How ARDS should be treated in 2017

2017, Ostrava

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1. Keep the patient alive  
   \begin{itemize}
     \item respiration
     \item circulation
   \end{itemize}

2. Cure the disease leading to the syndrome

3. Don’t add damage  
   \begin{itemize}
     \item lung
     \item body
   \end{itemize}

4. Provide the best environment for lung healing (???)
Aim of the respiratory support

To buy time with \textit{minimal} damage

Damaging factors

Lung
- Baby lung size
- Homogeneity
- Recruitability

Ventilator
- Mechanical power
VILI comes from a Small, inhomogeneous, recruitable lung.
# Acute Respiratory Distress Syndrome

## The Berlin Definition

The ARDS Definition Task Force*

<table>
<thead>
<tr>
<th>Timing</th>
<th>Within 1 week of a known clinical insult or new/worsening respiratory symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest Imaging</td>
<td>Bilateral opacities – not fully explained by effusions, lobar/lung collapse, or nodules</td>
</tr>
<tr>
<td>Origin of Edema</td>
<td>Respiratory failure not fully explained by cardiac failure or fluid overload; Need objective assessment (e.g., echocardiography) to exclude hydrostatic edema if no risk factor present</td>
</tr>
</tbody>
</table>

### Oxygenation

<table>
<thead>
<tr>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>$200 &lt; \frac{\text{PaO}_2}{\text{FiO}_2} \leq 300$ with PEEP or CPAP $\geq 5$ cmH$_2$O$^c$</td>
<td>$100 &lt; \frac{\text{PaO}_2}{\text{FiO}_2} \leq 200$ with PEEP $\geq 5$ cmH$_2$O</td>
<td>$\text{PaO}_2/\text{FiO}_2 \leq 100$ with PEEP $\geq 5$ cmH$_2$O</td>
</tr>
</tbody>
</table>

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*胸片或CT扫描

*如果海拔高于1000米，应根据以下公式进行修正：$\frac{\text{PaO}_2}{\text{FiO}_2} \times (\text{大气压}/760)$

*这可能在轻症ARDS组非侵入性地提供

---

MILD

P/F

0
40
80
120
160
200
240
280
320

PEEP

P/F

0
40
80
120
160
200
240
280
320

PEEP

SEVERE

P/F

0
40
80
120
160
200
240
280
320

PEEP

PEEP 5 cmH\textsubscript{2}O
Clinical PEEP

Caironi, et al. CCM 2015
Baby lung
**Baby Lung**  
*(1987)*

CT numbers frequency (%)

CT numbers (Hounsfield Units)

- Hyperinflated
- Normally aerated
- Poorly aerated
- Non aerated

Normal

ARDS
Inhomogeneity
Voxel $V_{\text{gas}}$

Gas fraction $= V_{\text{gas}0}/V_{\text{voxel}}$

Weighted gas ratio $= V_{\text{gas}1}/V_{\text{gas}0} \times \text{fraction of tissue}$
Average ratio in normal subjects: 1.37 ± 0.15
Ki/lung inhomogeneity interaction and gas/tissue composition

MILD

MODERATE

SEVERE
Recruitability
Morphological response (1986)

5 cm H₂O
PaO₂: 97 mm Hg
d. 59%

10 cm H₂O
PaO₂: 103 mm Hg
d. 56%

15 cm H₂O
PaO₂: 104 mm Hg
d. 53%

5 cm H₂O
PaO₂: 34 mm Hg
d. 70%

10 cm H₂O
PaO₂: 49 mm Hg
d. 52%

15 cm H₂O
PaO₂: 121 mm Hg
d. 32%

Potential for recruitment $\approx 100\%$

Inflation/Recruitment (2001)  

Potential for recruitment 5%

5 patients, ALI / ARDS

Recruitment and inflation %

Paw [cmH$_2$O]

Crotti et al. Am J Respir Crit Care Med 2001;
Potential for lung recruitment

5 ± 4%
(59 ± 51 grams)
lower

21 ± 10%
(374 ± 236 grams)
higher

Figure 1

ALI patients
ARDS patients

Opening Pressures

Recruited lung tissue (g)

Pressure (cmH\textsubscript{2}O)

Mild ARDS (N=5)
Moderate ARDS (N=19)
Severe ARDS (N=19)

Plateau pressure limit

Courtesy of dr. Cressoni M.
Aim of the respiratory support

To buy time with minimal damage

Damaging factors

Lung
- Baby lung size
- Homogeneity
- Recruitability

Ventilator
- Mechanical power
VILI comes from Excessive power
Time course of ventilator induced lung injury

Transpulmonary pressure (PL cmH\(_2\)O)

Strain

% Total Lung Capacity

Resting

Biotrauma

Stress at rupture

 Specific Lung Elastance
~12 (cmH\(_2\)O)

Agostoni, Mead, Weibel, Gattinoni
Stress-strain curve of healthy pigs

Specific Lung Elastance 5.8 cmH₂O

Mechanical ventilation and VILI

1. Volume

2. Pressure

3. Respiratory Rate

4. Flow

5. Or???
EXAMPLES OF ENERGY COMPUTATIONS AT DIFFERENT PRESSURES
Motion equation

Total pressure

\[(E_{rs} \cdot \Delta V) + (R_{aw} \cdot F) + PEEP\]

- Distend the lung
- Move the gas
- Keep open
Mechanical Power

Total pressure \cdot \Delta V \cdot RR

\[
\text{Power}_{rs} = 0.098 \cdot RR \cdot \left\{ \Delta V^2 \cdot \left[ \frac{1}{2} \cdot E_{rs} + RR \cdot \frac{(1 + I:E)}{60 \cdot I:E} \cdot R_{aw} \right] + \Delta V \cdot PEEP \right\}
\]

- Distend the lung
- Move the gas
- Keep open

TIME \times ENERGY
Contributions to Power generation

Baseline values
- RR: 20
- TV (L): 0.400
- Ers: 25
- I:E: 0.5
- Raw: 10
- PEEP: 10
- Power\textsubscript{rs}: 14.90
Summary

❖  TV  →  Power ²
❖  ΔP_{aw}  →  Power ²
❖  RR  →  Power ¹.₆
❖  PEEP  →  Power ¹
Interaction
Excessive power comes from small, inhomogeneous, recruitable lung.
Chest wall elastance

"Soft"  "Soft"

25  5  cmH₂O

15  15
Slope $P_L/P_{aw} = E_w/E_{tot} \ [0.2 - 0.8]$

Chiumello et al, Am J Respir Crit Care Med. 2008
Always consider:

\[ V_T \]

Baby lung size
The ARDS lung is small and not stiff

**Normal**
\[
\frac{V_T}{FRC} = \frac{500 \text{ ml}}{2500 \text{ ml}} = 0.2
\]

**ARDS**
\[
\frac{V_T}{FRC} = \frac{500 \text{ ml}}{500 \text{ ml}} = 1
\]
Always consider:

The lung inhomogeneity

- Stress raisers
- Atelectrauma
Lung expansion/gas-free state

\[ \text{STRESS RAISER} = \left(\frac{10}{1}\right)^{2/3} = 4.64 \]

# Lung dishomogeneity and ARDS

<table>
<thead>
<tr>
<th></th>
<th>Mild (N=82)</th>
<th>Moderate (N=71)</th>
<th>Severe (N=12)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dishomogeneity</td>
<td>1.49 ± 0.17</td>
<td>1.58 ± 0.29</td>
<td>1.75 ± 0.41</td>
<td>0.03</td>
</tr>
<tr>
<td>Dishomogeneity&lt;sup&gt;2/3&lt;/sup&gt;</td>
<td>1.30 ± 0.31</td>
<td>1.36 ± 0.44</td>
<td>1.45 ± 0.55</td>
<td></td>
</tr>
<tr>
<td>Extent</td>
<td>0.3 ± 0.1</td>
<td>0.36 ± 0.16</td>
<td>0.46 ± 0.18</td>
<td>0.01</td>
</tr>
<tr>
<td>Intensity</td>
<td>2.69 ± 0.27</td>
<td>2.76 ± 0.27</td>
<td>2.84 ± 0.41</td>
<td>0.31</td>
</tr>
<tr>
<td>Intensity&lt;sup&gt;2/3&lt;/sup&gt;</td>
<td>1.93 ± 0.42</td>
<td>1.97 ± 0.42</td>
<td>2.01 ± 0.55</td>
<td></td>
</tr>
</tbody>
</table>

*Am J Respir Crit Care Med. 2014 Jan 15;189(2):149-58*
The gas/tissue ratio as a function of lung height

2013 Jun 6;368(23):2159-68

**Gattinoni L. et al. Minerva Anestesiol.**
2010 Jun;76(6):448-54

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**PROSEVA STUDY**

- **Cumulative Probability of Survival**
  - **Prone group**
  - **Supine group**

Log-rank $< 0.001$

- **Time (Days since randomization)**

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**POOLED ANALYSIS**

- **Severly-hypoxaemic pooled population**

Log-rank = 0.03

- **Time (Days since randomization)**

---

**No. at Risk**

<table>
<thead>
<tr>
<th></th>
<th>Prone</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>237</td>
<td>229</td>
</tr>
<tr>
<td>202</td>
<td>163</td>
<td></td>
</tr>
<tr>
<td>191</td>
<td>150</td>
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<td>186</td>
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<tr>
<td>54</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>
Atelectrauma
Opening and closing (1995)
Plateau Pressure (cmH$_2$O)

<table>
<thead>
<tr>
<th>PEEP (cmH$_2$O)</th>
<th>End Expiration</th>
<th>End Inspiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21 ± 1.8</td>
<td>31 ± 1.8</td>
</tr>
<tr>
<td>5</td>
<td>26 ± 1.4</td>
<td>38 ± 2.1</td>
</tr>
<tr>
<td>10</td>
<td>31 ± 1.8</td>
<td>46 ± 3.2</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
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</table>

Recruitment-Pressure curve

Opening-closing

Recruited tissue

Pressure

5 15 25 35
Lung protective strategy

Less energy +

More homogeneous lung