Respiratory Failure & Mechanical Ventilation

Denver Health Medical Center Department of Surgery and the University Of Colorado Denver
Failure of the Respiratory Pump

1. Lack of patent airway
2. Bronchospasm
3. Bronchomalacia
4. Loss of respiratory drive
5. Denervation of respiratory muscles
6. Respiratory muscle fatigue
Failure of Gas Exchange

1. Impaired diffusion across alveolar-capillary interface
2. V/Q mismatching
3. Shunt
4. Dead space ventilation
At the bedside: two forms may require assisted ventilation

1. Hypercapnic pulmonary failure
   PaCO₂ >50
   Signifies a system unable to regulate pH – which affects every cellular process

2. Hypoxic pulmonary failure
   PaO₂ <60 despite supplemental oxygen
   Signifies a system unable to deliver O₂ – which affects every cell as well
Hypercapnic Pulmonary Failure

Most commonly
  manifestation of pump failure
  inadequate alveolar ventilation
Oxygenation may be maintained
Respiratory rate may be high or low – or nl
Don’t be fooled by a normal pulse ox
Get a blood gas
  Rapid, shallow or labored breathing
Mental status change
New organ dysfunction
More on Hypercapnic Failure

Inability to adequately excrete produced CO2

**Absolute**: \( \text{PaCO}_2 > 50 \)

example ABG: 7.24/60/70

**Relative**: \( \text{PaCO}_2 \) is not low enough to compensate for acidosis

example ABG: 7.14/40/70

**BOTH** of these are failure and require intervention
1. **Hypercapnic pulmonary failure**
   Assists the patient with the work of breathing
   Can help assure adequate alveolar ventilation

2. **Hypoxic pulmonary failure**
   Allows deliver of oxygen at
   higher concentrations
   higher pressures
Mechanical Ventilation – Cornerstone of ICU care

◆ 1928: Drinker-Shaw Iron Lung
◆ 1950s: Polio epidemic
◆ 1955: Invasive positive pressure ventilation
◆ 1973: Intermittent Mandatory Ventilation (IMV)
Fifty Six names of modes
Twenty four unique modes
Proprietary nomenclature
What kinds of MV are there?

- **Nomenclature of modes seems daunting**
- **Classification is actually *simple***
  - Triggering: how a breath is initiated
  - Cycling: switch from inhalation to exhalation
  - Inspiratory controls – how breath is delivered
  - Expiratory controls – limits on exhalation (if any)
MV Simplified

◆ Assist/Control
◆ Pressure Support
◆ SIMV with PS
Assist/Control

- **Trigger:**
  - Pt or Ventilator
  - Pressure
- **Control:** Flow
- **Cycle:** Volume
**Assist/Control**

◆ **Advantages:**
  ◆ Minimal or no patient effort
  ◆ Guaranteed Tidal Volume/Minute volume
  ◆ Easy to understand

◆ **Disadvantages**
  ◆ Inspiratory control (flow) may not match pt efforts
  ◆ Cycling (volume) may not match pt effort
Pressure Support Ventilation

- **Trigger:**
  - Patient only
  - Flow (or pressure)
- **Control:** pressure
- **Cycle:** flow
PSV

Advantages:

- Patient controls:
  - Inhalation:Exhalation ratio
  - Flow rate
  - Tidal Volume
- Much more comfortable than A/C
- Allows for graded exercise/pt effort

Disadvantages

- Requires intact drive/patient effort
- Cycling (flow) may not match pt effort
- Rate of pressure rise during inhalation can markedly affect work of breathing
SIMV with Pressure Support

Mandatory Breath
◆ Trigger: Vent or Pt
◆ Control: Flow
◆ Cycle: Volume

Patient Breath
◆ Trigger: Patient
◆ Control: Pressure
◆ Cycle: Flow
SIMV with PS

◆ **Advantages:**
  ◆ Mandatory breaths
    ◆ Guarantee some minimum minute volume
    ◆ Give “full” breath – prevent derecruitment

◆ **Disadvantages**
  ◆ Same as A/C and PSV
Do “conventional” modes work?

- Patient-Ventilator Interaction
- Important new focus
- How best to match ventilator to pt?
  - Preserve respiratory pump function
  - Avoid atrophy of disuse
  - Avoid injury of excessive work
- Minimize discomfort and anxiety
Do “conventional” modes work?

- Patient-Ventilator Interaction not as good as we think
- Types of Asynchrony
  - Triggering asynchrony
  - Cycling asynchrony
  - Inspiratory limit asynchrony
What do we do with asynchrony?

- Blame the Patient
- Sedate the Patient
- Paralyze the Patient
- Prolong MV
- Promote Lung Injury
- Prolong ICU length of Stay
Newer Modes: PAV

- Proportional assist ventilation
- An attempt to quantify % effort by machine/pt
- Patient triggered, flow cycled (like PSV)
- Inspiratory pressure varied in response to physiology
  \[ P_{\text{total}} = (V)(E) + (\dot{V})(R) \]
- Elastance and Tube size/length used to calculate
- Clinician sets % effort
- May decrease WOB in pts with poor synchrony in standard modes
- No outcome benefit in randomized trials
Newer Modes: PRVC

- Pressure regulated volume controlled
- An attempt to marry the comfort of PSV with the guaranteed TV of volume-cycled modes
- Patient triggered, flow cycled
- Pressure limit is adjusted by machine to meet a tidal volume goal
- “automatic” weaning?
- Not really: machine cannot differentiate between changes in pt effort and changes in elastance/resistance
Newer Modes: APRV

- Airway Pressure Release Ventilation
- Attempt to marry “safe pressures” used in pressure-controlled modes with the comforts of spontaneous breathing
- Pressure is time-cycled between two values
- Spontaneous breathing permitted throughout
The Question

The question “What is the evidence base for the newer ventilation modes?” is broad and difficult to answer. We could ask, “What is the evidence that the newer modes improve outcomes?” but that would bring this article to an abrupt end, because the answer is, “There is none.” We could in-
Scientific Evidence Summarized:

**Dean Hess: 2010**

“Many new modes [have been] introduced in recent years…..but have not been subjected to rigorous scientific study. None has been conclusively shown to improve patient outcomes. The Acute Respiratory Distress Syndrome Network study……..is the *only* study of mechanical ventilation ever shown to improve patient outcome”
Keep it simple: Only two kinds of Mechanical Ventilation

- **Full** MV support
  - Inadequate respiratory drive
  - Poor gas exchange
  - Cardiovascular instability
  - Inability to execute work of breathing

- **Partial** support
Recommended Approach

• **Initial full support:**
  – **Goal:** ensure adequate ventilation
  – **Recommend:** Assist-Control
    • Pt & machine triggered
    • Volume cycled – constant volume each breath
    • Flow limited – adjust flow for rate and comfort
Recommended Approach

• Subsequent partial support
  – Goal: exercise without tiring
  – Recommend:
    • Pt triggered – pt determines rate and I:E
    • Flow cycled – pt determines flow rates
    • Pressure limited
    • PSV, PRVC, APRV all acceptable
  – Spontaneous breathing trial when criteria met
Pressure/volume Curve: Idealized Normal Lung
Stress and Strain

- Tension on the Lung Skeleton
  - Proportional to Airway pressure minus pleural pressure
  - "Transpulmonary Pressure"
  - A static measurement
  - Pressure can induce injury

- Tension on Lung units as they move/deform
  - Proportional to Tidal volume
  - Related to End Expiratory Volume
  - A dynamic measurement
  - "Stretch" can induce injury
The Acutely Injured Lung (ALI/ARDS)

ARDS lungs
• Normal regions
• Collapsed regions
• Consolidated regions

VILI
• Overdistention of alveoli from high tidal volumes
• Repetitive opening/closing of lung units from low tidal volumes
**Lung Recruitment**

**Recruitment** = “…. A sustained increase in airway Pressure (30 – 90 Sec) with the goal to open collapsed lung Tissue”

Potential pressures of > 140 cm H₂O
Does Recruitment Help?

- Constantin et al., Crit Care 2010
  - Prospective, Randomized studies
  - Patients enrolled promptly after intubation for hypoxia
  - “Recruitment” = CPAP 40 for 30 seconds
  - Did not change PEEP (5 cm water)
Techniques to Facilitate Lung Recruitment

- Sigh Breaths: 1.5-2 times the Vt
- Temporary increase in PEEP
- Temporary increase in Tidal Volume
- Temporary use of CPAP
- High Frequency Ventilation
- APRV
- Pronation
Many questions Remain

Which patients will benefit??

ARDS$_{PULM}$
ARDS$_{EXtraPULM}$

Post R.M. PEEP

Optimal Duration of R.M.

Routine use or only during Hypoxic events

Contraindications:
Pneumonia ??
Unilateral Dz process
*Acute hypoxia without CXR*
## Overall Strategy for MV

<table>
<thead>
<tr>
<th>Ventilatory Parameter</th>
<th>Traditional</th>
<th>Lung-Protective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation Volume</td>
<td>10-15 ml/kg</td>
<td>5-7 ml/kg</td>
</tr>
<tr>
<td>End-insp. pressure</td>
<td>Peak Pr&lt;50 cm water</td>
<td>Plateau Pr&lt;30</td>
</tr>
<tr>
<td>PEEP</td>
<td>PRN to keep FiO2&lt;0.6</td>
<td>5-15 cm of water</td>
</tr>
<tr>
<td>ABG</td>
<td>Normal, pH 7.36-7.44</td>
<td>Hypercapnia allowed, pH 7.2-7.4</td>
</tr>
<tr>
<td>Recruitment Maneuvers?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Lung Protection Improves Survival

When and how do I “wean” MV?

- Better term: Withdrawal of mechanical ventilatory support
- Principles:
  - Work every day
  - Don’t work too hard
  - No scientific evidence supporting any given mode
    - PSV or CPAP
    - SIMV
    - T-piece
Does My Patient Need the Ventilator?

• Assess continuously
• Most patients should be on partial support during the day
• Should coincide with diminution of sedation
• Contraindications to Partial Vent Support:
  – Inadequate respiratory drive
  – Cardiovascular instability
  – Poor gas exchange
  – ICP requiring treatment
  – Minute volume > 14 lpm
Spontaneous Breathing Trials

- **Minimal Support**
  - PEEP = 5, PS = 0 – 5, FiO₂ ≤ 50%
  - Assess for 30 – 120 min
  - ABG obtained at end of SBT

- **Failed SBT Criteria**
  - RR > 35 for >5 min
  - \( S_\text{a}O_2 \) < 90% for >30 sec
  - HR > 140
  - Systolic BP > 180 or < 90mm Hg
  - Cardiac dysrhythmia
  - pH < 7.32
Are SBTs Beneficial?

- **Robertson et al., 2008**
  - 488 SICU patients
  - Routine SBTs initiated at beginning of study
  - Comparison of first and last two months

- **Observed**
  - Decreased days on ventilator
  - Decreased ICU stay
  - No change in reintubation rate
Predicting Successful Liberation from MV

Tobin: “A number of indices….have been proposed as predictors of weaning outcome. However, none….have ever been subjected to prospective investigation but have been passed on from one review article to another”
The Evidence: Discontinuation of Mechanical Ventilation

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<tr>
<th>Parameter</th>
<th>Threshold</th>
<th>PPV</th>
<th>NPV</th>
</tr>
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<tbody>
<tr>
<td>PaO2/FiO2</td>
<td>200</td>
<td>0.59</td>
<td>0.53</td>
</tr>
<tr>
<td>Minute Ventl.</td>
<td>&lt;10L/min</td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>10ml/kg</td>
<td>0.82</td>
<td>0.37</td>
</tr>
<tr>
<td>Rate/Tidal Volume (Rapid, Shallow Breathing Index)</td>
<td>&lt;105/min/L</td>
<td>0.78</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Tobin and Alex, in “Principles of Mechanical Ventilation”, 1994
Summary and Conclusions

- The respiratory system is a bellows connected to a gas exchanger
- Two basic types of respiratory failure: hypercapnic and hypoxic
- Ventilator modes are simple
- Ventilator modes do not determine outcome
- You should know how a mode you are using triggers, cycles and limits each breath
- Avoid high stretch and high pressure on the lung
- Regular spontaneous breathing trials improve outcome
- Prone ventilation and other recruitment maneuvers improve hypoxia but may not improve outcome