Modern approach for right ventricle evaluation

Christine Selton-Suty, Olivier Huttin, Clément Venner, Laura Fillipetti

Echocardiographists of the P(A)H center in the University Hospital of Nancy
Disclosure Statement of Financial Interest

I currently have, or have had over the last two years, an affiliation or financial interests or interests of any order with a company or I receive compensation or fees or research grants with a commercial company:

Speaker's name:

☑ I do not have any potential conflict of interest
Pivotal role of RV in many diseases

Intrinsic factors
- morphology
- contractility

Extrinsic factors
- preload
- AFTERLOAD
- interdependence

RV function

functional class

Prognosis
Right heart – PA unit analysis by MRI

- **morphology**
  - RV morphology
    - RV volumes
    - RV mass
    - Septal curvature
    - Eccentricity index

- **contractility**
  - RV « function »
    - **RVEF**
      - RV EDV
      - RA volume

- **preload**
  - RV preload
    - RV EDV
    - RA volume

- **afterload**
  - RV afterload
    - PA flow
    - PA area
    - PA pulsatility
    - Shunt fraction

- **interdependence**
  - L-R interdep
    - LV volumes (LVEDV)
    - LVEF
    - Cardiac index

No estimation of PA pressures
Right heart – PA unit analysis by Catheterization

- **RV morphology**
  - RV volumes with conductance catheters

- **RV « function »**
  - RV SV
  - Cardiac Index
  - RVEF with thermodilution method
  - RV elastance with conductance catheters

- **RV preload**
  - RAP

- **RV afterload**
  - PAP s,d,m
  - PCWP
  - PVR
  - PA elastance with conductance catheters

- **L-R interdependence**
  - Cardiac index

No estimation of RV morphology and function in routine
Right heart – PA unit analysis by Echocardiography

- RV morphology
  - RV size and area
  - RV/LV, Eccentricity index
  - Pericardial effusion

- RV « function »
  - Longitudinal displacement
  - Time intervals
  - RV deformation
  - RVFAC and RVEF
  - Elastance

- RV preload
  - RA area, RAP
  - Tricuspid flow
  - TDI e’, a’

- RV afterload
  - PAP s,d,m
  - PVR
  - Pulmonary capacitance
  - Elastance

- L-R interdep
  - LVEF
  - Cardiac index
  - Mitral flow

The only technique allowing a complete assessment of the RV-PA unit
Analysis of RV function

- RV longitudinal displacement
  - M mode: TAPSE
  - TDI: S’, IVA
- RV time intervals
  - RV MPI (Tei index)
  - RV dP/dt
- Surrogates of RVEF
  - RV FAC
- RV deformation
  - RV strain
- RV volumes
  - 3D RVEF
Analysis of RV function

- RV longitudinal displacement
  - M mode: TAPSE
  - TDI: S’, IVA
- RV time intervals
  - RV MPI (Tei index)
  - RV dP/dt
- Surrogates of RVEF
  - RV FAC
- RV deformation
  - RV strain
- RV volumes
  - 3D RVEF
Guidelines

- In all clinical studies, a comprehensive assessment based on both qualitative and quantitative parameters of the RV should be performed, including:
  - RV and RA size
  - A measure of RV systolic function (at least one or a combination of the following): RV FAC, S', TAPSE, RV MPI
  - sPAP
  - 3D RVEF and volumes when feasible

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>Abnormality threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAPSE (mm)</td>
<td>24 ± 3.5</td>
<td>&lt;17</td>
</tr>
<tr>
<td>Pulsed Doppler S wave (cm/sec)</td>
<td>14.1 ± 2.3</td>
<td>&lt;9.5</td>
</tr>
<tr>
<td>Color Doppler S wave (cm/sec)</td>
<td>9.7 ± 1.85</td>
<td>&lt;6.0</td>
</tr>
<tr>
<td>RV fractional area change (%)</td>
<td>49 ± 7</td>
<td>&lt;35</td>
</tr>
<tr>
<td>RV free wall 2D strain* (%)</td>
<td>-29 ± 4.5</td>
<td>&gt;-20 (&lt;20 in magnitude)</td>
</tr>
<tr>
<td>RV 3D EF (%)</td>
<td>58 ± 6.5</td>
<td>&lt;45</td>
</tr>
<tr>
<td>Pulsed Doppler MPI</td>
<td>0.26 ± 0.085</td>
<td>&gt;0.43</td>
</tr>
<tr>
<td>Tissue Doppler MPI</td>
<td>0.38 ± 0.08</td>
<td>&gt;0.54</td>
</tr>
</tbody>
</table>

Multiparametric approach of RV function

• Because of discrepancies between indices

• 413 pts before surgery, classified according to $S'$ (10 cm/s) and RVFAC (35%)

• In 93 patients (22%), $S'$ and/or RVFAC were abnormal, but both were abnormal in only 39 (42%) patients
Multiparametric approach of RV function

- To improve prognostic assessment
- 140 pts with heart failure, FU 17 months
- Combination of echo parameters: Sa<10.8 cm/s, Ea<8.9 cm/s, Tei>1.2, IVA<2.52 m/s²

A. Survival

B. Event free survival

Meluzin JASE 2005;18:435
Load dependence of RV function indices

<table>
<thead>
<tr>
<th>Functional Parameters</th>
<th>Normal Value</th>
<th>Load Dependence</th>
<th>Clinical Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVEF, %</td>
<td>61±7% (47%–76%)(^8)</td>
<td>+++</td>
<td>Clinical validation, wide acceptance</td>
</tr>
<tr>
<td></td>
<td>&gt;40%–45%</td>
<td></td>
<td>Prognostic value in cardiopulmonary disorders(^9)</td>
</tr>
<tr>
<td>RVFAC, %</td>
<td>&gt;32%(^6)</td>
<td></td>
<td>Good correlation with RVEF</td>
</tr>
<tr>
<td>TAPSE, mm</td>
<td>&gt;15(^4)</td>
<td></td>
<td>Prognostic value in MI and bypass surgery(^46)</td>
</tr>
<tr>
<td>Sm annular, cm/s</td>
<td>&gt;12(^5)</td>
<td></td>
<td>Simple measure not limited by endocardial border recognition: Good correlation with RVEF</td>
</tr>
<tr>
<td>Strain</td>
<td>Basal: 19±6(^6)</td>
<td>+++</td>
<td>Good sensitivity and specificity for RVEF &lt;50%(^52)</td>
</tr>
<tr>
<td></td>
<td>Mid: 27±6</td>
<td></td>
<td>Correlates with stroke volume(^60,70)</td>
</tr>
<tr>
<td></td>
<td>Apical: 32±6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strain rate, s(^-1)</td>
<td>Basal: 1.50±0.41(^6)</td>
<td>+ +</td>
<td>Correlates with contractility(^69,70)</td>
</tr>
<tr>
<td></td>
<td>Mid: 1.72±0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Apical: 2.04±0.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVMPI</td>
<td>0.28±0.04(^5)</td>
<td>+ +</td>
<td>Global nongeometric index of systolic and diastolic function, prognostic value PH, CHD(^60,62)</td>
</tr>
<tr>
<td>dP/dt max, mm Hg/s</td>
<td>100–250(^3)</td>
<td></td>
<td>Not a reliable index of contractility(^65)</td>
</tr>
<tr>
<td>IVA, m/s(^2)</td>
<td>1.4±0.5(^6)</td>
<td>+</td>
<td>More useful in assessing directional change when preload accounted for</td>
</tr>
<tr>
<td>Maximal RV elastance, mm Hg/mL</td>
<td>1.30±0.84(^20)</td>
<td>+</td>
<td>Promising new noninvasive index of contractility, studies in CHD(^64,65)</td>
</tr>
</tbody>
</table>

Haddad Circulation 2008;117:1436-1448
Elastance and RV-PA coupling

- RV ESP ≈ mPAP-PCWP ≈ mPAP
- PA-Ea = PVR x HR  
  ≈ RV ESP / RV SV (mmHg/mL/m²)
- RV-Emax = slope of the ESP versus the ESV  
  ≈ RV ESP/ RV ESV (mmHg/mL/m²)
- RVAC = Ea/Emax or Emax/Ea  
  ≈ ESV/SV or SV/ESV
- if Emax/Ea is between 1-2, RV efficiency is within normal range

Vonk Noordegraaf J Am Coll Cardiol 2017;69:236–43
Markers of RV-PA coupling

Non-invasive indices of right ventricular function are markers of ventricular–arterial coupling rather than ventricular contractility: insights from a porcine model of chronic pressure overload
3D Echo-derived pressure volume curves
3D Echo-derived Ea, Emax and RVAC

- Ea=mPAP/SV, Emax=mPAP/ESV, RVAC=Ea/Emax=ESV/SV in 90 pts who had 3D, CMR and RHC

<table>
<thead>
<tr>
<th>Variable</th>
<th>RHC-CMR</th>
<th>3DE</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ea (mmHg/mL/m²)</td>
<td>0.71 ± 0.52</td>
<td>1.27 ± 0.94</td>
<td>0.806</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Emax (mmHg/mL/m²)</td>
<td>0.38 ± 0.19</td>
<td>0.72 ± 0.37</td>
<td>0.798</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>RVAC</td>
<td>2.32 ± 1.77</td>
<td>2.01 ± 1.28</td>
<td>0.826</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

- Limits: underestimation of volumes by 3Decho as compared to CMR
### Approach of RVAC

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Afterload</th>
<th>RV function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive</td>
<td>RHC - PVR</td>
<td>RAP and CI</td>
</tr>
<tr>
<td>Combined invasive / non invasive</td>
<td>RHC - PVR</td>
<td>TAPSE, MRI-RVEF</td>
</tr>
<tr>
<td>Non invasive</td>
<td>Pulmonary flow (notch, AccT)</td>
<td>TAPSE</td>
</tr>
</tbody>
</table>

#### Diagram

- **PVR** and **TAPSE** are plotted on a grid with the following labels:
  - A: primary RV dysfunction
  - B: relative RV adaptation and maintained RV-PA coupling
  - C: RV-PA uncoupling

Kubba Prog Cardiovasc Dis. 2016;59:42-51
Combined parameters = analysis of RV-PA coupling

- Reflecting pressure-volume relationship or RV length-force relationship

<table>
<thead>
<tr>
<th>Author</th>
<th>RV</th>
<th>Afterload</th>
<th>Combined parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claessen 2016</td>
<td>RV ES area</td>
<td>sPAP</td>
<td>PAPs/RV ES area</td>
</tr>
<tr>
<td>Dandel 2013, 2015</td>
<td>RV ED length / area</td>
<td>TR TVI</td>
<td>Load adaptation index TR TVI x (RV ED length / area)</td>
</tr>
<tr>
<td>Guazzi 2013, 2015, 2017</td>
<td>TAPSE</td>
<td>sPAP</td>
<td>TAPSE / sPAP</td>
</tr>
<tr>
<td>Lopez Candales 2014</td>
<td>TAPSE</td>
<td>PVR</td>
<td>TAPSE / echo PVR</td>
</tr>
<tr>
<td>Dandel 2013, 2015</td>
<td>RV SR</td>
<td>TR TVI</td>
<td>Load corrected Peak systolic SR TR TVI x RV SR</td>
</tr>
<tr>
<td>Iacovelli 2017</td>
<td>RV strain</td>
<td>sPAP</td>
<td>Strain / sPAP</td>
</tr>
</tbody>
</table>
PAPs/RV ES area

- 61 subjects, echo compared to CMR-RHC at exercise

- Good correlations between echo and CMR-RCH
  - RVES P-Area and P-Volume ratio
  - peak/rest ratios of RVES PA and RVES PV (RV contractile reserve)
TAPSE/sPAP

- 2013: 247 HFrEF and 46 HFpEF; 2017: 387 HFpEF patients
- Independent predictor of worse outcome in HFrEF and in HFpEF

RV strain / sPAP

- 414 stable CHF pts
- RV-GLS/PASP and RV-fwLS/PASP associated with all-cause mortality
  - in a clinical model (corrected for age, NYHA class, mean BP, LVEF, natremia, GFR, NT-proBNP)
  - in an echocardiographic model (corrected for LVEF, EE’, MR, and TR)
- Better accuracy of combined parameters than that of the parameters evaluated separately

Iacoviello  Int J Cardiol. 2017; 15;241:318-321
Contractile reserve of RV

- During bicycle exercise

- Evolution under therapy
  - Thromboendarteriection
  - Specific PAH therapy
  - Post LVAD

- 61 subjects, echo compared to CMR-RHC at exercise
- Comparison between CTEPH and normal pts
  - High RVES P-Area ratio at rest = high contractility at rest to compensate for increased RV afterload
  - Low contractile reserve (peak/rest ratios of RVES PA) = reduced ability of RV to further increase contractility with exercise
Contractile reserve

- During bicycle exercise
- Evolution under therapy
  - Thromboendarterectomy
  - Specific PAH therapy
  - Post LVAD

<table>
<thead>
<tr>
<th></th>
<th>RHC before</th>
<th>RHC after</th>
<th>Echo before</th>
<th>Echo after</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM6 m</td>
<td>311</td>
<td>415</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAP mmHg</td>
<td>95-34 (54)</td>
<td>48-4 (27)</td>
<td>83 (53 à 59)</td>
<td>45 (29)</td>
</tr>
<tr>
<td>RAP mmHg</td>
<td>14</td>
<td>6</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>CI l/mn/m²</td>
<td>1.7</td>
<td>2.5</td>
<td>2.0</td>
<td>2.6</td>
</tr>
<tr>
<td>PVR dynes/s/cm⁵</td>
<td>1280</td>
<td>560</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVFAC %</td>
<td></td>
<td></td>
<td>0.24</td>
<td>0.42</td>
</tr>
<tr>
<td>TAPSE mm</td>
<td></td>
<td></td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>S’ cm/s</td>
<td></td>
<td></td>
<td>7.8</td>
<td>12.0</td>
</tr>
<tr>
<td>RV MPI</td>
<td></td>
<td></td>
<td>0.52</td>
<td>0.47</td>
</tr>
<tr>
<td>Strain lat/inf %</td>
<td></td>
<td></td>
<td>14/7</td>
<td>25/20</td>
</tr>
</tbody>
</table>
Contractile reserve of RV

• During bicycle exercise or after saline infusion
• Evolution under therapy
  ◦ Thromboendarterectomy
  ◦ Specific PAH therapy
  ◦ Post LVAD

• 50 incident pts with PAH
• FU 4 yrs, Change over 6 M
• Prognostic value of ε<-12.5% at 6 months FU
• Prognostic role of change in RV strain

Hardegree Am J Cardiol 2013;111:143-148
Contractile reserve of RV

- During bicycle exercise or after saline infusion
- Evolution under therapy
  - Thromboendarterriectomy
  - Specific PAH therapy
  - Post LVAD

- 205 patients before LVAD implantation
- ROC curve for prediction of post LVAD RV failure
- Load adaptation index = TR TVI x (RV ED length / RV ED area)
- Load corrected Peak systolic SR = RV SR x TR TVI

*Dandel Circulation 2013;128[suppl 1]:S14-S23*
Conclusion

• “To be appropriate, parameters assessing RV function must correlate with RV contractility, be affected predictably by PH, be sensitive to change in response to treatment and disease progression and, finally, be measures where the magnitude and direction of change predicts prognosis” (Galiè Chest 2012)

• All echocardiographic (and MRI) parameters of RV function are load dependent and the influence of RV afterload on RV « function » is considerable

• Great ability of RV to reverse remodel, impressive RV « plasticity »!