Echo in Pulmonary HTN

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I have NO relevant financial relationships
Pulmonary Artery Pressure
Clinical Importance

- **Responsible for symptoms and disability**
  (LV disease, valvular disease, etc)

- **Responsible for hemodynamic consequences**
  (acute and chronic lung disease)

- **Prognostic importance**

- **Management decisions**
  (eg operability in congenital HD, MV disease)
Noninvasive Assessment of PA Pressure
Progression of Pulmonary Vascular Disease

Right Ventricle | Pulmonary Arteries

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

**Compensated**
- 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 PA wall
- Obliterative PA remodeling
- Severe decrease in CO
- Severe increase in PVR
- Severe decrease in perfusion

Champion Circulation 2009;120:992-1007
RV – Pulmonary Circulation Unit

- Degree of pulm HTN does not strongly correlate with symptoms or survival

- RV size, RV mass, and RA pressure do reflect functional status and are strong predictors of survival
## Pulmonary Hypertension

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>PHTN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic</td>
<td>20-30</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Diastolic</td>
<td>5-12</td>
<td>&gt;12</td>
</tr>
<tr>
<td>Mean</td>
<td>10-20</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

What about 21 – 25 mm Hg?
## Pulmonary Hypertension

### Arbitrary Grading

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean PA (mm Hg)</th>
<th>Peak PA (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>20 - 30</td>
<td>30 - 45</td>
</tr>
<tr>
<td>Moderate</td>
<td>30 - 40</td>
<td>46 - 60</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;40</td>
<td>&gt;60</td>
</tr>
</tbody>
</table>
Estimation of PA Mean Pressure

\[ \text{PA}_{\text{mean}} = 0.6 \times \text{PA}_{\text{SP}} + 2 \text{ mm Hg} \]

Chemla Chest 2004;126:1313-17
Pulmonary Hypertension

- Mean PAP > 25 mm Hg
- PVR > 3 Wood units
- PCWP ≥ 15 mm Hg

Rudski  J Am Soc Echocardiogr 2010;23:685-713
Normal Resting Values

Guidelines for the Echocardiographic Assessment of the Right Heart in Adults (ASE, EAE, ESC, CSE)

Peak TR velocity  ≤ 2.8 – 2.9 m/s

Peak systolic pressure  35 or 36 mm Hg*
(assuming an RA pressure of 3 to 5 mm Hg)

* “This value may increase with age and increasing BSA . . . “

Rudski  J Am Soc Echocardiogr  2010;23:685-713
Badesch  J Am Coll Cardiol  2009;54:S55-66
Association of Systemic and PA Pressure with Age

Lam et al. Circulation 2009;119:2663-2670
Association of Pulmonary Pressure with Age

Pulmonary Circulation

Overall: $r=0.31; \ p<0.001$

Women: $r=0.34; \ p<0.001$

Men: $r=0.26; \ p<0.001$

Lam et al. Circulation 2009;119:2663-2670
Echo is the mainstay of screening and initial assessment of pulmonary HTN

- Low cost
- Widespread availability
- Potential for bedside application
- Suitable for serial evaluation

Echo is the **gold standard** for noninvasive hemodynamic assessment
Pulmonary Hypertension
Role of Echocardiography

• Diagnose pulmonary HTN
• Determine etiology
  (Left heart disease, MV disease, congenital HD, etc)
• Quantitate PA pressures (PASP, PADP, \( \text{PA}_{\text{mean}} \))
• Evaluate end effects
• Determine prognosis
  (RA pressure, mean PA pressure, large pericardial effusion)
Pulmonary Hypertension
Echo Findings

1. Right ventricular hypertrophy and/or dilatation

2. Abnl shape of LV in short axis ("D-shaped")

3. Right atrial dilatation

4. Dilated pulmonary artery

5. Abnormal systolic time intervals
   a. Prolonged RPEP/RVET
   b. Increased PV_c - TV_o interval

6. Abnormal pulmonic valve motion (M-mode)
M-Mode
Pulmonary Hypertension
M-Mode Echo Signs

Normal

diminished "a" dip

rapid opening slope (b-c)

flattened e-f slope

systolic notch
Estimation of PA Pressure

Limitations of M-Mode of PV

- Difficulty obtaining adequate recording of PV
- Relatively low sensitivity in detecting PHTN
- Inability to quantitate PA pressure
Flattened Ventricular Septum
(D-Shaped)
Determination of PA Pressure
Echo-Doppler Methods

1. Pulmonary acceleration time
2. TR jet velocity method
3. Pulmonic regurgitant jet method
Estimation of RV Systolic Pressure (RVSP) From Maximum Transtricuspid Gradient

\[ \text{RVSP} = \Delta P + \text{JVP} \]
Estimation of RV Systolic Pressure (RVSP) From Maximum Transtricuspid Gradient

\[ \text{RVSP} = \Delta P + \text{JVP} \]
Peak Velocity of Tricuspid Regurgitant Jet

Determination of RV-RA pressure gradient

RV-RA Gradient = 64 mmHg
Est. of RA Pressure = 10 mmHg
Pulm Art Pressure = 74 mmHg
Doppler Estimation of RV Systolic Pressure

Simultaneous Doppler and Cath Tracings

Currie  JACC  6:750(1985)
Doppler Estimation of RV Pressure

Simultaneous Cath and Doppler

Max Gradient (Doppler), mmHg vs. Max Gradient (catheter), mmHg

- n = 111
- r = 0.96
- SEE = 7

Currie JACC 6:750(1981)
Peak TR Jet Velocity
3 Methods of Estimating Right Atrial Pressure

1. Assume RA pressure of 5, 10, 15, or 20 mmHg

2. Clinical estimate of RA pressure (JVP)

3. IVC "collapsibility index"
# Evaluation of RA Pressure

<table>
<thead>
<tr>
<th>IVC (cm)</th>
<th>Δ with resp (%)</th>
<th>RA pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.5</td>
<td>Collapse</td>
<td>0-5</td>
</tr>
<tr>
<td>NI (1.5-2.5)</td>
<td>↓ &gt;50</td>
<td>5-10</td>
</tr>
<tr>
<td>NI</td>
<td>↓ &lt;50</td>
<td>11-15</td>
</tr>
<tr>
<td>&gt;2.5</td>
<td>↓ &lt;50</td>
<td>16-20</td>
</tr>
<tr>
<td>&gt;2.5</td>
<td>No change</td>
<td>&gt;20</td>
</tr>
</tbody>
</table>
## Estimation of Right Atrial Pressure

<table>
<thead>
<tr>
<th>IVC</th>
<th>Change with Respiration or &quot;sniff&quot;</th>
<th>Estimated Right Atrial Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (&lt;1.5cm)</td>
<td>Collapse</td>
<td>0 - 5 mmHg</td>
</tr>
<tr>
<td>Normal (1.5-2.0cm)</td>
<td>Decrease by &gt;50%</td>
<td>5 - 10 mmHg</td>
</tr>
<tr>
<td>Normal (1.5-2.0cm)</td>
<td>Decrease by &lt;50%</td>
<td>10 - 15 mmHg</td>
</tr>
<tr>
<td>Dilated (&gt;2.0cm)</td>
<td>Decrease by &lt;50%</td>
<td>15 - 20 mmHg</td>
</tr>
<tr>
<td>Dilated (&gt;2.0cm)</td>
<td>No change</td>
<td>&gt;20 mmHg</td>
</tr>
</tbody>
</table>
### IVC Collapsibility Index

<table>
<thead>
<tr>
<th>IVC Collapse</th>
<th>RA Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 40%</td>
<td>5 mmHg</td>
</tr>
<tr>
<td>&lt; 40%</td>
<td>10 mmHg</td>
</tr>
<tr>
<td>None</td>
<td>15 mmHg</td>
</tr>
</tbody>
</table>

Kirchner  Circ 78:II:550(1988)
Right Atrial Pressure
Doppler vs Right Heart Cath

Fisher (J Hopkins) Am J Resp Crit Care 2009;179:615-621
Doppler Estimation of RV Systolic Pressure

Currie JACC 6:750(1985)
Limitations of "Sniff" Test

• Requires patient cooperation

• Tachypneic patients

• Mechanical ventilation

• Lack of standardization of insp effort
Calculation of PA Systolic Pressure
Estimation of RA Pressure

<table>
<thead>
<tr>
<th>Degree TR</th>
<th>RA Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trace −1+</td>
<td>4</td>
</tr>
<tr>
<td>2+</td>
<td>8</td>
</tr>
<tr>
<td>3+</td>
<td>12</td>
</tr>
<tr>
<td>4+</td>
<td>16</td>
</tr>
</tbody>
</table>

Ribeiro   Am Heart J  134:479(1997)
Estimation of PA Pressure

Limitations of TR Jet Method

- Absence of detectable TR (10%)
- Nonparallel intercept angle of TR jet
- Misidentification of jet signal (AS, MR)
- RA pressure estimate in ventilated patients
- Presence of pulmonic stenosis
- Wide-open TR ("free TR") \(\Rightarrow\) equalization of RA and RV pressure (nonrestrictive TR jet orifice)
Pulmonary Artery Systolic Pressure

Difference b/w Echo-Doppler and Right Heart Cath Measurement

Average of Echo-Doppler and RHC Measurement

- Excellent and good quality Doppler signal
- Fair and poor quality Doppler signal

Mathai  Advances in Pulm Hypertension  2008;7:1-7
Case
Doppler Assessment of PA Systolic Pressure
Importance of Using Multiple Views


% Max Velocity Obtained

n = 614 pts
some pts had >1 view
with same max vel
Classification of TR Signal Quality

Amsallem  J Am Soc Echocardiogr 2016;29(2):93-102 (Feb)
Case
## Adequate Spectral Doppler Signals

<table>
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<tr>
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<th>Feasibility Without Contrast</th>
<th>Feasibility With Contrast</th>
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<tbody>
<tr>
<td>TR jet</td>
<td>94%</td>
<td>98%</td>
</tr>
<tr>
<td>PR jet</td>
<td>80%</td>
<td>85%</td>
</tr>
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Tramarin *Eur Heart J* 1991;12:102-112
PA Systolic Pressure
TR Jet Method

- Feasibility high – TR present in >85% normals
- Incidence higher in pulmonary hypertension
- If TR jet trivial or absent, can enhance TR velocity signal with agitated saline or echo-contrast agents (eg Definity, Optison)
- Or use alternative methods . . .
Guidelines for the Echocardiographic Assessment of The Right Heart in Adults: A Report from the American Society of Echocardiography

Endorsed by the European Association of Echocardiography, a registered Branch of the European Society of Cardiology, and the Canadian Society of Echocardiography

Lawrence G. Rudski, MD, FASE, Chair, Wyman W. Lai, MD, MPH, FASE, Jonathan Afilo, MD, Msc, Lanqi Hua, RDCS, FASE, Mark D. Handschumacher, BSc, Krishnaswamy Chandrasekaran, MD, FASE, Scott D. Solomon, MD, Eric K. Louie, MD, and Nelson B. Schiller, MD

J Am Soc Echocardiogr 2010;23(7):685-713
Guidelines for the Echocardiographic Assessment of the Right Heart in Adults (ASE, EAE, ESC, CSE)

Recommendations: “Pulmonary hemodynamics are feasible in a majority of subjects using a variety of validated methods. SPAP should be estimated and reported in all subjects with reliable tricuspid regurgitant jets. The recommended method is by TR jet velocity . . . “

Rudski J Am Soc Echocardiogr 2010;23:685-713
Pulmonary Systolic Flow Velocity Pattern
Position of Sample Volume in Short-Axis View
For Obtaining Pulmonary Flow-Velocity Profile
Sampling Sites in RVOT and PA
Pulmonary Flow-Velocity Patterns

A  B  C
Pulmonary Flow Velocity Profiles

PAcT = 140  110  70  60  60
Pulmonary Flow Velocity Profile
Pulmonary Flow Velocity Profile
Pulmonary Flow Velocity Profile
# Pulmonary Acceleration Time

<table>
<thead>
<tr>
<th>Condition</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>120 - 140 ms</td>
</tr>
<tr>
<td>Borderline</td>
<td>100 ms</td>
</tr>
<tr>
<td>Usually PHTN</td>
<td>&lt;80 - 90 ms</td>
</tr>
<tr>
<td>Severe PHTN</td>
<td>&lt; 60 ms</td>
</tr>
</tbody>
</table>
PA Pressure Using PAcT
Regression Equations

\[ \text{PA}_{\text{mean}} = -0.45 \times \text{PAcT} + 79 \]
\[ \text{PA}_{\text{mean}} = 80 - \frac{1}{2} \times \text{PAcT} \]
\[ \text{PA}_{\text{mean}} = 90 - 0.62 \times \text{PAcT} \]
\[ \text{PCW} = 57 - 0.39 \times \text{PAcT} \]
Mean Pulmonary Artery Pressure

\[ PA_{\text{mean}} = \frac{PA_s + 2 \times PA_d}{3} \]

\[ PA_{\text{mean}} = 79 - 0.45 \times PAcT \]

Normal cutoff value for invasively measured mean PA pressure = 25 mm Hg
Pulmonary Acceleration Time
Limitations/Pitfalls

- Waveform varies in different parts of PA
- Peak not always clearcut
- Poor RV function may decrease PAcT
- Inversely related to heart rate
Pulmonary Artery Acceleration Time Correction for Heart Rate

\[ \text{PAcT}_c = \text{PAcT} \times \frac{75}{\text{HR}} \]
Time to Peak Velocity (TPV) in 4 Sites in Pulmonary Artery

Panidis  Am J Cardiol  58:1145(1986)
Pulmonary Artery Flow Velocity Profile
Simple visual assessment of the RV outflow tract Doppler pattern provides powerful insight into the hemodynamic basis of PHTN !
## Echo Differentiation of PAH vs PVH

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PAH</th>
<th>PVH</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV size</td>
<td>Enlarged</td>
<td>May be enlarged</td>
</tr>
<tr>
<td>LA size</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>RA/LV size</td>
<td>Increased</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(LA&gt;RA size)</td>
</tr>
<tr>
<td>Atrial septum</td>
<td>Bows from right to left</td>
<td>Bows from left to right</td>
</tr>
<tr>
<td>RVOT notching</td>
<td>Common</td>
<td>Rare</td>
</tr>
<tr>
<td>E/A ratio</td>
<td>&lt;&lt; 1</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Lateral e’ velocity</td>
<td>Normal</td>
<td>Decreased</td>
</tr>
<tr>
<td>Lateral E/e’</td>
<td>&lt; 8</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>
3 Patterns of Pulmonary Flow-Velocity Curves

A. Dome-like, max velocity in mid-systole, no notching
B. Distinct notch in mid portion
C. Triangular contour, sharp peak in early systole, late systolic notch
RV Outflow Tract Flow Velocity
3 Distinct Patterns

No notch	Mid-systolic notch	Late-systolic notch

Forfia - Hospital of the University of Pennsylvania
RV Outflow Tract Flow Velocity
3 Distinct Patterns

- No notch
  - L-heart congestion
  - PH largely 2º ↑PCW
  - Absence of significant pulm vasc disease

- Mid-systolic notch
  - Markedly elevated PVR
  - Low PA compliance
  - RV dysfunction

- Late-systolic notch
  - Intermediate PVR
  - Mod pulm vasc disease
  - Mod L-heart congestion

Forfia - Hospital of the University of Pennsylvania
Differences among 3 RVOT velocity patterns

Pulmonary Hypertension Cohort

Differences among 3 RVOT velocity patterns

## Hemodynamic and Echo Data for Notch Groups (Mean ± SD)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NN</th>
<th>LSN</th>
<th>MSN</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAPs (mm Hg)</td>
<td>53 ±16</td>
<td>73 ±19</td>
<td>82 ±17</td>
</tr>
<tr>
<td>PAPm (mm Hg)</td>
<td>33 ±10</td>
<td>46 ±12</td>
<td>50 ± 9</td>
</tr>
<tr>
<td>PVR (WU)</td>
<td>3.3 ± 2.4</td>
<td>5.7 ± 3.1</td>
<td>9.2 ± 3.5</td>
</tr>
<tr>
<td>E/A</td>
<td>1.9 ± 1.1</td>
<td>1.1 ± 1.4</td>
<td>1.0 ± 0.9</td>
</tr>
<tr>
<td>PAcT (ms)</td>
<td>113 ±29</td>
<td>79 ±18</td>
<td>67 ± 21</td>
</tr>
<tr>
<td>RA (cm)</td>
<td>4 ± 0.8</td>
<td>4.5 ±1.5</td>
<td>4.9 ±1.0</td>
</tr>
</tbody>
</table>
PR Jet
Pulmonic Regurgitant Jet
Doppler Recording of Pulmonic Regurgitant Jet

PA_{EDP} - RV_{EDP} = 4V_{pi}^2 = 4(1.4)^2

PA_{EDP} = 4V_{pi}^2 + RV_{EDP} = 7.8 + 4

PA_{EDP} = 4V_{pi}^2 + RA_{EDP} = 12\text{mmHg}
### Adequate Spectral Doppler Signals

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Tramarin *Eur Heart J* 1991;12:102-112
Case
Prognosis
Prognosis in Pulmonary Hypertension
Echo Predictors

- RV systolic pressure (TR jet method)
- Size of pericardial effusion
- RA area index
- RV area index
- RV index of myocardial performance (RIMP)
- TAPSE
- Pulmonary vascular capacitance
Survival in Pulmonary Hypertension
Stratified by TAPSE Values

![Graph showing survival probability over months with TAPSE values.

- TAPSE ≥ 1.8 cm
- TAPSE < 1.8 cm

p = 0.009]
Final Examination
Case
If RA pressure = 10 mm Hg, what is RV syst. pressure?
RVSP = 77 + 10 = 87 mm Hg