Echo in Pulmonary HTN

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Pulmonary Artery Pressure
Clinical Importance

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

• Responsible for hemodynamic consequences
  (acute and chronic lung disease; TR; ↑d CVP)

• Prognostic importance

• Management decisions
  (eg operability in congenital HD, MV disease)
Noninvasive Assessment of PA Pressure

ECG
CHEST X-RAY
PHYSICAL EXAM
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
## Normal Right Heart Hemodynamics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVSP/PASP_{Echo}</td>
<td>&lt; 36 mm Hg*</td>
</tr>
<tr>
<td>Mean PAP</td>
<td>8 – 20 mm Hg</td>
</tr>
<tr>
<td>PAEDP</td>
<td>4 – 12 mm Hg</td>
</tr>
<tr>
<td>RAP</td>
<td>0 – 5 mm Hg</td>
</tr>
<tr>
<td>PVR</td>
<td>&lt; 2.0-3.0 WU</td>
</tr>
</tbody>
</table>

* (up to 40 mm Hg in older and obese patients)
Association of Systemic and PA Pressure with Age

<table>
<thead>
<tr>
<th>Age in Quartiles (years)</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>45-54</td>
<td>0.9</td>
</tr>
<tr>
<td>55-62</td>
<td>1.0</td>
</tr>
<tr>
<td>63-71</td>
<td>1.1</td>
</tr>
<tr>
<td>72-96</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Lam et al. *Circulation* 2009;119:2663-2670
Normal Resting Values

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

Peak TR velocity \( \leq 2.8 - 2.9 \text{ m/s} \)

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
Pulmonary Hypertension

- Mean PAP > 25 mm Hg
- PVR > 3 Wood units
- PCWP ≥ 15 mm Hg
Pulmonary Hypertension
Role of Echocardiography

- Diagnose pulmonary HTN
- Determine etiology
  (Left heart disease, MV disease, congenital HD, etc)
- Quantitate PA pressures (PASP, PADP, PA_{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 $P_{Vc} - T_{Vo}$ 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
Flattened Ventricular Septum
(D-Shaped)
Dilated coronary sinus $\rightarrow$ Increased RA pressure
Determination of PA Pressure Echo-Doppler Methods

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

$$RVSP = \Delta P + JVP$$
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 (catheter), mmHg

Max Gradient (Doppler), mmHg

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"
## Estimation of Mean RA Pressure

2005

<table>
<thead>
<tr>
<th>IVC size</th>
<th>Collapsibility Index</th>
<th>RA Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal IVC (≤ 1.7 cm)</td>
<td>50% decrease</td>
<td>0 – 5 mm Hg</td>
</tr>
<tr>
<td>Dilated IVC (&gt; 1.7 cm)</td>
<td>≥ 50% insp collapse</td>
<td>6 – 10 mm Hg</td>
</tr>
<tr>
<td></td>
<td>&lt; 50% insp collapse</td>
<td>10 – 15 mm Hg</td>
</tr>
<tr>
<td></td>
<td>No collapse</td>
<td>&gt; 15 mm Hg</td>
</tr>
</tbody>
</table>

Lang, et al Quantitation Guidelines
J Am Soc Echocardiogr 2005;17:1155-1160
### Estimation of Mean RA Pressure

**2015**

<table>
<thead>
<tr>
<th></th>
<th>Normal RAP (0-5 [3] mm Hg)</th>
<th>Intermediate (5-10 [8] mm Hg)</th>
<th>High RAP (15 mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVC diameter</td>
<td>≤ 2.1 cm</td>
<td>≤ 2.1 cm &gt; 2.1 cm</td>
<td>&gt; 2.1 cm</td>
</tr>
<tr>
<td>Collapse with sniff</td>
<td>&gt; 50%</td>
<td>&lt; 50% &gt; 50%</td>
<td>&lt; 50%</td>
</tr>
</tbody>
</table>

Lang, et al. Quantitation Guidelines
## Evaluation of RA Pressure

<table>
<thead>
<tr>
<th>IVC (cm)</th>
<th>∆ with insp (%)</th>
<th>RA pressure (mm Hg)</th>
</tr>
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<tr>
<td>&lt;2.1</td>
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<td>0-5 (3)</td>
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Cardiac Chamber Quantification Guidelines (ASE/EAC)
IVC measured perpendicular to its long-axis
Inner edge-to-inner edge
Just proximal to junction of IVC with hepatic vein
Or 1 – 2 cm proximal to IVC entrance into RA
IVC from Subcostal Long-Axis View

End-expiration
End-inspiration (with or without sniff)
Subcostal View – M-mode

Place cursor perpendicular to IVC
Just proximal to junction b/w IVC and hepatic vein
Use slow sweep speed to include 1 or 2 respirations
IVC Collapse
Normal size, normal collapse $\rightarrow$ RA pressure $\approx 3$ mm Hg
Mildly dilated, normal collapse $\rightarrow$ RA pressure $\approx 8$ mm Hg
Dilated, minimal or no collapse $\rightarrow$ RA pressure $\geq 15$ mm Hg
Limitations of "Sniff" Test

- Requires patient cooperation
- Tachypneic patients
- Mechanical ventilation
- Lack of standardization of insp effort

Decrease sweep speed to include 1 or more resp cycles
Secondary Indices for RA Pressure

- Restrictive filling (TV inflow pattern)
- Tricuspid E/e’ > 6
- Diastolic flow predominance in hepatic veins
PW Doppler from Hepatic Vein

SFF = systolic filling fraction (%) = \( \frac{S_{VTI}}{S_{VTI} + D_{VTI}} \) x 100

\( S_{VTI} \) = Systolic velocity time integral (or peak velocity)
\( D_{VTI} \) = Diastolic velocity time integral (or peak velocity)
Impact of Body Size on Inferior Vena Cava Parameters for Estimating Right Atrial Pressure: A Need for Standardization?

Tatsunori Taniguchi, MD, Tomohito Ohtani, MD, PhD, Satoshi Nakatani, MD, PhD, Kenichi Hayashi, PhD, Osamu Yamaguchi, MD, PhD, Issei Komuro, MD, PhD, and Yasushi Sakata, MD, PhD, Suita and Tokyo, Japan

Background: Inferior vena cava (IVC) diameter and its respiratory change, as determined using echocardiography, are commonly used to assess right atrial pressure (RAP). Despite the widespread use of the IVC approach for RAP assessment, the relations among body surface area (BSA), IVC diameter, and respirophasic change remain unclear. The aim of this study was to investigate the impact of BSA on IVC parameters for predicting elevated RAP.

Methods: Ninety consecutive patients undergoing right-heart catheterization or central venous catheter insertion were prospectively included. To investigate the impact of BSA on IVC parameters, patients were divided into higher and lower BSA groups by comparing individual BSA measurements with the median value. Optimal cutoff points of IVC parameters for detecting RAP of ≥10 mm Hg were defined using receiver operating characteristic curves.

Results: The median RAP and BSA were 8 mm Hg (range, 1–25 mm Hg) and 1.61 m² (range, 1.23–2.22 m²), respectively. In all patients, the optimal cutoff point for maximal IVC diameter (IVCDmax) and IVC collapsibility for the detection of RAP ≥ 10 mm Hg were 20 mm and 49.0%, respectively. The optimal cutoff point of IVCDmax for predicting RAP of ≥10 mm Hg was significantly larger in patients with higher BSAs than in those with lower BSAs (21 vs 17 mm, P = .0342). No differences in collapsibility indices were detected between the two groups. IVCDmax was larger in men (19 ± 5 vs 17 ± 5 mm in women, P = .0347) and weakly correlated with BSA (r = 0.35, P = .0007), whereas no relation was found between IVCDmax and age. However, the partial correlation coefficient of the entire cohort demonstrated that only BSA was still associated with IVCDmax after adjusting for age and gender (partial correlation coefficient = 0.32, P = .0020).

Conclusions: Body size, measured as BSA, is important to consider when IVC diameter is used to assess RAP. The optimal cutoff point of IVCDmax was 21 mm for patients with larger BSAs and 17 mm for those with smaller BSAs. However, the cutoff point of IVC collapsibility was not influenced by the difference of BSA. (J Am Soc Echocardiogr 2015;28:1420-7.)
Impact of Body Size on IVC Parameters

Figure 3 Scatterplot of the relation between IVCD\textsubscript{max} and RAP, differentiating patients with BSAs of $\geq 1.61$ m\textsuperscript{2} (red crosses) and those with BSAs of $< 1.61$ m\textsuperscript{2} (black circles).
Limitations of "Sniff" Test

- Requires patient cooperation
- Tachypneic patients
- Mechanical ventilation
- Lack of standardization of inspiratory effort

Decrease sweep speed to include 1 or more resp cycles
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
- Inadequate signal in COPD patients
- Wide-open TR (“free TR”)
Pulmonary Artery Systolic Pressure

Average of Echo-Doppler and RHC Measurement

Difference b/w Echo-Doppler and Right Heart Cath 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

n = 614 pts
some pts had >1 view
with same max vel

V1 - RV inflow
V2 - mod'd RV inflow
V3 - SAX
V4 - Ap-4
V5 - Ap RV inflow
V6 - sub-cost.
V7 - Pedoff apical

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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<tr>
<td>TR jet</td>
<td>94%</td>
<td>98%</td>
</tr>
<tr>
<td>PR jet</td>
<td>80%</td>
<td>85%</td>
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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 . . .
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
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 (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>120 - 140</td>
</tr>
<tr>
<td>Borderline</td>
<td>100</td>
</tr>
<tr>
<td>Usually PHTN</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>Severe PHTN</td>
<td>&lt; 60</td>
</tr>
</tbody>
</table>
PA Pressure Using PAcT Regression Equations

\[
\begin{align*}
\text{PA}_{\text{mean}} &= 79 - (0.45)(\text{PAcT}) \\
\text{PA}_{\text{mean}} &= 80 - \frac{1}{2}(\text{PAcT}) \\
\text{PA}_{\text{mean}} &= 90 - 0.62(\text{PAcT}) \\
\text{PCW} &= 57 - 0.39(\text{PAcT})
\end{align*}
\]
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
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 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
Time to Peak Velocity (TPV) in 4 Sites in Pulmonary Artery

Panidis Am J Cardiol 58:1145(1986)
Pulmonary Artery Flow Velocity Profile
Pulmonary Artery Acceleration Time Correction for Heart Rate

$\text{PAcT}_c = \text{PAcT} \times \frac{75}{\text{HR}}$
Simple visual assessment of the RV outflow tract Doppler pattern provides powerful insight into the hemodynamic basis of PHTN!
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**

<table>
<thead>
<tr>
<th>No notch</th>
<th>Mid-systolic notch</th>
<th>Late-systolic notch</th>
</tr>
</thead>
</table>

*Courtesy of Forfia - Hospital of the University of Pennsylvania*
# RV Outflow Tract Flow Velocity

## 3 Distinct Patterns

<table>
<thead>
<tr>
<th>No notch</th>
<th>Mid-systolic notch</th>
<th>Late-systolic notch</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-heart congestion</td>
<td>Markedly elevated PVR</td>
<td>Intermediate PVR</td>
</tr>
<tr>
<td>PH largely $2^\circ , \uparrow$PCW</td>
<td>Low PA compliance</td>
<td>Mod pulm vasc disease</td>
</tr>
<tr>
<td>Absence of significant pulm vasc disease</td>
<td>RV dysfunction</td>
<td>Mod L-heart congestion</td>
</tr>
</tbody>
</table>

---

*Courtesy of Forfia - Hospital of the University of Pennsylvania*
Pulmonary Hypertension Cohort

Differences among 3 RVOT velocity patterns

Pulmonary Hypertension Cohort

Differences among 3 RVOT velocity patterns

Arkles ... Forfia  Am J Resp Crit Care Med 2011;183:268-276
## 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>

Differentiate PAH from PVH

Signs Favoring PVH

- LA enlargement (LA size > RA size)
- Atrial septum bows toward RA
- E/A ratio > 1.2
- E/e’ (lateral) > 11; lateral e’ < 8 cm/s
- RVOT notching uncommon

McLaughlin J Am Coll Cardiol 2015;68(18):1976-97
Differentiate PAH from PVH

Signs Favoring PAH

- Marked RV enlargement
- LA size normal or small
- Atrial septum bows toward LA
- RVOT notching
- E/A ratio << 1
- Lateral E/e’ < 8

McLaughlin J Am Coll Cardiol 2015;68(18):1976-97
PR Jet
Pulmonic Regurgitant Jet
Doppler Recording of Pulmonic Regurgitant Jet

\[
\begin{align*}
PA_{\text{EDP}} - RV_{\text{EDP}} &= 4V_{Pl}^2 = 4(1.4)^2 \\
PA_{\text{EDP}} &= 4V_{Pl}^2 + RV_{\text{EDP}} = 7.8 + 4 \\
PA_{\text{EDP}} &= 4V_{Pl}^2 + RA_{\text{EDP}} = 12\text{mmHg}
\end{align*}
\]
## Adequate Spectral Doppler Signals

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Case
Pulmonary Artery Pressure

PA diast = $4V^2_{PR \text{ end}} + RA$

PA syst = $4V^2_{TR} + RA$
The End