Heart-lung interactions: insights from pleural pressure

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Outline:

• Basics of heart-lung interaction
  – Venous return/cardiac function relationship
  – Importance of transmural pressure
    • Does heart function decrease with PEEP
    • Mueller maneuver

• Lessons from Peso
  1. Forced expiration
  2. Inspiratory load on RV
  3. Ventilator triggered breaths.
\[ \text{Pra} = \text{MCFP} \]

\[ \text{Pra < MCFP} \]
Cardiac function curve

Cardiac output vs. Right Atrial Pressure
Maximal return
“Cardiac independent”

Cardiac limited
“Wasted preload”

Pra/CVP

Cardiac output

Cardiac Preload

Gradient for VR
Effect of decrease in Ppl
Return function intersects plateau of cardiac function curve

No change in Pra
No change in RV filling
Effect of increase in Ppl

“O” transmural is normally at –ve Pra
What happens when the Return Curve intersects plateau of Cardiac Function Curve?

But, if ↑Ppl is large enough

↑Ppl

No change in Q (or SV)

Reduced TM diastolic wall tension - less “wasted” preload

Cardiac output falls
2nd Effect of increase in Ppl

"Collapse" pressure occurs at +v Pra
**Principle**: The pressure that determines the volume or filtration across an elastic structure is the Transmural Pressure

\[ P_{TM} = P_{\text{inside}} - P_{\text{outside}} \]

Eg. - Starling’s forces across capillaries
- Ventricular preload
Problem of the reference point for thoracic structures

Says V increased

Says V decreased

B

C

A
Does positive pressures “depress” cardiac function?

Observed fall
ΔTransmural $P_w = -10-(-40) = +30$ mmHg!
PS = 6 cmH₂O
VC = 650 ml

dPpao is greater than dPeso
Increased filling of left heart with lung inflation

Inter-alveolar vessels (corners) do not expand when Pla > ~ 3 mmHg
VC = 650 ml
Lung inflation can load the RV by creating "zone II conditions". It then directly impedes RV ejection.

\[ P_{alv} < P_{LA} \]

\[ P_{alv} > P_{LA} \]
VC = 650 ml
Ventilator triggered breaths
PS = 6
Possible insp non-zone III?
Summary

- Intrathoracic transmural pressures in the chest are relative to pleural pressure.
- Inspiratory and expiratory activity can dramatically change the “apparent” transmural pressure.
- These efforts also can have significant hemodynamic effects.
Increase in abdominal pressure on circuit function curve
How does positive pressure effect outflow from the right heart?
Does lung inflation increase PVR?

- Whittenberg et al. 1960: Increase in resistance
  
- Permutt et al. 1962: Vascular waterfall effect
? Rise in pulmonary vascular resistance?

Inspiration (Paw = 20 cmH₂O)

But increase afterload on RV through rise in PVR
Permutt et al 1962
Vascular waterfall effect
Cyclic “insp” +ve pressure

Time

LV

RV

Part
Pulmonary vascular reservoir and buffer
Key points:

- Dominant factor in heart-lung interaction is change in pleural pressure (Ppl) relative to atmosphere
  - Increase Ppl decreases venous return and cardiac output
  - Decreased Ppl increases venous return and cardiac output
  - Transpulmonary pressure becomes important when West Zone II conditions are present
Conclusions 2:

• Left heart can only put out what the right heart gives it (in the steady state)
• Do not get fooled by pressures relative to atmosphere
• Effects of ventilation on the heart are dependent upon blood volume (systemic and pulmonary) and cardiac function
Decreasing Cardiac function decreased PP variation

N Eeslv

Depressed Eeslv

Part

Part

11.7 mmHg

8.3 mmHg
**A**

- Pressure: 100 mmHg
- Difference: 100 mmHg

**B**

- Pressure: 140 mmHg
- Difference: 100 mmHg + 40 mmHg

**Equation:**

\[ TM = 100 \text{mmHg} \]

\[ TM = 140 \text{mmHg} \]
Pulmonary artery flow velocity
1 2 3 4

Tricuspid flow velocity
1 2 3 4

Vieillard-Baron A et al J Appl Physiol 87:1644-1650, 1999
PA – velocity Jardin & Vieillard-Baron 2003
End-expiration (PEEP = 5 cmH$_2$O)
Royal Victoria Hospital 1893