Mechanical Ventilation for Dummies
Keep It Simple Stupid

• Indications
  – Airway
  – Ventilation failure (CO2)
  – Hypoxia
  – Combination

• Airway obstruction
• Inability to protect airway
• Hypoxia (PaO$_2$ < 50)
• Hypercapnia (PaCO$_2$ > 50)
• Respiratory distress (RR > 30, use of accessory muscles)
Ventilator Management

Scalar

- CMV
- ACV
- IMV
- SIMV
- SIMV + PS
- PCV
- IRV
- PRVC
- APRV
- CPAP

Control Mode - Scalars
(Volume- Targeted Ventilation)

Preset Peak Flow

Pressure (cm H₂O)

Flow (L/min)

Volume (ml)

Time (sec)

Dependent on $C_L$ & $R_{aw}$

Preset $V_t$

Essentials of Ventilator Graphics

CLINICAL UTILITY OF VENTILATOR GRAPHICS
Vijay Deshpande, MS, RRT, FAARC
Ventilator Management

Loops

Pressure-Volume Loops

Flow-Volume Loop

CLINICAL UTILITY OF VENTILATOR GRAPHICS
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Ventilator Management

*This really is all there is to it*

- Time (RR)
- Volume (Vt)
- Pressure (PIP, $P_{plat}$)
- Flow

![Volume vs Time Scalar](image)
Ventilator Management

*Control Mechanical Ventilation*

- Time – Set respiratory rate
- Volume – Set Vt
- Flow – Set to deliver the Vt
- Airway Pressure – **Dependent** on the interaction of the above and on the respiratory system compliance and airflow resistance

} **Independent Variables**
Ventilator Management

*Pressure Control Ventilation*

- Time – Set respiratory rate
- Pressure – Set pressure
- Flow – Set to deliver pressure
- Volume – Dependent on the interaction of the above and on the respiratory system compliance and airflow resistance

\[\text{Independent Variables}\]
Ventilator Management

*Dual Control Modes* - PRVC

- Time – Set RR
- Volume – Set $V_T$
- Flow – Set
- Pressure – increases or decreases to maintain the set $V_T$ (*Dependent variable*), but this is *Limited* (i.e. controlled)

{ Independent Variables }
Airway Pressure Release Ventilation
APRV-BILEVEL

Advantages
1. Lower Paw for a given $V_T$
2. Lower $V_E$, i.e., less dead space
3. Limited adverse effects on cardiac function
4. Spontaneous breathing
5. Decreased sedation

Potential Disadvantages
1. Volumes change with changes in compliance and resistance
2. New technology
3. Limited access to technology
4. Limited research and clinical experience

CPAP is transiently decreased or “released” to a lower level during expiration.
Ventilator Management

- Peak Insp Pressure (PIP) vs.
- Plateau airway pressure (Pplat)
- Transairway pressure
  - PIP-Pplat
    - Obstruction
    - Secretions
    - RAD

Components of Inflation Pressure

1. PIP
2. Pplat/Alveolar Pressure
   A. Airway Resistance
   B. Distending Pressure

Paw (cm H₂O)

Begin Inspiration

Begin Expiration

Time (sec)

CLINICAL UTILITY OF VENTILATOR GRAPHICS
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Ventilator Management

• Compliance
  – Relationship of volume to pressure
  – Dynamic vs static
History of Mechanical Ventilation

- Poliomyelitis
  - Negative pressure (iron lung)
- WW II
  - Positive pressure cycled (Bennett and Bird)
- Volume cycle (Emerson)
- $V_T$ 6-8 ml/kg, Sigh 12-18 ml/kg
- $V_T$ 10-15ml/kg without sighs
- ARDS & PEEP
  - Ashbaugh Bigelow and Petty UCHSC 1967
Ventilator Induced Lung Injury

**VILI is due to volume** (*Overdistension*)

Ventilation 45 cm $H_2O$

Baseline  5 min  20 min

ARDS is Not Homogeneous
Inflection Points

*Paw increases with little change in the volume*

**Lower**

**Upper**

**Lung Compliance Changes in the P-V Loop**

**Overdistension**

*Paw rises with little or no change in VT*

CLINICAL UTILITY OF VENTILATOR GRAPHICS
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ARDSnet
NIH NHLBI ARDS Clinical Trials Network
ARDS Network: ARMA
Respiratory Management in ARDS
6 vs. 12 ml/kg Tidal Volume

- **Mode**: Volume Assist / Control
- **Rate**: Set rate < 35; adjust for pH goal = 7.30-7.45
- **Oxygenation**
  - $\text{PaO}_2 = 55-80 \text{ mmHg}$
  - $\text{SaO}_2 = 88-95%$
- **PEEP**
  - 5  5  8  8  10  10  10  10  ....  20
- **FiO$_2$**
  - .3  .4  .4  .5  .5  .6  .7  ....  1.0
- **I:E** = 1:1.8-1.3
- **Weaning by Pressure Support** when PEEP/FiO$_2$ $\leq$ 8/.40

New Eng J Med 2000; 342: 1301
ARDS Network: ARMA
Respiratory Management in ARDS
6 vs. 12 ml/kg Tidal Volume

**12 ml/kg Group**
- Initial Vt = 12 ml/kg IBW
- If Pplat > 50 cmH2O, reduce Vt by 1 ml/kg.
- Minimum Vt = 4 ml/kg
- If Pplat < 45 cmH2O and Vt ≤ 11 ml/kg, increase Vt by 1 ml/kg.

**6 ml/kg Group**
- Initial Vt = 6 ml/kg IBW.
- If Pplat > 30 cmH2O, reduce Vt by 1 ml/kg.
- Minimum Vt = 4 ml/kg.
- If Pplat < 25 cmH2O and Vt ≤ 5 ml/kg, increase Vt by 1 ml/kg.

New Eng J Med 2000; 342: 1301
ARDS Network: ARMA
Respiratory Management in ARDS
6 vs. 12 ml/kg Tidal Volume

Plateau Pressure

New Eng J Med 2000; 342: 1301
ARDS Network: ARMA
Respiratory Management in ARDS
6 vs. 12 ml/kg Tidal Volume

New Eng J Med 2000; 342: 1301
ARDS Network: ARMA

Respiratory Management in ARDS

6 vs. 12 ml/kg Tidal Volume

• Vt 6 vs. 12 ml/kg
• Mortality
• 31.0 vs 39.8%

New Eng J Med 2000; 342: 1301
ARDS Network: ALVEOLI

High vs. Low PEEP

• Ventilator management the same as ARMA except PEEP

<table>
<thead>
<tr>
<th>Lower – PEEP/ Higher FiO₂ Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>FiO₂</td>
</tr>
<tr>
<td>PEEP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Higher - PEEP/Lower FiO₂ Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>FiO₂</td>
</tr>
<tr>
<td>PEEP</td>
</tr>
</tbody>
</table>

## ARDS Network: ALVEOLI

### High vs. Low PEEP

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>PEEP</td>
<td>8.9</td>
<td>14.7</td>
<td>8.5</td>
</tr>
<tr>
<td>P/F</td>
<td>168</td>
<td>220</td>
<td>169</td>
</tr>
</tbody>
</table>

Conclusions
• VT goal 6 ml/kg
• Pplat limit of 30 cm H2O,
• Outcomes are similar whether lower or higher PEEP levels are used.
ARDS Network: FACTT
Fluids and Catheter Treatment Trial
PAC vs. CVP

## ARDS Network: FACTT

### Conservative vs. Liberal Fluid

<table>
<thead>
<tr>
<th>Measured intravascular pressure (mm Hg)</th>
<th>MAP &lt; 60 mm Hg or a need for any vasopressor (except dopamine ≤ 5 µg/kg/min); consider correctable causes of shock first</th>
<th>MAP ≥ 60 mm Hg without vasopressors (except dopamine ≤ 5 µg/kg/min)</th>
<th>Average urinary output &lt; 0.5 ml/kg/hr</th>
<th>Average urinary output ≥ 0.5 ml/kg/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVP</td>
<td>Conservative strategy</td>
<td>Liberal strategy</td>
<td>Conservative strategy</td>
<td>Liberal strategy</td>
</tr>
<tr>
<td><strong>Range 1</strong></td>
<td>&gt;13</td>
<td>&gt;18</td>
<td>&gt;18</td>
<td>&gt;24</td>
</tr>
<tr>
<td><strong>Range 2</strong></td>
<td>9–13</td>
<td>15–18</td>
<td>13–18</td>
<td>19–24</td>
</tr>
<tr>
<td><strong>Range 3</strong></td>
<td>4–8</td>
<td>10–14</td>
<td>8–12</td>
<td>14–18</td>
</tr>
<tr>
<td><strong>Range 4</strong></td>
<td>&lt;4</td>
<td>&lt;10</td>
<td>&lt;8</td>
<td>&lt;14</td>
</tr>
</tbody>
</table>

**Conservative Circulation**
- Cardiac index < 2.5 liters/min/m² or cold, mottled skin with capillary-refilling time > 2 sec

**Effective Circulation**
- Cardiac index ≥ 2.5 liters/min/m² or absence of criteria for ineffective circulation

**1. Vasopressor**
- Fluid bolus

**2. Fluid bolus**
- Vasopressor

**3. KVO IV Dobutamine**
- Furosemide

**4. KVO IV Dobutamine**
- Furosemide

**5. Fluid bolus**
- Furosemide

**6. Fluid bolus**

**7. KVO IV Furosemide**
- Dobutamine

**8. KVO IV Furosemide**
- Dobutamine

**9. Fluid bolus**

**10. Fluid bolus**

**11. KVO IV Dobutamine**
- Furosemide

**12. KVO IV Dobutamine**
- Furosemide

**13. Fluid bolus**

**14. Fluid bolus**

**15. KVO IV Furosemide**
- Dobutamine

**16. KVO IV Furosemide**
- Dobutamine

**17. Liberal KVO IV**

**18. Conservative Furosemide**

**19. Liberal fluid bolus**

**20. Conservative KVO IV**

---

# ARDS Network: FACTT

## Conservative vs. Liberal Fluid

<table>
<thead>
<tr>
<th>D</th>
<th>Furosemide mg/d</th>
<th>Intake ml/d</th>
<th>Output ml/d</th>
<th>Balance ml/d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liberal</td>
<td>Conserve</td>
<td>Liberal</td>
<td>Conserve</td>
</tr>
<tr>
<td>1</td>
<td>74</td>
<td>148</td>
<td>5029</td>
<td>4230</td>
</tr>
<tr>
<td>2</td>
<td>72</td>
<td>157</td>
<td>4467</td>
<td>3590</td>
</tr>
<tr>
<td>3</td>
<td>65</td>
<td>166</td>
<td>3997</td>
<td>3390</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>154</td>
<td>3752</td>
<td>3430</td>
</tr>
<tr>
<td>5</td>
<td>73</td>
<td>164</td>
<td>3825</td>
<td>3201</td>
</tr>
<tr>
<td>6</td>
<td>58</td>
<td>158</td>
<td>3782</td>
<td>3159</td>
</tr>
<tr>
<td>7</td>
<td>51</td>
<td>127</td>
<td>3639</td>
<td>3226</td>
</tr>
</tbody>
</table>

7 day fluid balance: 6992±502, -136±491
ARDS Network: FACTT
Conservative vs. Liberal Fluid

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Liberal</th>
<th>Conserve</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death (60d)</td>
<td>28.4%</td>
<td>25.5%</td>
<td>0.30</td>
</tr>
<tr>
<td>VFD (28d)</td>
<td>12.1</td>
<td>14.6</td>
<td>.001</td>
</tr>
<tr>
<td>ICU-FD (28d)</td>
<td>11.2</td>
<td>13.4</td>
<td>.001</td>
</tr>
<tr>
<td>Dialysis (60d)</td>
<td>14</td>
<td>10</td>
<td>.06</td>
</tr>
</tbody>
</table>
ARDS Network: LASRS

Late ARDS Steroid Rescue Study

Methylprednisolone
• 2 mg/kg load
• 0.5 mg / kg q 6 for 14d,
• 0.5 mg / kg q 12 for 7d,
• Taper over 4 days
• Taper over a 2 days if septic shock
• Intensive infection surveillance

New Eng J Med Volume 2006; 354:1671-1684
### ARDS Network: LASRS
#### Late ARDS Steroid Rescue Study

<table>
<thead>
<tr>
<th></th>
<th>Placebo (91)</th>
<th>MP (89)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality (60d)</td>
<td>28.6%</td>
<td>29.2%</td>
<td>1.0</td>
</tr>
<tr>
<td>VFD (28d)</td>
<td>6.8 ± 8.5</td>
<td>11.2 ± 9.4</td>
<td>.001</td>
</tr>
<tr>
<td>ICU FD (28d)</td>
<td>6.2 ± 7.8</td>
<td>8.9 ± 8.2</td>
<td>.02</td>
</tr>
<tr>
<td>Myopathy (no.)</td>
<td>0</td>
<td>9</td>
<td>.001</td>
</tr>
<tr>
<td>Infections / pts</td>
<td>43/30</td>
<td>25/20</td>
<td>.14</td>
</tr>
<tr>
<td>Amylase (D7)</td>
<td>73 ±50</td>
<td>125 ± 131</td>
<td>.003</td>
</tr>
<tr>
<td>Glucose (D7)</td>
<td>144.0 ± 61.8</td>
<td>158.7 ± 64.4</td>
<td>.14</td>
</tr>
</tbody>
</table>

New Eng J Med Volume 2006; 354:1671-1684
Institute for Healthcare Improvement (IHI)
Ventilator Bundle

- HOB > 30°
- DVT prophylaxis
- PUD Prophylaxis
- Daily sedative vacation and assessment of readiness to extubate

http://www.ihi.org/IHI/
Mechanical Ventilation
Weaning

- What was the reason for intubation?
- Has that reason been resolved?
- Can patient protect airway?
- Can patient handle secretions?
- Oxygenation?
- Ventilation? (CO2)
- Others: Cardiac function, acid base, abdomen, renal function
- 35% prediction
  - “You will never find a fever if you do not measure a temperature?”
Nonphysician Directed Weaning

Ely AmJRCCM 1999; 159: 439

Kollef CCM 1997; 25: 567
Daily Sedative Vacation

Mechanical Ventilation
Weaning

- Pressure Support
  - Gradual reduction in ventilator work is assumed by the patient

- SIMV + PS
  - Some breaths are ventilator work and some are patient work

- T-piece
  - Discontinuation of ventilator work is assumed by patient.

Brochard AJRCCM 1994; 150: 896
Esteban NEJM 1995; 332: 345
Mechanical Ventilation
Failure to Wean

• Increase in demands
  – Abnormal respiratory mechanics
    • RAD
    • Decrease C
  – Unresolved infection
    • Fever = Me = work

• Decrease in patient capability
  – Sedation
  – Weakness
    • Malnutrition
    • Neuro- or Myo-pathy
  – Chest wall mechanics

Demands | Capability
--- | ---
Total Support | Ventilator Independence
Deleterious work | Tolerable load
Weaning Guidelines

- Daily assessment of potential
- Spontaneous breathing trials (30-120 min)
- Stable support between SBTs
- Ability to protect airway
- Reverse causes of failure
- Weaning protocols for nonphysician
- Prolonged ventilation = slow gradual lengthening of SBTs
Mechanical Ventilation

Weaning

• Withdrawal of the ventilator
• Test for successful extubation
  – Vt 5-7 ml/kg
  – RR < 30
  – Me < 15 L
  – RR/Vt < 105
  – NIF < 20
  – FVC 10-15 ml/kg

10% Failure
Questions?

KISS