<table>
<thead>
<tr>
<th>TIME</th>
<th>SESSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00 AM</td>
<td>The Left Ventricle: How Should We Quantify Its Size and Function; Is It Time for 3D in Everyone?</td>
</tr>
<tr>
<td>8:25 AM</td>
<td>Myocardial Imaging: Strain in the Assessment of Left Ventricular Function</td>
</tr>
<tr>
<td>9:00 AM</td>
<td>Echocardiographic Evaluation of Left Ventricular Diastolic Function</td>
</tr>
<tr>
<td>9:25 AM</td>
<td>The Silent Epidemic: Diastolic Function and Clinical Outcome</td>
</tr>
<tr>
<td>9:45 AM</td>
<td>Cases: Evaluation of Diastolic Function</td>
</tr>
<tr>
<td>10:30 AM</td>
<td>Refreshment Break and Visit Exhibits</td>
</tr>
<tr>
<td>10:50 AM</td>
<td>Pericardial Disease: Constriction and Tamponade</td>
</tr>
<tr>
<td>11:15 AM</td>
<td>How Should I Evaluate Right Ventricular Size and Function?</td>
</tr>
<tr>
<td>11:40 AM</td>
<td>Echocardiography: A Pulmonary Artery Catheter in a Box</td>
</tr>
<tr>
<td>12:05 PM</td>
<td>Read With The Experts: Interesting Cases Highlighting the Evaluation of Ventricular Function</td>
</tr>
<tr>
<td>12:30 PM</td>
<td>Lunch and Visit Exhibits</td>
</tr>
</tbody>
</table>

Echocardiography: PA Catheter in a Box

Muhamed Sarić MD, PhD, MPA
Director of Noninvasive Cardiology | Echo Lab
Associate Professor of Medicine
Disclosures

Speakers Bureau (Philips, Medtronic)
Advisory Board (Siemens)

Question

Can echocardiography obtain noninvasively the same value that a PA catheter records invasively?
Catheterization: Competitive Edge

They had a big head start!

---

History of Catheterization

Catheterization is as old as human civilization.
(Urinary catheterization, that is).

1510 A.D.
Catheter treatment from a Renaissance medical picture book.
Drawn by Heinrich Füllmaurer and Albrecht Meyer,
Werner Forssmann (1904 – 1979)
Born in Berlin
German urologist
Inventor of right heart catheterization in 1929

André Frédéric Cournand (1895–1988)
Born in Paris
French-American physician

Dickinson W. Richards (1895 – 1973)
Born in Orange, NJ
American physician

Cardiac catheterization pioneers (1940 – 1950’s)
Bellevue Hospital in New York City.

Nobel Prize Winners in Physiology & Medicine in 1956

First Catheterization Case by Forssmann

DIE SONDIERUNG DES RECHTEN HERZENS.

Von

Dr. WERNER FORSSMANN.

Aus der II. Chirurgischen Abteilung des Auguste-Viktoria-Stifts zu Berlin.


Forssmann W. Die Sondierung des rechten Herzens
[Probing of the right heart]. Klin Wochenschr 1929:8:2085-87
Values Obtained by PA Catheter

<table>
<thead>
<tr>
<th></th>
<th>Normal Values</th>
<th>Mean Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA Pressure</td>
<td>0-8</td>
<td>4</td>
</tr>
<tr>
<td>RV Pressure</td>
<td>15-25/0-8</td>
<td>5-12</td>
</tr>
<tr>
<td>PA Pressure</td>
<td>15-25/8-12</td>
<td>10-20</td>
</tr>
<tr>
<td>PA Wedge Pressure</td>
<td>9-23/1-12</td>
<td>6-12</td>
</tr>
<tr>
<td>Cardiac Output</td>
<td>4 - 8 L/min</td>
<td>5 L/min</td>
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</table>

Swan-Ganz PA Catheter
PA Catheter Tracings

RA & RV pressure can be measured only once (at the time of PA catheter placement)

PA and wedge pressures can be measured repeatedly.

Swan-Ganz Catheter Inventors


Jeremy Swan (1922-2005)
Ireland-born American cardiologist

William Ganz (1919-2009)
Czechoslovakia-born American cardiologist

Responsible for balloon-tipped catheter
Responsible for thermodilution aspect
Swan-Ganz Catheter Complications

1. Complications of central venous access

2. Complications related to insertion and manipulation

3. Complications associated with short or long-term presence of the catheter in the cardiovascular system

4. Errors resulting from incorrect interpretation/use derived data

Prevented by using vascular ultrasound.
### Values Obtained by PA Catheter

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### RA Pressure by Echo
### RA Pressure by Echo

<table>
<thead>
<tr>
<th>IVC Size</th>
<th>IVC Collapse</th>
<th>RAP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤2.1 cm</td>
<td>&gt;50%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>&gt;2.1 cm</td>
<td>&lt;50%</td>
<td>15</td>
</tr>
</tbody>
</table>

### Low RA Pressure

[Image of echocardiogram with annotations]
Normal RA Pressure

Severely Elevated RA Pressure
RA Pressure by Echo

IVC diameter should be measured just proximal to the entrance of hepatic veins

2010 ASE guidelines on right heart in adults
J Am Soc Echocardiogr 2010;23:685-713.

RV & PA Pressures by Echo
Typically done to diagnose or exclude pulmonary hypertension
Pulmonary hypertension is classified by WHO.

Who is WHO?

The WHO
British rock band

WHO Classification Pulmonary Hypertension

1. PULMONARY ARTERIAL HYPERTENSION (PAH)
   Genetic or associated with CTD, HIV, Eisenmenger, portal HTN, drugs

2. DUE TO LEFT HEART DISEASE
   Systolic and/or diastolic heart failure; MV or AV disease

3. DUE TO LUNG DISEASE OR HYPOXEMIA
   COPD, sleep apnea, high altitude...)

4. CHRONIC PULMONARY EMBOLISM

5. MISCELLANEOUS
   Sarcoidosis, histocytosis X, fibrosing mediastinitis

Source: saric.us/echonomy
Principles

Pressure gradient ($\Delta P$) is estimated across regurgitant tricuspid & pulmonic valve.

$\Delta P$ is estimated using the $4V^2$ formula.
Tricuspid & Pulmonic Regurgitation

Small degree of tricuspid and pulmonic regurgitation is present in the majority of humans.

**TR Prevalence**

~ 70% of normals


**PR Prevalence**

~ 78% of normals


**TR Jet**

3 m/s

**PR Jet**

1.5 m/s

**PASP** = $4 \times (3 \text{ m/sec})^2 + \text{RAP} = 39 \text{ mm Hg}$

**PADP** = $4 \times (1.5 \text{ m/sec})^2 + \text{RAP} = 12 \text{ mm Hg}$

---

**Origin of $4V^2$ Formula**

First developed for calculation of mitral stenosis gradient.

*British Heart Journal* 1978;40:131-140

By neglecting the second acceleration term and the viscous losses, the pressure drop can be calculated from $v_2$ alone. Inserting the value for $\rho$ in Eq. (1), the following simple formula is found:

$$P_1 - P_2 = 4 \cdot v_2^2 \text{ (mmHg)}$$

(5)

where $v_2$ is in units of m/s, while the pressure drop is found in units of mmHg. $P_1$ is the atrial pressure, and $P_2$ is the pressure in the jet where $v_2$ is achieved. $P_2$ will actually be less than the ventricular pressure since a pressure drop working against the flow is needed to retard the large jet velocity to a much smaller ventricular velocity. However, most of the
Case Presentation

41-y/o woman

- Progressive dyspnea on exertion and decrease in exercise tolerance
- A few years earlier she had bilateral hip replacement
- Body surface area = 1.6 m²

ACTION PLAN

1. Establish existence of pulmonary hypertension
2. Evaluate left heart size and function
3. Further characterize pulmonary hypertension
Step #1: Measure PA Pressures

Estimate RVSP

PASP = RVSP, if there is no pulmonic stenosis

First Use of $4V^2$ Formula for PASP

*Quantitative assessment of pulmonary hypertension in patients with tricuspid regurgitation using continuous wave Doppler ultrasound.*

Berger M, Haimowitz A, Van Tosh A, Berdoff RL, Goldberg E.

**Abstract**

Doppler ultrasound examination was performed in 69 patients with a variety of cardiopulmonary disorders.


Estimate Right Heart Pressure

<table>
<thead>
<tr>
<th>IVC Size</th>
<th>IVC Collapse</th>
<th>RAP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2.1 cm</td>
<td>&gt;50%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>&gt;2.1 cm</td>
<td>&lt;50%</td>
<td>15</td>
</tr>
</tbody>
</table>

IVC exp = 1.6 cm; IVC ins = 0.9 cm
RAP = 8 mm Hg

RV Systolic Pressure Estimation

Faint Tricuspid Regurgitant Jet
\[ \Delta P(RV - RA) = 4V^2 = 4 \times (3.24 \text{ m/sec})^2 = 42 \text{ mm Hg} \]

Possible pulmonary hypertension
RVSP = 42 + 8 = 50 mm Hg

Additional echo imaging revealed no pulmonic stenosis.

PASP = RVSP = 50 mm Hg

If there were pulmonic stenosis...
PASP = RVSP - PS gradient
PASP Estimate in Pulmonic Stenosis

Option #1: Enhance TR jet Doppler signal with echo contrast, if necessary

Option #2: Use a non-TR jet based method of estimated PAP (such as RVOT acceleration time)
**Estimate Mean PA Pressure**

**Mahan Equation**

\[ \text{Mean PAP} = 79 - 0.46 \times \text{AT} \]


**Normal and Severe Pulmonary Hypertension**

- Normal: Mean PA Pressure ≤ 25 mm Hg
- Severe: Mean PA Pressure ≥ 45 mm Hg

**Example Calculation**

Mean PAP = 79 - 0.46 * 95 = 35 mm Hg
PA Diastolic Pressure

Estimate PA Diastolic Pressure

Small degree of pulmonic regurgitation

\[ \text{PADP} = \text{RAP} + \text{End-diastolic } \Delta P(\text{PA-RV}) \]

\[ \text{PADP} = 8 + 16 = 24 \text{ mm Hg} \]

\[ \text{Mean PAP} = \text{RAP} + \text{Initial } \Delta P(\text{PA-RV}) \]

\[ \text{Mean PAP} = 8 + 30 = 38 \text{ mm Hg} \]
Step #1 Conclusion

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>8 mm Hg</td>
<td>Normal</td>
</tr>
<tr>
<td>PASP</td>
<td>50 mm Hg</td>
<td></td>
</tr>
<tr>
<td>Mean PAP</td>
<td>35 – 38 mm Hg</td>
<td>Elevated</td>
</tr>
<tr>
<td>PADP</td>
<td>24 mm Hg</td>
<td></td>
</tr>
</tbody>
</table>

**Step #1 Conclusion:**
Patient does have pulmonary hypertension.

---

Step #2: Evaluate Left Heart
Patient with SOB and Decreased Exercise Tolerance

- Normal LVEF
- Normal mitral & aortic valve
- Dilated RV

Normal LVEF

1. Average E/e' > 14
2. Septal e' velocity < 7 cm/s or Lateral e' velocity < 10 cm/s
3. TR velocity > 2.8 m/s
4. LA volume index > 34 ml/m²

- <50% positive
  - Normal Diastolic function
- 50% positive
  - Indeterminate
- >50% positive
  - Diastolic Dysfunction

Depressed LVEF

Left Atrial Size

LA Volume Index (LAVI)

\[ \frac{1}{2} \times \left( \frac{31 + 27}{1.6} \right) \text{ mL/m}^2 \]

LAVI = 18 mL/m² [Normal]
Estimate LA Pressure

**MITRAL INFLOW**

- E = 95 cm; A = 50 cm; E/A = 1.9
- E wave deceleration time = 175 msec

**MITRAL TISSUE DOPPLER**

- Medial E’ = 10 cm/s
- Lateral E’ = 15 cm/s

\[
\frac{E}{E'} = \frac{95}{12.5} = 7.6
\]

E/E’ Ratio < 8; thus LA pressure is NORMAL.

---

**Step #2 Conclusion**

Patient DOES have pulmonary hypertension....

...but it is NOT related to left heart disease.
Step #3: Further Evaluation

**CHEST RADIOGRAPH**
Clear lungs; enlargement of the proximal pulmonary arterial tree suspicious for **pulmonary arterial hypertension**.

**CHEST CT**
The pulmonary artery is enlarged, measures 4.4 cm in transverse dimension.
Additional Data

Rheumatology panel

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Value</th>
<th>Abnormal Flag</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>dsDNA, IgG</td>
<td>9</td>
<td>H</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Chromatin, IgG</td>
<td>&gt;8.0</td>
<td>H</td>
<td>&lt;1</td>
</tr>
<tr>
<td>SS-A (S2 &amp; 60), IgG</td>
<td>&gt;8.0</td>
<td>H</td>
<td>&lt;1</td>
</tr>
<tr>
<td>SS-B, IgG</td>
<td>3.5</td>
<td>H</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Centromere B, IgG</td>
<td>&lt;0.2</td>
<td>H</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Smith, IgG</td>
<td>1.5</td>
<td>H</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Ribonucleoprotein (RNP), IgG</td>
<td>&gt;8.0</td>
<td>H</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Rheumatology panel consistent with systemic lupus erythematosus (SLE)

Patient is on chronic steroid therapy
>>> avascular hip necrosis
>> bilateral hip replacement

Case Presentation Recap

41-y/o woman

- Progressive dyspnea on exertion and decrease in exercise tolerance
- A few years earlier she had bilateral hip replacement related to steroid therapy
- Body surface area = 1.6 m²

Final Conclusion

Patient has pulmonary arterial hypertension associated with systemic lupus erythematosus (SLE)

[WHO Class 1]
Thank You!

New York University Langone Medical Center