Cardiovascular insufficiency with Initiation and Withdrawal of Mechanical Ventilation

Michael R. Pinsky, MD, Dr hc
Department of Critical Care Medicine
University of Pittsburgh
Ventilation and Cardiovascular Stress

- Spontaneous Ventilation is Exercise
- Spontaneous Ventilation Increases Preload and LV Afterload
- Positive-Pressure Ventilation Decreases Preload and LV Afterload
Breathing as Exercise

• Nasal CPAP treatment improved gut blood flow in CHF patients
  • Baratz et al. Chest 102: 1397-401, 1992

• Gastric mucosal pH predicts weaning success

• Both upper airway and endotracheal tubes contribute to breathing workload

• Increase a-v $O_2$ gradients in COPD weaning failures
  • Jubran et al. Am J Respir Crit Care Med. 158:1763-9, 1998

• Increased gastric PCO$_2$ during exercise indicates gastric ischemia
  • Kolkman et al. Gut 44:163-7, 1999

• Gastric mucosal pH and pCO$_2$ change during exercise
  • Hurtado et al. Crit Care Med 29:70-6, 2001

• Exercise induces gastric ischemia in health volunteers
Gastric mucosal pH predicts success in weaning

Evidence of cardiovascular failure in patients with COPD who fail weaning


**Graph**

- Weaning Successes
- Weaning Failures

**Axes**
- Y-axis: \( \text{S}_\text{v} \text{O}_2 \), percent
- X-axis: Time, percent
- Mech Vent
- Spontaneous Breathing

- Plot shows changes in \( \text{S}_\text{v} \text{O}_2 \) over time from mechanized ventilation to spontaneous breathing.
Breathing is Exercise

Potentially, the reason why all mechanical weaning parameters are so poor at predicting weaning success is that they do not include cardiovascular reserve in their determination.

Exercise Limitation is a Big Fish
Weaning is a Cardiac Stress Test

- Acute LV dysfunction during unsuccessful weaning from MV in COPD patients
- Thallium-201 myocardial perfusion impaired during weaning from MV in ventilator-dependent patients
- LV dysfunction during weaning in COPD patients
- Association of myocardial ischemia with failure to wean
- Cardiac ischemia during weaning from MV
- Increase a-v O₂ gradients in COPD weaning failures
- Cardiac ischemia during weaning from MV
Effects of Spontaneous Ventilation on LV Filling

Baseline

5 min SV

9 min SV

Liberation from Mechanical Ventilation
Hemodynamic Effects of Ventilation

• Changes in Lung Volume

• Changes in Intrathoracic Pressure
Lung Volume and Pulmonary Vascular Resistance

Pulmonary Vascular Resistance can be altered by ventilation through changes in:

- $P_{\text{A}}O_2$ and Blood pH (Hypoxic pulmonary vasoconstriction)
- Lung volume (Mechanical vascular compression)
- Autonomic Tone
Effects of Lung Volume on Pulmonary Vascular Resistance

- Differential Effects on Alveolar and Extra-Alveolar Vessels

  - *Extra-Alveolar Vessels* sense interstitial or pleural pressure ($P_{pl}$) as outside pressure
  - *Alveolar Vessels* sense alveolar pressure ($P_{alv}$) as outside pressure
  - $P_{alv} - P_{pl} = \text{transpulmonary pressure}$

Lung Volume and PVR

Pulmonary Vascular Resistance

Total
Alveolar
Extra-Alveolar

Lung Volume

RV  FRC  TLC

Effect of PEEP on Pulmonary Vascular Resistance

PEEP and Cardiac Output

- PEEP decreases cardiac output by decreasing LV preload
- Minimal effects at ≤ 5 cm H₂O PEEP
- Mitigated by Volume Loading or Heart Failure
  - Grace & Greenbaum Crit Care Med 10:358-60, 1982
Hyperinflation is Common

• Induced by increased respiratory rate, larger tidal volume or inadequate expiratory time
  • Bergman Anesthesiology 37:626-33, 1969

• Hyperinflation can induce acute RV failure (acute cor pulmonale)
  • Conway. Br J Anaesth 47:761-6, 1975

• Marked over-ventilation induces an auto PEEP effect compromising blood flow
  • Pepe & Marini. Am Rev Respir Dis 126:166-70, 1982
Occult PEEP and Cardiovascular Compromise

PEEP Decreases Bi-ventricular Volumes

Expiration  Inspiration

ZEESP

10 PEEP
Hemodynamic Effects of Ventilation

- Changes in Lung Volume
- Changes in Intrathoracic Pressure
Hemodynamic Effects of Changes in Intrathoracic Pressure

Venous Return

Thorax

LV Ejection
Simultaneous Determinants of Cardiac Output and Venous Return

Blood Flow (l/min)

Equilibrium Point

LV Function Curve

Venous Return Curve

Right Atrial Pressure (mm Hg)
Effect of Decreases in Intrathoracic Pressure on LV Performance and Venous Return

Blood Flow (l/min)

Right Atrial Pressure (mm Hg)

No change in LV Function

Decreased ITP

Thoracic Pump

A

B

Figure

0 5 10

Right Atrial Pressure (mm Hg)
Effect of spontaneous efforts on venous return

Normal spontaneous inspiration

Occluded inspiration

Pinsky J Appl Physiol 56:765-71, 1984
Loaded Spontaneous Inspiration Increases Venous Return

- Heart failure increases depth of ventilation
- Loaded inspiration causes pulmonary edema
- Inspiratory impedance during CPR increases CBF
- Some researchers are now recommending resistive loaded breathing for trauma patients who can not be initially resuscitated to augment cardiac output!
- Negative expiratory pressure ventilation improves cardiac output and short term survival during porcine hemorrhagic shock
Effect of Increases in Intrathoracic Pressure on LV Performance

Blood Flow (l/min)

Right Atrial Pressure (mm Hg)

0 5 10

No change in LV Function

Increased ITP

Volume Infusion

Effect of Positive-Pressure Ventilation on LV Volumes and Pressure

Intact Anesthetized Human

Effect of Tidal Volume on the Dynamic Intrathoracic Blood Volume Shifts

Transmural Pressure is the Amount Above the Surface

Do you care how tall the kids are?

Or how far above the water’s surface their heads end up?

<table>
<thead>
<tr>
<th>Height:</th>
<th>1.4m</th>
<th>1.7m</th>
<th>1.2m</th>
</tr>
</thead>
<tbody>
<tr>
<td>above water</td>
<td>0.21m</td>
<td>0.24m</td>
<td>0.21m</td>
</tr>
</tbody>
</table>
Effects of changes in ITP on LV ejection

- Decreases in ITP increase LV ejection pressure increasing LV AFTERLOAD

- Increases in ITP decrease LV ejection pressure decreasing LV AFTERLOAD
Decreases in ITP increase LV Afterload

Decreases in ITP Increase LV Afterload

Negative Swings in ITP Produce Pulmonary Edema

- **Status Asthmaticus**

- **Upper Airway Obstruction**

- **Pulmonary Edema**
  - Oswalt et al. JAMA 238:1833-1835 1977
Increases in Intrathoracic Pressure Decrease LV Afterload and Increases Cardiac Output

- Acute heart failure induced by β-blockage in dogs

- In human CHF cardiomyopathies

- Cardiac cycle-specific increases in ITP in acute heart failure dogs

- Prevents the fall in CO in hypovolemia

- In acute mitral regurgitation in dogs
Effect of Increased Intrathoracic Pressure on LV Performance

- Blood Flow (l/min)
- Right Atrial Pressure (mm Hg)

Acute Ventricular Failure
- Increased LV Performance

Increased ITP

Points A and B on the graph illustrate the impact of increased intrathoracic pressure on blood flow and right atrial pressure.
Asynchronous High Frequency Jet Ventilation in Acute Ventricular Failure

Application:

Any relative increase in intrathoracic pressure decreases LV afterload.

Abolishing negative swings in ITP will decrease LV afterload.
Noninvasive CPAP and BiPAP Decrease Cardiac Stress

- CPAP decreases ischemia in acute cardiogenic pulmonary edema (ACPE)
- CPAP benefits seen only if negative ITP swings abolished in ACPE
- Mask CPAP prevents need for intubation in ACPE
- Both mask BiPAP and PSV improve gas exchange and prevents the need for intubation in ACPE
- CPAP and BiPAP have similar survival benefit in ACPE
- Mask BiPAP improves LV function in OSA patients
Summary

- As the work of breathing increases or cardiovascular reserve decreases spontaneous ventilation may impose an excessive metabolic demand on the heart inducing shock.
- Failure to wean from mechanical ventilation often reflects cardiovascular insufficiency.
- Spontaneous inspiration cyclically increases intrathoracic blood volume (ITBV).
- Positive airway pressure by reversing negative swings in ITP decreases LV afterload.
Thank You