THE RIGHT VENTRICLE
IN PULMONARY HYPERTENSION

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Why the Right Ventricle?

Pulmonary hypertension (PH)

Right ventricle (RV) function

Outcome
RV dysfunction & outcome

Ghio, et al. JACC 2001;37:138-188
RV dysfunction & outcome

A

![Graph showing survival rate over time for NYHA classes I-II, III, and IV.]

B

![Graph showing survival rate over time for 6MWD categories <250 m, 250-350 m, and >350 m.]

NYHA class

6MWD

<table>
<thead>
<tr>
<th>Better prognosis</th>
<th>Determinants of prognosis</th>
<th>Worse prognosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Clinical evidence of RV failure</td>
<td>Yes</td>
</tr>
<tr>
<td>Slow</td>
<td>Rate of progression of symptoms</td>
<td>Rapid</td>
</tr>
<tr>
<td>No</td>
<td>Syncope</td>
<td>Yes</td>
</tr>
<tr>
<td>I, II</td>
<td>WHO-FC</td>
<td>IV</td>
</tr>
<tr>
<td>Longer (&gt;500 m)^\text{a}</td>
<td>6MWT</td>
<td>Shorter (&lt;300 m)</td>
</tr>
<tr>
<td>Peak O$_2$ consumption $&gt;$15 mL/min/kg</td>
<td>Cardio-pulmonary exercise testing</td>
<td>Peak O$_2$ consumption $&lt;$12 mL/min/kg</td>
</tr>
<tr>
<td>Normal or near-normal</td>
<td>BNP/NT-proBNP plasma levels</td>
<td>Very elevated and rising</td>
</tr>
<tr>
<td>No pericardial effusion TAPSE$^b$ $&gt;$2.0 cm</td>
<td>Echocardiographic findings$^b$</td>
<td>Pericardial effusion TAPSE$^b$ $&lt;$1.5 cm</td>
</tr>
<tr>
<td>RAP $&lt;$8 mmHg and CI $&gt;$2.5 L/min/m$^2$</td>
<td>Haemodynamics</td>
<td>RAP $&gt;$15 mmHg or CI $&lt;$2.0 L/min/m$^2$</td>
</tr>
</tbody>
</table>

RV response to PH

- Variable
- Depends on:
  - PH type
  - Onset rapidity
  - PH severity

Prediction of future dysfunction

LIMITED
RV Chamber characteristics

- Thinner free wall
- Lower mass
- Different geometry
- Greater distensibility
- Operates at higher volumes

Difference from LV
RV response in PH

A

RCA (IPAH #2)

Systole

Diastole

Flow (mL/s)

250 500 750 1000

Time (ms)

LAD (IPAH #2)

Systole

Diastole

Flow (mL/s)

250 500 750 1000

Time (ms)

B

RCA (Control #2)

Systole

Diastole

Flow (mL/s)

250 500 750 1000

Time (ms)

LAD (Control #2)

Systole

Diastole

Flow (mL/s)

250 500 750 1000

Time (ms)

Wolferen et al. Eur Heart J 2008; 29:120-7
RV response to PH


RV afterload

- **PVR**
  - used in clinical practice as equivalent for afterload
  - may not reflect its complex nature

- **Pulmonary arterial system**
  - Low impedance / high distensible
    - High compliance
    - Low resistance
    - Low peripheral pulse wave reflection coefficient
Systemic circulation

- Resistance
  - small arteries
  - arterioles

- Compliance
  - aorta

Pulmonary circulation

- Resistance
  - small arteries
  - arterioles

- Compliance
  - entire pulmonary circulation
Windkessel model

Veins  Heart  Elastic arteries  PVR

2-element WK

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C  R
RC constant

Decrease steady afterload

\[ C = \frac{\tau}{R} \]

Patient A

Patient B
Capacitance and outcome

Mahapatra et al. JACC 2006;47, 799-806

Dragu et al. IHS Congress 2013
Capacitance and outcome

Dragu et al. IHS Congress 2013
Assessment of RV function in PH

- Mechanisms of RV failure in PH
- Prognostic implications
- Effect of PH-specific tx on RV
Parameters that reflect RV function

**Echocardiography**

- RA area\(^1\)
- RV Area\(^1\)
- TAPSE\(^1,2\)
- Tei index\(^3\)
- RV fractional area change\(^2\)
- Degree of tricuspid regurgitation\(^2\)
- Pericardial effusion\(^4\)
- Inferior vena cava collapsibility\(^2\)
- Superior vena cava flow velocity pattern\(^2\)

**MRI**

- RV EF% and SV\(^6\)
- Mass index\(^7\) and geometry\(^8\)

**RHC**

- Right atrial pressure\(^9\)
- Cardiac index\(^10\)

**Biomarkers**

- NT-proBNP\(^{11}\)
- Troponin T\(^{12}\)

Echo

- **Variables in good correlation with:**
  - Hemodynamics
  - Anatomy

- **Limited visualisation of RV:**
  - Complex geometry
  - Extensive trabeculations
  - Retrosternal position
Echo - Pericardial effusion

Echo - Pericardial effusion


Echo - TAPSE

- Longitudinal movement of lateral tricuspid annulus towards apex at peak systole
- Abundant longitudinal fibres
- Correlates with RV systolic function

Normal TAPSE

Low TAPSE

Echo - TAPSE

Echo - RV morphology

Survival curves in patients with RV wall thickness ≤ 6.6 mm

Survival curves in patients with RV wall thickness > 6.6 mm

- Death rate per 100 patient-year:
  - RV diameter < 36.5 mm
    - 6.6 (95%CI 3.3-13.2)
  - RV diameter > 36.5 mm
    - 15.9 (95%CI 9.4-26.8)

Echo - 2D longitudinal strain

- Percentage change in myocardial deformation
- Doppler or speckles
- More negative = better contractility
- Unlike TAPSE it takes whole RV into account
- Load dependent

Echo - 2D longitudinal strain

Loop diuretics

Oedema despite loop diuretics

Proportion with symptom progression, %

Survival, %

Follow-up, years

-20 to ≤-20
-12.5 to >-20
-12.5 to ≤-12.5

-20
-12.5
0
20%
40%
60%
80%
100%

Mild (> -20%)
Moderate (-20 to -12.5%)
Severe (< -12.5%)

Echo - 3D

- Rapid acquisition of full volume 3D data
- Accurate & reproducible measures of RV

<table>
<thead>
<tr>
<th></th>
<th>ESV (ml)</th>
<th>EDV (ml)</th>
<th>EF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMR</td>
<td>0.89</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>CT</td>
<td>(-9ml)</td>
<td>(-14ml)</td>
<td>(-2%)</td>
</tr>
<tr>
<td>3DE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 64 IPAH prevalent patients
- Measured at baseline by MRI
- Mean follow-up: 32 months

CMRI - RV ejection fraction

1-Clinical worsening (%)

Days to event

Log-rank $p = 0.0063$

Time (months)

$p < 0.001$

- Blue line: RVEF < 39%
- Red line: RVEF ≥ 39%
- Blue line: RVEF > 35%
- Red line: RVEF < 35%

Freed et al. JCMR 2012; 14:11.
CMRI - Myocardial delayed enhancement
CMRI - Myocardial delayed enhancement

Right ventricular insertion point-late gadolinium enhancement (RVIP-LGE)

Log-rank $p = 0.0065$

Days to event

1-Clinical worsening (%)

Total delayed enhancement mass (g)

Ventricular mass index

BNP as surrogate of RV function

* $p < 0.05$ vs control
† $p < 0.05$ vs RVVO

44 patients
18 - ASD (RVVO)
16 - CTEPH (RVPO)

Prognostic value of cardiac troponin T in PAH and CTEPH patients

Cumulative survival

Time (months)

Numbers at risk, n

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>6</th>
<th>12</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac troponin T (-)</td>
<td>48</td>
<td>43</td>
<td>33</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Cardiac troponin T (+)</td>
<td>8</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Conclusion

- Sir William Harvey 1616 – “De Motu Cardis”
  “Thus the right ventricle may be said to be made for the sake of transmitting blood through the lungs, not for nourishing them.”

- Paucity of knowledge regarding RV

- Understanding of RV adaptation to PH crucial for Tx.