ADVANCES IN
THE ECHOCARDIOGRAPHIC
ASSESSMENT OF THE RIGHT HEART

PROGRAM DEVELOPED BY DR. JAMES TAM & DR. LISA MIELNICZUK
• Dr. James Tam
  ▪ Honoraria and Clinical Trials:
    ○ Actelion
    ○ Astra Zeneca
    ○ Merck
    ○ Novartis
    ○ Sanofi-Aventis
  ▪ Advisory Board:
    ○ Boehringer Ingelheim
• Dr. Lisa Mielniczuk
  
  ▪ Honoraria:
    ○ Actelion
  
  ▪ Advisory Board:
    ○ Actelion
    ○ Eli Lilly
    ○ Pfizer
Speakers

- (Insert name of PAH Expert speaker for event)
- (Insert name of Echo Expert speaker for event)
Disclosures

• (Enter any disclosures of the event speakers)
Learning Objectives

After completing this program, the physician will be able to:

- Recognize the importance of early detection in the management of PAH
- Identify and discuss the highlights of the recent ASE Guidelines - *Echocardiography of the Right Heart*
- Identify and implement a four step process for echocardiographic assessment of patients presenting with symptoms consistent with pulmonary hypertension
- Interpret specific echo statements that are included in an echo lab report
- Relate shared patient case experiences to their own clinical practice

Definition of PAH

Normal

Early PAH

Late PAH

Adventitia
Media
Intima

Smooth muscle dystrophy
Early intimal proliferation
Vasoconstriction

Intimal proliferation & fibrosis
Thrombosis
Plexiform lesions
Smooth muscle hypertrophy
Advanced vascular lesion Proliferation

Hemodynamic Definition of PAH

Mean pulmonary arterial pressure of
≥ 25 mmHg at rest

+ 

Pulmonary capillary wedge pressure of
< 15 mmHg

+ 

Pulmonary vascular resistance of
> 3 mmHg/L/min (Wood units)

25 mmHg at Rest Does NOT Reflect the Upper Limit of Normal for Mean PAP

- Normal mean PAP at rest: **14 ± 3.3 mmHg**
- Upper limit of normal (mean ± 2SD): **20.6 mmHg**

**Proposal for New PH Definition**

<table>
<thead>
<tr>
<th>Mean PAP (mmHg*)</th>
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<tbody>
<tr>
<td>Upper limit of normal</td>
<td>20</td>
</tr>
<tr>
<td>Borderline PH</td>
<td>21-24</td>
</tr>
<tr>
<td>Manifest PH</td>
<td>≥25</td>
</tr>
</tbody>
</table>

*obtained at right heart catheterization

Clinical Classification of Pulmonary Hypertension (Dana Point Classification 2008)

Group 1
PAH

Group 1'
PVOD and/or PCH

Group 2
PH Owing to Left Heart Disease

Group 3
PH Owing to Lung Diseases and/or Hypoxia

Group 4
Chronic Thromboembolic Pulmonary Hypertension (CTEPH)

Group 5
PH with Unclear Multifactorial Mechanisms

Group 1: PAH
Group 1’: PVOD and/or PCH

1. PAH
   - Idiopathic PAH
   - Heritable
   - Drug- and toxin-induced
   - Persistent PH of newborn
   - Associated with:
     - Connective tissue disease
     - HIV infection
     - Portal hypertension
     - Congenital heart disease
     - Schistosomiasis
     - Chronic hemolytic anemia

1’. Pulmonary Veno-occlusive Disease and/or Pulmonary Capillary Hemangiomatosis

Group 2: PH Owing to Left Heart Disease

2.1 Systolic dysfunction
2.2 Diastolic dysfunction
2.3 Valvular heart disease

Group 3: PH Owing to Lung Diseases and/or Hypoxia

3.1 Chronic obstructive pulmonary disease
3.2 Interstitial lung disease
3.3 Other pulmonary diseases with mixed restrictive and obstructive pattern
3.4 Sleep-disordered breathing
3.5 Alveolar hypoventilation disorders
3.6 Chronic exposure to high altitude
3.7 Developmental abnormalities
Group 4: Chronic Thromboembolic PH
Group 5: PH with Unclear Multifactorial Mechanisms

4. Chronic Thromboembolic PH (CTEPH)

5. PH With Unclear or Multifactorial Mechanisms
   5.1 Hematologic disorders
   5.2 Systemic disorders
   5.3 Metabolic disorders
   5.4 Others

Why is PAH Now Getting More Attention?

• Newspaper coverage
  ▪ Ignored symptoms and missed diagnosis
  ▪ Limited access to medications

• Genetic abnormalities now known

• New treatments resulting in improved survival and QOL
## Symptoms of Idiopathic Pulmonary Hypertension

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Initial</th>
<th>Eventual</th>
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<tbody>
<tr>
<td>Dyspnea</td>
<td>60</td>
<td>98</td>
</tr>
<tr>
<td>Fatigue</td>
<td>19</td>
<td>73</td>
</tr>
<tr>
<td>Chest pain</td>
<td>7</td>
<td>47</td>
</tr>
<tr>
<td>Near syncope</td>
<td>5</td>
<td>41</td>
</tr>
<tr>
<td>Syncope</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td>Edema</td>
<td>3</td>
<td>37</td>
</tr>
</tbody>
</table>

Diagnosis is Made Late in Disease

- Mean duration from symptom onset to diagnosis of PAH is 2.5 years
- Late diagnosis due to
  - Under-recognition
  - Non-specific symptoms
  - Confusion with other conditions
  - iPAH is a diagnosis of exclusion
Diseases Most Commonly Associated with PAH

- Connective tissue diseases
  - Scleroderma (SSc)
  - Systemic lupus erythematosus (SLE)
  - Mixed connective tissue disease (MCTD)

- Congenital heart diseases
  - ASD/VSD/PDA
  - Reversed shunt: Eisenmenger’s syndrome

- Portal hypertension

- HIV infection
EARLY Detection is Paramount

• High clinical index of suspicion necessary
  - Identify “AT RISK” individuals for PAH
    - Known CTD
    - Family History
    - Congenital Heart Disease
    - Unexplained dyspnea

• **Goal:**
  - Identify and treat patients before the development of advanced symptoms or right heart failure
PPH Survival According to NYHA Functional Class

- Data from NIH Registry - preceding treatment era (1980s)

<table>
<thead>
<tr>
<th>NYHA Class</th>
<th>Median Survival</th>
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<tbody>
<tr>
<td>I and II</td>
<td>58.6 months</td>
</tr>
<tr>
<td>III</td>
<td>31.5 months</td>
</tr>
<tr>
<td>IV</td>
<td>6 months</td>
</tr>
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</table>

Current Survival on Treatment

Remember the Footprints of PAH

- connective tissue disease
- congenital heart disease
- previous PE or DVT
- family history
- associated risk factors
- unexplained dyspnea

- echo suggesting RV dysfunction, RVSP > 40
- RBBB or RAD on ECG
- low DLCO on PFT
- PA enlargement on CXR

PATIENTS AT RISK | ABNORMAL INVESTIGATIONS | SCREEN WITH ECHO | REFER FOR FURTHER EVALUATION
Echocardiographic Techniques

- Evidence supporting a diagnosis of PH can be derived from several echo techniques including:
  - **M-Mode**
    - A one-dimensional view of the cardiac structures moving over time
  - **2-D**
    - A real-time reconstructed image in 2-dimensions
  - **Color Doppler**
    - A computer-generated color image in which different directions of flow are represented by different colors
  - **Pulsed / Continuous Wave and Tissue Doppler**
    - Additional echo modalities used to quantify valvular and cardiac function as well as to estimate pressure gradients within the heart
Limitations of Echocardiography

• Requirements for an optimal echo study not met:
  - State of the art cardiac ultrasound equipment
  - Image and data acquisition skills and adequate time
  - Experienced interpretation and reporting

• Suboptimal or nondiagnostic echo study due to poor acoustic “windows”:
  - Surgical dressings
  - Chest wall deformity (e.g. pectus excavatum)
  - Pulmonary hyperinflation (e.g. COPD)
Steps for Diagnosis of PH Using Echocardiography

<p>| | |</p>
<table>
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<tbody>
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<td>3.</td>
<td>Exclude RVOT/pulmonic valve obstruction as cause of elevated RVSP</td>
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<tr>
<td>4.</td>
<td>Determine etiology of PH (Precapillary vs Postcapillary)</td>
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Step 1:
Find Supportive Evidence for PH

Supportive Evidence for PH

- RV shape
  - “D shaped” Interventricular Septum (IVS)
- RV size and thickness
- PA size and flow pattern
- Pulmonic valve motion

“D” Shaped Interventricular Septum

- Very abnormal septal shape and motion in parasternal short axis view (SAX)
Very Abnormal Septal Shape
Echo Views of the Right Ventricle

Right Ventricular Enlargement

- Four chamber view (4CH)

- Right ventricle (on the left) demonstrates enlargement relative to the size of the left ventricle

Useful Tips for Echo Assessment of Right Ventricle

- RV can be assessed by 2D echo in the LAX, SAX, 4CH and subcostal 2D echo views
- RV is about two thirds the size of the LV
- RV dilatation may be present if:
  - RV appears larger than the LV
  - RV shares or occupies the apex
- In SAX view:
  - RV should be smaller than the LV
  - LV shape should have a circular geometry throughout the cardiac cycle

Subcostal View
PA Size and Flow Characteristics

- **PA size:**
  - Measure in PSAX or RV outflow view
  - Normal MPA < 22 mm

- **PA flow characteristics:**
  - Pulsed wave Doppler in RVOT or PA
  - Early peak velocity (PAT < 100 msec)

Pulmonary Artery in PSAX
Estimating Mean PAP

- Mean PAP = 79 - 0.45 X RVOT AT
- Mean PAP = 60 - 0.33 X PAT
Step 2:
Estimate RVSP Using Doppler

Hemodynamic Assessment of PH

- Estimation of pulmonary pressures
  - Systolic (PAPs)
  - Diastolic (PAPd)
  - Mean (PAPm)

- Estimation of right atrial pressure
  (Central Venous Pressure - CVP)

Diagnosing Pulmonary Arterial Hypertension

- In the absence of RVOT obstruction or pulmonic valve stenosis:

\[ \text{PAP} = \text{RVSP} \]

(Pulmonary Arterial Pressure = Right Ventricular Systolic Pressure)

Calculating Pulmonary Arterial Systolic Pressure

- $PAP_s$ is measured by the modified Bernoulli equation:

$$PAP_s = 4 TR^2 + CVP$$

Calculating PAP$_s$

- The peak velocity of the jet is close to 4 m/s.

- PAP$_s = 4(4)^2 + \text{CVP}$

- Assuming a right atrial pressure of 10 mmHg, the RVSP would be 74 mmHg (64 mmHg + 10 mmHg)

- In the absence of pulmonic stenosis, this patient has a PAP$_s$ of 74 mmHg
**PH Estimation and Interpretation: Common Pitfalls**

<table>
<thead>
<tr>
<th>PH Underestimation</th>
<th>Suboptimal TR jet Doppler cursor alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weak TR jet Doppler signal (trivial or no TR jet)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PH Overestimation</th>
<th>Artfactually enhanced (shaggy) Doppler signal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tricuspid valve closure motion artifact</td>
</tr>
<tr>
<td></td>
<td>Unrecognized RVOT narrowing / pulmonic valve stenosis</td>
</tr>
<tr>
<td></td>
<td>Overestimation of RA pressure</td>
</tr>
</tbody>
</table>

| Incorrect Interpretation of Changes in PH Over Time | Failure to measure and report stroke volume and cardiac output with each echo study (needed to derive pulmonary vascular resistance and thus interpret PA pressures correctly) |

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Contrast Enhancement Improves CW Signal of Tricuspid Regurgitation (TR)

<table>
<thead>
<tr>
<th>Before contrast enhancement</th>
<th>With injection of 10% air – 90% saline mixture</th>
<th>With injection of 10% air – 10% blood - 80% saline mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>• TR signal was not detected.</td>
<td>• Complete CW signal of TR could be observed.</td>
<td>• Complete CW signal of TR could be observed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Exhibited a higher peak velocity vs air-saline mixture.</td>
</tr>
</tbody>
</table>

Contrast Enhancement Improves Accuracy of PA Pressure Determination

# Estimating CVP

<table>
<thead>
<tr>
<th>IVC</th>
<th>Resp Variation</th>
<th>CVP</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2.1</td>
<td>&gt;50%</td>
<td>3</td>
</tr>
<tr>
<td>&lt;2.1</td>
<td>&lt;50%</td>
<td>8</td>
</tr>
<tr>
<td>&gt;2.1</td>
<td>&gt;50%</td>
<td>8</td>
</tr>
<tr>
<td>&gt;2.1</td>
<td>&lt;50%</td>
<td>15</td>
</tr>
</tbody>
</table>

Revised by ASE July 2010

Echo Image of Respiratory Variation in Calibre of IVC
ESC 2009: Arbitrary Criteria for Estimating the Presence of PH by Echo

- Arbitrary criteria used, assume CVP = 5
- Match TR velocity with presence/absence of qualitative features (QF)

<table>
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<tr>
<th>TR (m/s)</th>
<th>QF</th>
<th>PH Status</th>
</tr>
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<tbody>
<tr>
<td>≤2.8</td>
<td>No</td>
<td>“Unlikely”</td>
</tr>
<tr>
<td>≤2.8</td>
<td>Yes</td>
<td>“Possible”</td>
</tr>
<tr>
<td>2.9-3.4</td>
<td>Yes or No</td>
<td>“Possible”</td>
</tr>
<tr>
<td>&gt;3.4</td>
<td>Yes or No</td>
<td>“Likely”</td>
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Qualitative Features

- Increased velocity of pulmonary valve regurgitation
- Short acceleration time of RV ejection into the PA
- Increased dimensions of right heart chambers
- Abnormal shape and function of the septum
- Increased RV wall thickness
- Dilated main PA
- Sensitivity and actual cutoffs questionable
Step 3:
Exclude RVOT / Pulmonic Valve Obstruction as Cause of Elevated RVSP

Pulmonic Valve Stenosis

- Doppler signal demonstrates high velocity flow within the right ventricular outflow tract, corresponding to pulmonic valve stenosis.

- In this setting, elevated RVSP does not reflect elevated PAPs.

Step 4:
Determine Etiology of Pulmonary Hypertension

## Simple Approach to PH

<table>
<thead>
<tr>
<th>Category</th>
<th>Features</th>
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<tr>
<td><strong>Pre-capillary</strong></td>
<td>1. PAH</td>
</tr>
<tr>
<td></td>
<td>Includes idiopathic PAH</td>
</tr>
<tr>
<td></td>
<td>Includes shunt (ASD, VSD)</td>
</tr>
<tr>
<td></td>
<td>2. Lung Disease</td>
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<tr>
<td></td>
<td>3. Thromboembolic PH</td>
</tr>
<tr>
<td></td>
<td>4. Unclear/multifactorial</td>
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<tr>
<td><strong>Post-capillary</strong> (high PCWP)</td>
<td>2. PH due to left heart disease</td>
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Determining Cardiac Causes of Pulmonary Hypertension

- In general, LV dysfunction and mitral valve disease can be identified and assessed by Doppler echocardiography.

- Important to exclude:
  - High LA pressure (Dana point group 2)
  - Pitfall is unrecognized diastolic dysfunction (Dana point group 2.2)
  - Left to right shunt (Dana point group 1.4.4 Congenital heart diseases)

- Echo cannot differentiate between other causes of PH (eg thromboemboli, COPD, PAH)

LV Enlargement and Dysfunction with Evidence of High LA Pressure (Doppler)
LV Enlargement and Dysfunction With Evidence of High LA Pressure (Doppler)
LV Enlargement and Dysfunction With Evidence of High LA Pressure (Doppler)
Right Heart Catheterization (RHC)

- RHC is indicated in all patients with PAH to confirm the diagnosis, to evaluate the severity and when PAH specific drug therapy is considered.
- RHC should be performed for confirmation of efficacy of PAH-specific drug therapy.
- RHC should be performed for confirmation of clinical deterioration and as baseline for the evaluation of the effect of treatment escalation or combination.

Remember the Footprints of PAH

**Patients at Risk**
- connective tissue disease
- congenital heart disease
- previous PE or DVT
- family history
- associated risk factors
- unexplained dyspnea

**Abnormal Investigations**
- echo suggesting RV dysfunction, RVSP > 40
- RBBB or RAD on ECG
- low DLCO on PFT
- PA enlargement on CXR

**Screen with Echo**

**Refer for Further Evaluation**
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THANK YOU!

Questions?