Echo Doppler Assessment of PVR

Robin Shandas
Professor of Pediatrics, Cardiology
Professor of Mechanical Engineering
Director, Center for Bioengineering
University of Colorado

No disclosures

IS PVR THE RIGHT METRIC FOR RV AFTERLOAD?

Components of load on the RV pump

- Coupling between ventricle and proximal vasculature is important in efficiently transporting blood.
- Assumption: Proximal vessels are NOT simply conduits.

Hypothesis

Upstream vascular compliance is an important component of RV afterload.
Decreased Hemodynamic Efficiency

Importance in the adult systemic circulation

- Growing body of evidence documenting the importance of arterial stiffness as an independent factor in predicting morbidity and mortality.


Many, many others....

Methods for Measuring Stiffness

- Most conventional methods fall into those that measure or estimate pressure, flow, compliance (stiffness).
  - Pulse pressure (stress)
  - Distensibility / pulsatility (strain)
  - Arterial wave velocity (indirect estimate of compliance)
  - Flow or pressure augmentation (indirect estimate of compliance and effect of wave reflection)

- Newer methods
  - Correlates of endothelial function
    - Flow mediated dilation

Issues to Consider

Pulse wave speed measurement techniques:

- Biological variability
  - Ex: Arterial wave velocities range from 2 - 10 m/sec.
  - Assumptions of pulse wave speed methods:
    - Constant wave speed over length of vessel.
    - No “complicating” influences (ex: derivation of the wave speed equation)
      - No blood viscosity
      - Only “small” deformations of vessel wall
      - Simple relationship between pressure and vessel area
        - Usually linear
  - Measurement uncertainty
    - Typical sampling rate is 200 Hz - gives an inherent measurement uncertainty of +/- 2.5 msec.
    - In 5 msec, a wave traveling at 10 m/sec will travel 5 cm.
    - 2 m/sec wave will travel 1 cm.
    - Length of vessel thus becomes critical.
RV failure due to elevated afterload is the proximate cause of death in patients with PAH.

Two basic loads on the right heart:
1. Vascular resistance
   - PV Resistance = \( \frac{M\text{PAP}}{C\text{O}} \)

Two basic loads on the right heart:
2. Vascular distension/stiffness
   - Impedance quantifies both vascular resistance and stiffness
   - PV Impedance = \( \frac{M\text{PAP} - P\text{CWP}}{C\text{O}} \)
**Impedance**

- Measure of static (PVR) + dynamic (PVS) resistance imposed by vasculature on cardiac pump.
- First described by Minor (‘66, ‘69)
  - Separated total right heart work into mean + oscillatory
  - Showed significance of oscillatory component
  - Performed first impedance study in the human
  - Showed right and upward shift in impedance curves for PAH indicative of vascular stiffening.
- Difficult to obtain clinically since instantaneous pressure and flow are required.

**Noninvasive measurement of systemic impedance**

- Combination of Doppler (aortic flow) and carotid applanation tonometry
- Attempted in 95 healthy subjects (successfully obtained data in 71).
- Only correlate found was minimum frequency of the impedance spectrum.

**Impedance**

*Input impedance found from corresponding harmonics of pressure and flow*

|Z(w)| = |P(w)| / |Q(w)|

Flow Q(t) found from midline velocity in MPA

V_{echo}(t), mean flow Q_{mean}, and the expressions

A_{corr} = V_{echo} / Q_{mean}

Q(t) = A_{corr} V_{echo}(t)

**Typical Impedance Curves**

- Significant differences between groups in both zero harmonic (Z_0) and first two higher harmonics (Z_1, Z_2)
**Impedance and Proximal Stiffness**

- **Effect of PA Stiffness on Input Impedance**

  - **PVR**
  - **PVS**

  

  - **$Z_0$ shows exceptional correlation ($R^2 = 0.974$) to hemodynamically measured PVR**
  - **Reduces need for wedge pressure measurements.**

- **$Z_1 + Z_2$ vs PVS**

  - **$Z_1 + Z_2$ correlates well to global measure of vascular stiffness, PP/SV**

- **PVR vs Zero Harmonic of Impedance ($Z_0$)**

  

  - $Z_0 = 1.17247 \times PVR + 4.8506$
  - $R^2 = 0.98$

- **Impedance demonstrates proportionally greater afterload from vascular stiffening in patients with PAH**

  

  - Control
  - Hypertensive

  

  - $Z_1 + Z_2$ = Stiffness
  - $Z_0$ = Resistance
Impedance provides increased sensitivity to outcomes than PVR

<table>
<thead>
<tr>
<th>Patient</th>
<th>Reactive in Resistance?</th>
<th>Reactive in Stiffness?</th>
<th>Free of Complications at 1 year?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Patient 2</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Patient 3</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Patient 4</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Patient 5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Patient 6</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Patient 7</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Patient 8</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Patient 9</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Patient 10</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Does pulmonary vascular stiffness (PVS) increase in PAH?

- Strain stiffening.
- Remodeling.
- SMC activation.

How do pulmonary arteries stiffen?
Role of Elastin

How do pulmonary arteries stiffen?
- Strain stiffening
- Remodeling
- SMC activation

Media Elastin Area Fraction
- MPA
- H-1 41%
- H-2 36%
- N 29%

Elastin in the MPA stiffens and its fractional area decreases in PAH

Role of Elastin in Arterial Stiffening
How do pulmonary arteries stiffen?

- Strain Stiffening.
- Remodeling.
- SMC Activation.

Pulmonary vascular stiffness is a critical yet overlooked component in the evaluation of PAH.

Proximal Artery Pressure-Diameter Loops

- Simultaneous acquisition of arterial diameter and pressure vs time.
- Information on local artery stiffness.
- May be useful in evaluating proximal vascular remodeling.
- Suprasternal short-axis.
- Combination of conventional and tissue-Doppler M-mode to obtain diameter.
- Pressure signal digitized simultaneously into ultrasound system.

Clinical Acquisition and Analysis of P-D and Impedance
Non-invasive measurement of PA stiffness

Clinical measurement of pulmonary vascular stiffness (PVS)

- Growing body of evidence regarding its importance. Vascular mechanics easier to understand than myocardial mechanics.
- Cardiac catheterization laboratory is well-suited to making routine vascular function measurements.
- Measurements are relatively simple to implement clinically.
  - Do not need significant additional equipment
- Need pressure to maintain robustness in mechanical calculations.
- Awareness of measurement uncertainty.
- Validation is important.

Acknowledgements

Supported by:
NIH (HL 067393, HL 072738, MO1 RR00069, SCCOR HL084923, K24 HL 081506)
Children’s Hospital Heart Institute, Denver, CO