Mechanical Ventilation of the Patient with ARDS

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ARDS/ALI

- Acute onset of respiratory distress
- Hypoxemia: \( \text{PaO}_2/\text{FiO}_2 \leq 200 \)
  \( \text{PaO}_2/\text{FiO}_2 \leq 300 \) for ALI
- Bilateral consolidations on chest radiograph
- Absence of cardiogenic pulmonary edema
Common Causes of ARDS

- Direct lung injury (pulmonary ARDS)
  - aspiration and other chemical pneumonitis
  - infectious pneumonia
  - trauma: lung contusion, penetrating chest injury
  - near drowning
  - fat embolism
- Distant injury (nonpulmonary ARDS)
  - inflammation; sepsis syndrome
  - multiple trauma, burns
  - shock, hypoperfusion
  - acute pancreatitis

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ARDS
Avoid over-distention (limit tidal volume and Plateau pressure)

Avoid derecruitment (adequate PEEP)
ARDS Network Study

- 861 patients with ALI/ARDS at 10 centers
- Patients randomized to tidal volumes of 12 mL/kg or 6 mL/kg (volume-control, assist-control, Pplat ≤ 30 cm H₂O)
- 25% reduction in mortality in patients receiving smaller tidal volume
- Number-needed-to-treat: 12 patients


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**ARDS Network Study**

- **PaCO₂**: 43 ± 12 vs. 36 ± 9 (6 mL/kg vs. 12 mL/kg)
- **Respiratory rate**: 30 ± 7 vs. 17 ± 7
- **PaO₂/FI O₂**: 160 ± 68 vs. 177 ± 81
- **Plateau pressure**: 26 ± 7 vs. 34 ± 9
- **PEEP**: 9.2 ± 3.6 vs. 8.6 ± 4.2

ARDSnet Protocol

- Calculate predicted body weight (PBW)
  Male = 50 + 2.3 [height (inches) - 60]
  Female = 45.5 + 2.3 [height (inches) - 60]
- Mode: volume assist-control
- Change rate to adjust minute ventilation (not >35/min); pH goal: 7.30-7.45
- Plateau pressure goal: ≤ 30 cmH₂O
- PaO₂ goal: 55-80 mm Hg or SpO₂ 88-95%; use FiO₂/PEEP combinations to achieve oxygenation goal:

<table>
<thead>
<tr>
<th>FiO₂</th>
<th>PEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>5</td>
</tr>
<tr>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>0.5</td>
<td>8</td>
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<tr>
<td>0.6</td>
<td>8</td>
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<tr>
<td>0.7</td>
<td>10</td>
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<tr>
<td>0.8</td>
<td>10</td>
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<tr>
<td>0.9</td>
<td>10</td>
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<tr>
<td>1.0</td>
<td>12</td>
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<tr>
<td>1.0</td>
<td>14</td>
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<tr>
<td>1.0</td>
<td>16</td>
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<tr>
<td>1.0</td>
<td>18</td>
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<tr>
<td>1.0</td>
<td>20</td>
</tr>
<tr>
<td>1.0</td>
<td>22</td>
</tr>
<tr>
<td>1.0</td>
<td>24</td>
</tr>
</tbody>
</table>


ARDSnet and Auto-PEEP

- ARDSnet did not report auto-PEEP
- Several studies have reported auto-PEEP with the respiratory rates used in ARDSnet
  de Durante et al, Am J Respir Crit Care Med 2002;165:1271
- When respiratory rate is increased, inspiratory time must be decreased (mean airway pressure does not change if I:E maintained constant)
- Due to lower tidal volume and increased elastic recoil (low compliance), risk of auto-PEEP is low
- Prudent to monitor auto-PEEP when ARDSnet strategy is used

ARDSnet and Long-Term Outcomes

- 120 patients randomized to low V₉ or high V₉
  - 25% mortality with low tidal volume
  - 45% mortality with high tidal volume
  - ≈ 20% of patients had restrictive defect and ≈ 20% had obstructive defect 1 yr after recovery
  - About 80% had D₅₀CO reduction 1 yr after recovery
  - Standardized tested showed health-related quality of life lower than normal
  - No difference in long-term outcomes between tidal volume groups

Omer, Am J Respir Crit Care Med 2001;167:690
Permissive Hypercapnia
- Low $V_T$ (6 mL/kg) to prevent over-distention
- Increase respiratory rate to avoid hypercapnia
- PaCO$_2$ allowed to rise
- Usually well tolerated???
- May be beneficial – “therapeutic hypercapnia”??
  Laffey & Kavanagh, Lancet 1999; 9186:1283
- Potential problems: tissue acidosis, autonomic effects, CNS effects, circulatory effects
  JAMA 1994;272:957-982
  AJRCCM 1994;150:870-874
  AJRCCM 1994;150:1722-1737

What About Non-ARDS?
- COPD: issue is air-trapping and auto-PEEP
- Patients with normal lung function; overdose, post-operative???
Open Lung Approach & Low Distending Pressure for ARDS

- Conventional approach: \( V_T \) 12 mL/kg, volume control, \( \text{PaCO}_2 \) 25 - 38 mm Hg, PEEP as necessary to keep \( \text{FiO}_2 < 0.60 \)
- New approach: \( V_T < 6 \) mL/kg, pressure ventilation, PIP < 40 cm H\(_2\)O, permissive hypercapnia, high PEEP, recruitment maneuver

But:
- Multiple interventions
- Single center
- High mortality in control group
- Small sample size

Pressure-Controlled Ventilation

- Greatest lung strain with PC-IRV (I:E 2:1), least with PC (I:E 1:2); VC (I:E 1:2, intermediate)
- Edibam et al, Am J Respir Crit Care Med 2003;167:702
- No difference in gas exchange, hemodynamics, and plateau pressure
- Did not evaluate VC with descending ramp
- Mean tidal volume 0.6 L (±10 mL/kg – not reported)
- Differences between groups were small and clinical importance unknown
- No difference in outcome with ARDS patients randomized to PC (n=37) or VC (n=42)
- Esteban et al, Chest 2000;117:1690-1696
Why not PSV or PCV?

transpulmonary pressure = 45 cm H₂O

+20 cm H₂O PCV;
PEEP 10 cm H₂O;
Pplat 30 cm H₂O

-15 cm H₂O

Vₜ > 6 mL/kg — Active inspiratory effort

ARDS Network Study

- 800 patients with ALI/ARDS at 10 clinical centers throughout the United States
- Patients randomized to tidal volumes of 12 mL/kg or 6 mL/kg (volume-control, assist-control, Pplat ≤ 30 cm H₂O)
- 25% reduction in mortality in patients receiving smaller tidal volume
- Number-needed-to-treat: 12 patients with ALI/ARDS


How to Select PEEP?

- PEEP/FIO₂ relationship to maintain adequate PaO₂/SpO₂ (ARDSnet)
  - PaO₂ goal: 55 - 80 mm Hg or SpO₂ 88 - 95%; use FIO₂/PEEP combinations to achieve oxygenation goal:
    - FIO₂: 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0
    - PEEP: 5, 8, 10, 12, 14, 16, 18, 20, 22, 24
  - Maintain maximal lung recruitment (open lung approach): highest PaO₂ for lowest FIO₂

Open Lung Approach & Low Distending Pressure for ARDS

- Conventional approach: V₉ 12 mL/kg, volume control, PaCO₂ 25 - 38 mm Hg, PEEP as necessary to keep FIO₂ < 0.60
- New approach: V₉ < 6 mL/kg, pressure ventilation, PIP < 40 cm H₂O, permissive hypercapnia, high PEEP, recruitment maneuver

ALVEOLI
(assessment of low tidal volume and elevated end-expiratory volume to obviate lung injury)

- Compared two PEEP levels
- PEEP separation ≈6 cm H₂O (9 ± 3.5 vs. 14.6 ± 3.6 cm H₂O)
- Stopped early at 550 patients for futility
- No safety concerns

FIO₂
0.3 0.3 0.3 0.3 0.3 0.4 0.4 0.5 0.5 0.5 0.5 0.6 0.7 0.8 0.8 0.8 0.9 0.9 0.9 0.9 1.0

PEEP
5 8 10 12 14 16 18 20 22 24

FIO₂
0.3 0.3 0.3 0.4 0.4 0.5 0.5 0.5 0.6 0.6 0.6 0.7 0.7 0.8 0.8 0.8 0.9 0.9 0.9 0.9 1.0

PEEP
5 5 8 10 12 14 16 18 20 20 20 20 20 20 20 20 20 20 20 20 20 20
Best PEEP

- The “best PEEP” for recruitment may not be the “best PEEP” for the patient
- “Best PEEP” for recruitment may not be “Best PEEP” to avoid over-distention
- “Best PEEP” for the lungs may not be the “Best PEEP” for the patient
  - Hemodynamic effects
  - Renal perfusion effects
  - Cerebral perfusion effects

When all else fails ....

- Recruitment maneuvers
- Prone
- Inhaled nitric oxide
- High frequency oscillation

Unproven therapies; may improve gas exchange but effect on mortality unknown

Physiologic Benefits (PaO₂) vs Patient-Important Outcomes (Survival)

- For ARDS, inhaled nitric oxide improves PaO₂, but not mortality
  (Taylor et al, JAMA 2004;291:1603)
- High tidal volumes in patients with ARDS improves PaO₂, but mortality is lower for small tidal volumes
- For ARDS, prone position improves PaO₂, but not mortality
  (Gattinoni, N Engl J Med 2001;345:568)
Open Lung Approach & Low Distending Pressure for ARDS

- Conventional approach: $V_T$ 12 mL/kg, volume control, $\text{PaCO}_2$ 25 - 38 mm Hg, PEEP as necessary to keep $\text{FiO}_2 < 0.60$
- New approach: $V_T < 6$ mL/kg, pressure ventilation, PIP < 40 cm H$_2$O, permissive hypercapnia, high PEEP, recruitment maneuver

Amato, AJRCCM 1995; 152:1835-1846
Amato, NEJM 1998; 338:347-354

Recruitment Maneuver: Definition

Sustained increase in airway pressure with the goal to open collapsed lung tissue, after which PEEP is applied sufficient to keep the lungs open

CPAP 40 cm H$_2$O for 40 seconds

Medoff et al, Crit Care Med 2000; 28:1210

Before recruitment

After recruitment
ARDSnet Recruitment

- Multi-center crossover physiologic study of recruitment maneuver versus sham
- Recruitment maneuver: CPAP 35 to 45 cm H₂O for 30 s
- Changes in SpO₂ and FiO₂/PEEP step change recorded
- Response to recruitment maneuvers highly variable
- No significant difference in oxygenation for recruitment maneuvers and sham

<table>
<thead>
<tr>
<th>Step Change</th>
<th>After RM</th>
<th>After Sham</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Unchanged</td>
<td>41</td>
<td>49</td>
</tr>
<tr>
<td>Worse</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

Recruitment Maneuvers in ARDS

Grasso, Anesthesiology 2002; 96:795

Are Recruitment Maneuvers Safe?
Recruitment Maneuvers

Conclusion: “…recruitment maneuvers have no short-term benefit on oxygenation, and regional alveolar over-distention … may occur”

Villagra et al, Am J Respir Crit Care Med 2002; 165:165

A Recruitment Maneuver?

Severe abdominal distention  After 6 L abdominal fluid tap
**Prone and Patient Outcome**

- 304 patients randomized to prone versus supine
- Minimum 6 hrs per day in prone position
- No difference in complications for prone versus supine
- No overall mortality benefit for prone, but post-hoc analysis suggested potential benefit for the sickest patients


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**Post-Hoc Analysis**

_Courtesy of Dr. Luciano Gattinoni_

_N Engl J Med 2001; 345:568_
**NO: ARDS Applications**

- Phase 2 study: With 5 ppm inhaled NO, increased number of days alive and off ventilator at day 28 (post-hoc)  
  (Dellinger et al, Crit Care Med 1998;26:15)
- Phase 3 American trial: inhaled NO did not lead to a sustained improvement in PaO2 and did not affect outcome  
  (Taylor et al, JAMA 2004;291:1603)
- Phase 3 European trial: inhaled NO did not improve survival  
- NO did not lead to a sustained improvement in PaO2  
  (Michael et al, Am J Respir Crit Care Med 1998; 157:1380)
- NO improved gas exchange, but did not improve mortality  
  (Troncy et al, Am J Respir Crit Care Med 1998; 157:1483)

**Airway Pressure-Release Ventilation (APRV)**

- Produces alveolar ventilation as an adjunct to CPAP
- Allows spontaneous breathing at any time during the ventilator cycle
- Minimizes hazards of high airway pressure
- Decreased need for sedation
- Improved ventilation of dependant lung zones

**Spontaneous Breathing**

- During spontaneous breathing, the dependent part of the diaphragm has the greatest displacement
- Paralysis causes a cephalad shift of the end-expiratory position of the diaphragm (predominantly in the dependant region) and reverses the pattern of diaphragmatic displacement

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From, Anesthesiology 1974;41:242
Airway Pressure Release Ventilation (APRV)

PCV+ (BIPAP); Bilevel

High Frequency Oscillation

- High PEEP, avoid over-distention, clear CO₂
- Case series in adults have reported efficacy (improved oxygenation and ventilation with lower FIO₂)
- Technique appears safe in adults

Yeatts et al, Crit Care Med 1997; 25:937
Mehta et al, Crit Care Med 2001; 29:1360
Doldak et al, A/JRCCM 2002; 166:801
Are New Ventilator Modes Useful in ARDS?

The Evidence ....

Use Ventilation Strategies That Are Effective And

*Do No Harm*