Acute Respiratory Failure

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Respiratory Failure

Physiologic Definition:

Inability of the lungs to meet the metabolic demands of the body

Can't take in enough O₂
or
Can't eliminate CO₂ fast enough to keep up with production
**Respiratory Failure**

- Failure of Oxygenation: $P_aO_2<60$ mmHg
- Failure of Ventilation*: $P_aCO_2>50$ mmHg

*$P_aCO_2$ is directly proportional to alveolar minute ventilation

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### Acute Respiratory Failure

**Physiologic Classification**

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Type 1 Hypoxemic</th>
<th>Type 2 Hypercarbic</th>
<th>Type 3 Post-op</th>
<th>Type 4 Shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etiology</td>
<td>Shunt</td>
<td>↓ $Va$</td>
<td>Atelectasis</td>
<td>Cardiac Output</td>
</tr>
<tr>
<td>Clinical Setting</td>
<td>Airspace Flooding</td>
<td>Increased Respiratory load, Decreased ventilatory drive</td>
<td>Decreased FRC and increased Closing Volume</td>
<td>Decreased FRC and increased Closing Volume</td>
</tr>
<tr>
<td></td>
<td>Water, Blood or Pus filling alveoli</td>
<td>CNS depression, Bronchospasm, Stiff respiratory system, respiratory muscle failure</td>
<td>Abdominal surgery, poor inspiratory effort, obesity</td>
<td>Sepsis, MI, acute hemorrhage</td>
</tr>
</tbody>
</table>
Ventilatory Failure

*Inbalance between load on the lungs and the ability of bellows to compensate*

Acute Hypoxemic Respiratory Failure

- Shunt disease - intracardiac or intrapulmonary
- Severe V/Q mismatch - asthma, PE
- Venous admixture due to low cardiac output states, severe anemia coupled with shunt and/or V/Q mismatch
Acute Respiratory Distress Syndrome (ARDS)

Leaky alveolar capillaries
Plasma fluid and leukocytes leak into the airspace
Shunt
Hypoxemia
Acute Respiratory Distress Syndrome (ARDS)

American-European Consensus Definition:

- Refractory hypoxemia
  \[ \frac{P_aO_2}{F_2O_2} \text{ (P/F ratio)} \]
  <300 for ALI
  <200 for ARDS
- A disease process likely to be associated with ARDS
- No evidence of elevated left atrial pressure elevation (by clinical exam, echo or PA catheter)
- Bilateral airspace filling disease on X-ray


Acute Respiratory Distress Syndrome

Each year in the U.S.:

75,000-150,000 cases
Causes of ARDS

DIRECT LUNG INJURY
- Pneumonia
- Aspiration of gastric contents
- Pulmonary contusion
- Near-drowning
- Inhalation injury (Cl-, smoke)
- Reperfusion pulmonary edema after lung transplantation or pulmonary embolectomy

INDIRECT LUNG INJURY
- Non-pulmonary sepsis/SIRS
- Severe trauma with shock
- Cardiopulmonary bypass
- Drug overdose (Narcotics)
- Acute pancreatitis
- Transfusion (TRALI)
- Drug reaction (ARA-C, nitrofurantoin)
- fat/air/amniotic fluid embolism, bypass

The Normal Alveolus
ARDS

Fundamental Pathophysiology:

*Increased alveolar permeability due to direct neutrophil-mediated injury to the alveolar epithelium*

Not a distinct disease - rather a sequelae of activation of lung and systemic inflammatory pathways

Infiltration of the alveolar septum with neutrophils, macrophages, erythrocytes

Presence of hyaline membranes, and protein-rich edema fluid in the alveolar spaces, capillary injury, and disruption of the alveolar epithelium
Adapted from: A. Katzenstein

**Fibroliferative Phase**
- Increased dead space (CO2 retention)
- Decreased lung compliance, pulmonary HTN/right heart failure

**Exudative Phase**
- Rapid onset of respiratory failure, refractory hypoxemia, pulmonary edema on CXR (indistinguishable from CHF)

**Fibroliferative Phase**
- Fibroangiolitis
- Increased dead space (CO2 retention)
- Decreased lung compliance, pulmonary HTN/right heart failure
Optimal V/Q matching

Shunt
Severe Hypoxemia

Therapeutic Goals

Maintain reasonable oxygen delivery

Find & fix the primary cause
FRC can be reduced by 80% or more in ARDS

ARDS Network Trial

Day 1 Ventilatory Characteristics

<table>
<thead>
<tr>
<th>Low Vt Group</th>
<th>Traditional Vt Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=432</td>
<td>n=429</td>
</tr>
<tr>
<td>Vt: 6.2 ± 0.9</td>
<td>11.8 ± 0.8</td>
</tr>
<tr>
<td>PEEP: 9.4 ± 3.6</td>
<td>8.6 ± 3.6</td>
</tr>
<tr>
<td>F_{1}O_{2}: 0.56 ± 0.19</td>
<td>0.51 ± 0.17</td>
</tr>
<tr>
<td>P_{plat}: 25.7 ± 7</td>
<td>33 ± 9</td>
</tr>
<tr>
<td>P_{peak}: 32.8 ± 8</td>
<td>39 ± 10</td>
</tr>
<tr>
<td>P_{a}O_{2} / F_{1}O_{2}: 158 ± 73</td>
<td>176 ± 76</td>
</tr>
<tr>
<td>P_{c}CO_{2}: 40 ± 10</td>
<td>35 ± 8</td>
</tr>
<tr>
<td>pH: 7.38 ± 0.08</td>
<td>7.41 ± 0.07</td>
</tr>
</tbody>
</table>

NEJM 342:1301-1308, 2000
ARDS Network Trial

Mortality: 39.8% in traditional tidal volume group, 31% in low tidal volume group (P=0.007)

Also: @ 28 days: more ventilator free days (12 vs. 10), more days without organ failure (15 vs 12), higher rate of liberation from ventilation rate (65.7% vs 55%)
What happens to alveoli in ARDS?

- Edema accumulates in alveoli
- Diluting & disaggregating surfactant
- Surface tension increases

Alveoli collapse

Alveolar collapse decreases FRC and contributes to hypoxemia
Positive End-Expiratory Pressure (PEEP)

- **Beneficial Effects**
  - Increases FRC, CI, PaO₂
  - Recruits Atelectatic Units
  - Decreases Qs/Qt
  - Allows Reduction in F₁O₂

- **Detrimental Effects**
  - Volutrauma
    - Alveolar Overdistention
  - Hemodynamic Derangements
PEEP

Oxygen is:
- A) good for you
- B) bad for you
- C) all of the above

$F_O^2 > 0.6$ for 24 hours or more may cause lung injury

PEEP recruits collapsed alveoli,
improves FRC and
improves oxygenation

An essential therapy for patients with ARDS

ARDS Network Trial

Assist Control
$V_t$ 6 cc/kg ideal body weight
PEEP of $\approx 8-10$
Generally not due to respiratory failure

Does Mechanical Ventilation Contribute to MSOF?


Controls (n=19): Rate 10-15 bpm, V, targeted to maintain PaCO₂ 35-40 mmHg (mean: 11 ml/kg), PEEP titrated to SaO₂ (mean: 6.5), Pplat maintained <35 cmH₂O

Lung protective ventilation (n=18): Rate 10-15 bpm, V, targeted to keep Pplat less than upper inflexion point (mean: 7 ml/kg), PEEP 2-3 cmH₂O above LIP (mean: 14.8)

Plasma and BALF levels of IL-1β, IL-6, IL-8, TNFα, TNFα-sr 55, TNFα-sr 75, IL-1ra, measured within 8 hrs of intubation and again @24-30 hours & 36-40 hours after entry

Significant Reductions of:

- TNF-α
- %Neutrophils
- IL-1β
- IL-8
- IL-6
- Soluble TNFα Receptor 55 & 75
- IL-1 Receptor Antagonist

Mechanical ventilation can induce a cytokine response that may cause or contribute to multiple organ system failure.

The lung is not just an innocent bystander - it functions as an immunomodulatory organ that may participate in the systemic inflammatory response that leads to multiple organ system dysfunction syndrome.

Biotrauma
Goals for Management of ARDS

The American-European Consensus Conference on ARDS, Part 2

• Ensure appropriate $O_2$ delivery to vital organs
• Minimize oxygen toxicity/tolerate mediocre ABG's
• Reduce edema accumulation
• Minimize airway pressures
• Prevent atelectasis/Recruit alveoli
• Use sedation and paralysis judiciously


Survival from “pure” ARDS

1979: 20-50%
2002: 50-90%