ~ 45%
- Mass regresses as PVR drops at birth
  - Adult 1/6th the LV mass
- Better adapted to handle volume overload
Right Ventricular Pathophysiology

Patho-anatomical change

- Chronic volume overload
  - Progressive lengthening of base to apex and septum to free wall
  - D shaped LV in diastole
- Chronic pressure overload
  - D shaped LV short axis in systole

RV Basics

- Immediate survival Rates for post op RV failure ~ 25-30%
- RV systolic dysfunction or severe RV dilation
  - Present in almost ½ the patients with hemodynamic compromise
- 2 year all cause mortality
  - RVEF <20%: 16.7%
  - 20-30%: 8.2%
  - >30%: 4.1%

RV Post Cardiac Surgery

- Refractory RV failure post cardiac surgery needing prolonged ionotropic support or RVAD
  - 0.1% all comers
  - 2-3% Heart Transplants
  - 20-30% of patients with LVAD

Definitions of RV Function

RV Dysfunction

- INTERMACS definition:
  - CVP > 16 cmH₂O
  - Dilated IVC with absence of respiratory variation by TTE
  - Associated clinical features of venous congestion

RV Failure

- Need for inhaled vasodilator >48 hours
- Intravenous inotropes >14 days
- Right ventricular assist device

Right Ventricular Dysfunction
Echocardiography

- Evaluating the RV
- Mid Esophageal
  - Modified 4 chamber
  - RV inflow-outflow
  - Bicaval (for Tricuspid jet doppler)
- Transgastric
  - Short and long axis
  - Modified view

Esophageal Views

Midesophageal View

Transgastric Views

Transgastric views

RV Assessment

- Tricuspid Annular Plane systolic excursion (TAPSE)
  - Modified deep transgastric long index
- RV Fractional Area Change (FAC)
- Tei index/ RV index of myocardial performance (RIMP)
  - Tissue doppler
- 3D TEE
- Speckle tracking and strain
**Echocardiography Caveats**

- Imaging modality matters
- 2D options
  - TAPSE vs FAC vs speckle tracking
- 2D vs 3D
  - Changes in RV long axis performance
  - Opening the pericardium?
- TTE vs TEE

<table>
<thead>
<tr>
<th>Parameter Control</th>
<th>Inflow RV Repair</th>
<th>After RV Repair</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAPSE (mm)</td>
<td>25.8 ± 4.4</td>
<td>25.2 ± 4.1</td>
</tr>
<tr>
<td>PV (m/s)</td>
<td>10.2 ± 2.3</td>
<td>11.3 ± 3.8</td>
</tr>
<tr>
<td>RV EF (%)</td>
<td>65.6 ± 5.3</td>
<td>59.6 ± 6.8†</td>
</tr>
<tr>
<td>RV FAC (%)</td>
<td>45.4 ± 10.2</td>
<td>42.7 ± 8.1</td>
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</tbody>
</table>

* Versus Pre-operative value
† Versus controls

**TAPSE VS FAC**

![Graph showing TAPSE vs FAC comparison](image_url)

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**Deep Transgastric RV Inflow-Outflow**


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**Echocardiographic Imaging Modalities**

![Graph showing echocardiographic imaging modalities](image_url)
TAPSE vs Free wall post CPB

Perioperative RVD Risks
- Identify Patients at high risk
  - Long cardiopulmonary bypass runs (>150 min)
- Suboptimal intraoperative myocardial protection
- Coronary Embolism or graft occlusion
- Lung Injury or mechanical ventilation induced lung injury
  - ARDS post cardiac surgery ~10%
- Heart Transplants
  - Donor heart ischemia or pre-op pulmonary vascular dysfunction

Avoiding RV Failure
- Appropriate Timing of Surgery
- Optimizing myocardial protection
- Selective Use of Pulmonary Vasodilators
- Avoiding liberal transfusion strategies
  - Avoiding old blood products

Timing
- Things out of our control
  - Valvular induced pre-op RV failure
    - Someone waited too long
- Acute RV infarction
  - 1 month wait to allow for RV recovery

Surgical Technique
- Choice and route of cardioplegia
- Choice of bypass graft targets
  - For long term revascularization
  - Improve myocardial protection
- Addition of tricuspid repair
- Atrial and ventricular wires

Cardioplegia
- Beware the RCA obstruction
- Retrograde cardioplegia caveats
  - Thebesian vessels
- Data on choice of cardioplegia still to come
**Pulmonary Vasodilation**
- Nitric Oxide
- Inhaled Prostaglandins
- Other inhaled agents
- Timing of use

**Nitric Oxide**
- Primary pulmonary vasodilator
  - No effect on systemic circulation
- V-Q matching
- Reduced RV afterload
- Negatives:
  - Methemoglobinemia
  - Cost
  - Weaning required

**How about Data?**
- LVAD implantation on CPB, multi-center, blinded trial
- About 75 patients per group*: iNO 40ppm vs placebo
- Open label cross over for safety
- Primary outcome: Reduction in RVD
- Outcomes:
  - No statistical changes in any outcomes
  - Trends towards shorter mechanical ventilation, RVDs

**Inhaled Prostaglandins**
- Epoprostenol/Iloprost (prostaglandin I₂)
- Similar effects as NO
  - Longer half life
  - Less rebound pulmonary hypertension?
- Possible synergistic effect when combined with NO
- Negative
  - Potential for impaired platelet aggregation

**Inhaled Milrinone**
- Phosphodiesterase type III inhibitor
- Adds ionotropic effects vs other inhaled agents
- Inhaled has reduced effect on SVR and MAP
  - With maintaining increased CO, PAP, and PVR reduction
- 125 high risk cardiac surgical patients
- Valve or valve-CABG (complex) operations
- Blinded, single inhaled dose pre-CPB
- SV and CO improved
- Improved ventricular performance and reduced LA size
- No differences in difficulty separating from CPB or RV failure
**AV Synchrony**
- Sinus Rhythm maintenance
  - Cardioversion
  - Anti-arrhythmics
- Atrial pacing wires in high risk patients

**Ionotropic Support**
- Is there evidence for one ionotropic agent?
- Pros/Cons
  - Dobutamine
  - Milrinone
  - Epinephrine
  - Vasopressin
  - Norepinephrine

**Mechanical Support Options**
- Impella
- RVAD
- ECMO
- Outcomes data

**Impella RP**

**RECOVER Right**
- Cohort A: Post LVAD (n=18)
- Cohort B: Post Cardiotomy (n=7) or acute MI (n=5)

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<thead>
<tr>
<th></th>
<th>Cohort A</th>
<th>Cohort B</th>
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<tbody>
<tr>
<td>Survival to Discharge</td>
<td>85.3%</td>
<td>58.3%</td>
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<tr>
<td>180 day survival</td>
<td>70%</td>
<td>58.3%</td>
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Perioperative RVAD support

- Caveats – LVAD surgery, 25 patients, 2 institutions
- Pre-operative RV impairment by TAPSE criteria
- Received RVAD therapy after 1 failed wean from CPB
- 3 day weaning protocol for RVAD
- Hospital survival 68% (vs 70%) of isolated LVAD recipients
- Discussion
  – Integrated ECMO oxygenation with lung protective ventilation

Summary

- RV failure is rare but can be catastrophic
- Beware of pre-operative RV dysfunction
- Many factors are under surgeon's control
- Intraoperative TEE will help guide your decision making
- Ionotropes and vasopressors each have pros and cons
- There is no perfect solution!