Lung Recruitment in
ALI/ARDS

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JRUR, Marseille, France, 2012
AGENDA

- ARDS: principles of treatment
- Recruitment in ARDS:
  - The rationale
  - Experimental data
  - “New” recruitment manoeuvres
- Clinical data
- Recruitment and prone position
- How to set PEEP after Recruitment
- Conclusions
The ARDS Lung


**Superimposed Pressure**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Opening Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0</td>
</tr>
<tr>
<td>Small Airway Collapse</td>
<td>10-20 cmH₂O</td>
</tr>
<tr>
<td>Alveolar Collapse (Reabsorption)</td>
<td>20-30 cmH₂O</td>
</tr>
<tr>
<td>Consolidation</td>
<td>∞</td>
</tr>
</tbody>
</table>

Rouby Intensive Care Med 2000
EDEMA – ATELECTASIS IN ALI/ARDS

LESS EDEMA-ATELECTASIS
LOWER PEEP – LOWER MORTALITY

P = 5 cmH2O

HIGHER EDEMA-ATELECTASIS
HIGHER PEEP – HIGHER MORTALITY

P = 10 cmH2O

\[ \rho \times g \times h \]
<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Timing</strong></td>
<td>Acute onset within 1 week of a known clinical insult or new/worsening respiratory symptoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hypoxemia</strong></td>
<td>PaO₂/FiO₂ 201-300 with PEEP/CPAP ≥ 5</td>
<td>PaO₂/FiO₂ ≤ 200 with PEEP ≥ 5</td>
<td>PaO₂/FiO₂ ≤ 100 with PEEP ≥ 10</td>
</tr>
<tr>
<td><strong>Origin of Edema</strong></td>
<td>Respiratory failure not fully explained by cardiac failure or fluid overload**</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Radiological Abnormalities</strong></td>
<td>Bilateral opacities*</td>
<td>Bilateral opacities*</td>
<td>Opacities involving at least 3 quadrants*</td>
</tr>
<tr>
<td><strong>Additional Physiological Derangement</strong></td>
<td>N/A</td>
<td>N/A</td>
<td>Vₑ Corr &gt; 10 L/min or Cₛ&lt;40 ml/cmH₂O</td>
</tr>
</tbody>
</table>

*Not fully explained by effusions, nodules, masses, or lobar/lung collapse; use training set of CXRs

**Need objective assessment if no risk factor present (See table)

\[
Vₑ Corr = Vₑ \times \frac{PaCO₂}{40}
\]
Low Tidal Volume Ventilation

Increasing Intensity of Intervention

Low - Moderate PEEP

NIV

Higher PEEP

Low Tidal Volume Ventilation

Increasing Severity of Lung Injury

Mild ARDS

Moderate ARDS

Severe ARDS

PaO₂/FiO₂
We suggest recruitment maneuvers in patients with severe refractory hypoxemia (Grade 2C).
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- Conclusions
The concept of PEEP and Recruitment

Recruitment in ALI/ARDS?

WHY NOT?

• Improves oxygenation
• Improves respiratory mechanics
• Increases lung volume/reduces atelectasis
• Not associated with major adverse effects

WHEN?

• Before PEEP setting
• After dysconnection from MV or suctioning
• Rescue manoeuvre

Recruitment Maneuvers for Acute Lung Injury: A Systematic Review

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Recruitment maneuver in experimental acute lung injury: the role of alveolar collapse and edema


ALI-M with the same alveolar collapse but less edema compared to ALI-S
Hypervolemia induces and potentiates lung damage after RM in a model of sepsis-induced ALI

Silva PL et al. Critical Care 2010, 14:R114
Effects of pressure profile and duration of RM on lung morpho-functional and biological impact in experimental lung injury

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“New” recruitment Maneuvres:
Assisted Ventilation
Sigh
Variable Ventilation
Ventilator Induced Lung Injury

Effects of frequency and inspiratory plateau pressure during recruitment manoeuvres on lung and distal organs in acute lung injury

Variable VTs improve different lung protective ventilation strategies in experimental ALI

Spieth PM et al Am J Respir Crit Care Med 2009 15;179(8):684-93
Variable VTs improve different lung protective ventilation strategies in experimental ALI

Spieth PM et al Am J Respir Crit Care Med 2009 15;179(8):684-93
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Recruitment Maneuvers for Acute Lung Injury: A Systematic Review


Hypotension
Desaturation
Respiratory and hemodynamic changes during decremental open lung PEEP titration in ARDS

Gernoth W et al Critical Care 2009, 13:R59; Epub 2009 Apr 17

Right ventricular Tei index [%]

Before

39±11

During RM

42±10

After

36±11
Peep 5 cmH₂O

Paw 45cmH₂O

Gattinoni et al. NEJM 2006, 354(17):1775-86

Non recruiter

Weight (grams)
Potential for lung recruitment

Gattinoni et al NEJM 2006, 354(17):1775-86

5 ± 4%
(59 ± 51 grams)
lower

21 ± 10%
(374 ± 236 grams)
higher

ALI patients

ARDS patients

frequency [no. of patients]

potential for lung recruitment [% total lung weight]
Recruitment is a function of lung weight

Gattinoni et al NEJM 2006, 354(17):1775-86
Mortality at ICU-discharge

Gattinoni et al NEJM 2006, 354(17):1775-86

lower-potential

higher-potential

mortality [%]

<table>
<thead>
<tr>
<th>Quartile</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>17</td>
</tr>
<tr>
<td>2nd</td>
<td>17</td>
</tr>
<tr>
<td>3rd</td>
<td>17</td>
</tr>
<tr>
<td>4th</td>
<td>17</td>
</tr>
</tbody>
</table>

n = 17

P = 0.006

quartiles of potential for lung recruitment
How large is the lung recruitability in early ARDS: a prospective case series of patients monitored by CT

De Matos GFJ et al Critical Care 2012, 16:R4

- Less than 72 hours onset
- PaO2/FIO2 < 200, with PEEP ≥ 10 cmH2O, FIO2 of 1.0 and pressure-controlled ventilation with driving pressure set at 15 cmH2O
How large is the lung recruitability in early ARDS: a prospective case series of patients monitored by CT

De Matos GFJ et al Critical Care 2012, 16:R4
How large is the lung recruitability in early ARDS: a prospective case series of patients monitored by CT

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How large is the lung recruitability in early ARDS: a prospective case series of patients monitored by CT

De Matos GFJ et al Critical Care 2012, 16:R4
Optimal duration of a sustained inflation recruitment maneuver in ARDS patients

Arnal JM et al Intensive Care Med (2011) 37:1588–1594
Optimal duration of a sustained inflation recruitment maneuver in ARDS patients

Arnal JM et al Intensive Care Med (2011) 37:1588–1594

A 10-s sustained inflation RM may be recommended to achieve a plateau in the volume recruited and to prevent hemodynamic compromise.
Prolonged moderate pressure recruitment manoeuvre results in lower optimal PEEP and plateau pressure

Prolonged moderate pressure recruitment manoeuvre results in lower optimal PEEP and plateau pressure

Randomised controlled trial of an open lung strategy with staircase recruitment, titrated PEEP and targeted low airway pressures in patients with ARDS

Hodgson et al. Critical Care 2011, 15:R133

<table>
<thead>
<tr>
<th></th>
<th>PHARLAP</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number in group</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Male, number</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Age, years</td>
<td>60 ± 5</td>
<td>58 ± 4</td>
</tr>
<tr>
<td>APACHE 2 score</td>
<td>20.1 ± 3</td>
<td>20.1 ± 2</td>
</tr>
<tr>
<td>APACHE 3 score</td>
<td>66.3 ± 8</td>
<td>64.8 ± 7</td>
</tr>
<tr>
<td>SOFA score</td>
<td>8.6 ± 0.9</td>
<td>8.4 ± 0.5</td>
</tr>
<tr>
<td>PaO₂/FiO₂, mmHg</td>
<td>155 ± 8</td>
<td>149 ± 12</td>
</tr>
<tr>
<td>Diagnostic group</td>
<td>5 pneumonia</td>
<td>6 pneumonia</td>
</tr>
<tr>
<td></td>
<td>2 AAA</td>
<td>2 AAA</td>
</tr>
<tr>
<td></td>
<td>1 necrotising fascitis</td>
<td>1 burn</td>
</tr>
<tr>
<td></td>
<td>2 trauma</td>
<td>1 sepsis</td>
</tr>
<tr>
<td>Static lung compliance, ml/cm H₂O</td>
<td>45.8 ± 5.4</td>
<td>37.3 ± 5.4</td>
</tr>
<tr>
<td>PEEP, cm H₂O</td>
<td>11.8 ± 0.7</td>
<td>14.2 ± 1.2</td>
</tr>
</tbody>
</table>
Randomised controlled trial of an open lung strategy with staircase recruitment, titrated PEEP and targeted low airway pressures in patients with ARDS

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Hodgson et al. Critical Care 2011, 15:R133
Randomised controlled trial of an open lung strategy with staircase recruitment, titrated PEEP and targeted low airway pressures in patients with ARDS

Hodgson et al. Critical Care 2011, 15:R133
Clinical efficacy and safety of recruitment maneuver in patients with acute respiratory distress syndrome using low tidal volume ventilation: a multicenter randomized controlled clinical trial


<table>
<thead>
<tr>
<th>Characteristics</th>
<th>RM group (n=55)</th>
<th>Control group (n=55)</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>62.2±16.0</td>
<td>65.5±15.2</td>
<td>0.28</td>
</tr>
<tr>
<td>Male (n (%))</td>
<td>38 (69.1)</td>
<td>40 (72.7)</td>
<td>0.68</td>
</tr>
<tr>
<td>APACHE II score</td>
<td>21.5±6.7</td>
<td>23.1±8.6</td>
<td>0.28</td>
</tr>
<tr>
<td>Tidal volume (ml/kg of PBW)</td>
<td>6.6±0.9</td>
<td>6.8±1.1</td>
<td>0.39</td>
</tr>
<tr>
<td>PEEP (cmH$_2$O)</td>
<td>10.5±3.2</td>
<td>9.7±2.4</td>
<td>0.18</td>
</tr>
<tr>
<td>Ppeak (cmH$_2$O)</td>
<td>28.0±5.9</td>
<td>27.9±6.8</td>
<td>0.94</td>
</tr>
<tr>
<td>Pplat (cmH$_2$O)</td>
<td>24.2±5.3</td>
<td>23.4±5.3</td>
<td>0.47</td>
</tr>
<tr>
<td>Respiratory rate (breaths/min)</td>
<td>27.3±8.0</td>
<td>26.5±9.1</td>
<td>0.39</td>
</tr>
<tr>
<td>PaO$_2$/FiO$_2$</td>
<td>93.8 (68.7–150.0)</td>
<td>120.0 (88.3–140.0)</td>
<td>0.06</td>
</tr>
<tr>
<td>Causes of ARDS (n (%))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pneumonia</td>
<td>19 (34.5)</td>
<td>17 (30.9)</td>
<td></td>
</tr>
<tr>
<td>Aspiration</td>
<td>6 (10.9)</td>
<td>4 (7.3)</td>
<td></td>
</tr>
<tr>
<td>Sepsis</td>
<td>7 (12.7)</td>
<td>16 (29.1)</td>
<td></td>
</tr>
<tr>
<td>Trauma</td>
<td>2 (3.6)</td>
<td>3 (5.5)</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>21 (38.2)</td>
<td>15 (27.3)</td>
<td></td>
</tr>
</tbody>
</table>
Clinical efficacy and safety of recruitment maneuver in patients with acute respiratory distress syndrome using low tidal volume ventilation: a multicenter randomized controlled clinical trial


AND Less organ failure at day 28th
Brazil
-Hospital das Clínicas, Dr. Marcelo Amato

Chile
-Clinica Alemana de Santiago, Dr. Vinko Tomicic

Korea
-Asan Medical Center, Ulsan College of Medicine, Dr. Younsuck Koh

Japan
-Tokushima University Hospital, Dr. Masaji Nishimura

Spain
-Hospital Fundacion Jimenez-Diaz, Dr. Fernando Suarez-Sipmann
-Hospital Clinico Universitario de Valencia, Dr. Javier Belda
-Hospital de Leon, Dr. Demetrio Carriedo
-Hospital Universitario Ntra. Sra. de Candeleria, Dr. Santiago Lubillo
-Hospital Universitario Rio Hortega, Dr. Jesus Blanco
-Hospital Morales Meseguer, Dr. Gumersindo Gonzalez
-Hospital Clinic de Barcelona, Dr. Elizabeth Zavala
-Hospital Universitario La Paz, Dr. Julia Lopez
-Hospital Universitario Txagorritxu, Dr. Nela Hernandez
-Hospital Virgen de la Salud, Dr. Maria del Mar Cruz Acquaroni
-Hospital Universitario Virgen de la Arrixaca, Dr. Domingo Martinez
-Hospital Virgen de la Luz, Dr. Juan Bautista Araujo
-Hospital Universitario de Valencia, Federico Aguar
-Hospital Galdakano, Dr. Higinio Martin
-Hospital de Navarra, Dr. Juan Pedro Tirapu
-Consortio Hospitalario de Mauresa, Dr. Rafael Fernandez
-Hospital Donostia, Dr. Pilar Marco
-Hospital Universitario Juan Canalejo, Dr. Miguel A. Solla
-Hospital Universitario Santiago de Compostela, Dr. Valentín Carneze

Peru
-Hospital Nacional Edgardo Rebagliati Martins, Dr. Rollin Roldán Mori

USA
-Massachusetts General Hospital, Dr. Robert Kacmarek
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Focal loss of areation

Diffuse loss of areation
Prone Position Augments Recruitment and Prevents Alveolar Overinflation in Acute Lung Injury

Eftichia Galiatsou, Eleonora Kostanti, Eugenia Svarna, Athanasios Kitsakos, Vasilios Koulouras, Stauros C. Efremidis, and Georgios Nakos
Lung recruitment: More normally aerated zones
Lung recruitment: No more non aerated zones

Nougaret et al, in progress
Sigh in supine and prone during ARDS

Pelosi P et al Am J Respir Crit Care Med 2003; 167: 521-527
Prone position and recruitment manoeuvre: the combined effect improves oxygenation

Rival G et al. Critical Care 2011, 15:R125
Prone position and recruitment manoeuvre: the combined effect improves oxygenation

Rival G et al. Critical Care 2011, 15:R125

<table>
<thead>
<tr>
<th>Gas exchanges</th>
<th>Time 0</th>
<th>Time 1 (RM1)</th>
<th>Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.37 ± 0.08</td>
<td>7.37 ± 0.07</td>
<td>7.40 ± 0.08b</td>
</tr>
<tr>
<td>PaO₂, mmHg</td>
<td>75.6 ± 19</td>
<td>85.4 ± 28</td>
<td>94.5 ± 39</td>
</tr>
<tr>
<td>PaCO₂, mmHg</td>
<td>39 ± 7</td>
<td>39 ± 7.7</td>
<td>35 ± 7.4l</td>
</tr>
<tr>
<td>PaO₂/FiO₂ ratio, mmHg</td>
<td>98.3 ± 28</td>
<td>111.4 ± 41.2</td>
<td>123 ± 52.3</td>
</tr>
</tbody>
</table>
Prone position and recruitment manoeuvre: the combined effect improves oxygenation

Rival G et al. Critical Care 2011, 15:R125

<table>
<thead>
<tr>
<th>Gas exchanges</th>
<th>Time 4 (RM2)</th>
<th>Time 5</th>
<th>Time 6 (RM3)</th>
<th>Time 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.39 ± 0.08</td>
<td>7.43 ± 0.08(^d)</td>
<td>7.40 ± 0.09</td>
<td>7.47 ± 0.08(^e)</td>
</tr>
<tr>
<td>PaO(_2), mmHg</td>
<td>117 ± 63</td>
<td>138 ± 77</td>
<td>138.6 ± 70</td>
<td>171.5 ± 84(^g)</td>
</tr>
<tr>
<td>PaCO(_2), mmHg</td>
<td>37 ± 8.4</td>
<td>35 ± 7.7(^k)</td>
<td>36.4 ± 8.4</td>
<td>31.5 ± 8.4(^l)</td>
</tr>
<tr>
<td>PaO(_2)/FiO(_2) ratio, mmHg</td>
<td>151.2 ± 75.7</td>
<td>178 ± 99</td>
<td>177 ± 75</td>
<td>218.2 ± 99.5(^n)</td>
</tr>
</tbody>
</table>
Prone position: CO$_2$ and Survival

Gattinoni et al Crit Care Med 2003;31:2727
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Oxygenation and collapsed tissue

Borges et al. Am J Respir Crit Care Med 174; 268-278, 2006

\[
\text{PaO}_2 / \text{FiO}_2 < 150 \text{ at PEEP } 5 \text{ cmH}_2\text{O}
\]
Assessment of Pulmonary Morphology in ALI
Absence of Lower Inflection Point in the P-V Curve

Assessment of Pulmonary Morphology in ALI
Significance of Lower Inflection Point in the P-V Curve
Elastance to titrate PEEP in ALI/ARDS

The stress index: is it useful to set TV?

PEEP-induced changes in lung volume in ARDS. Two methods to estimate alveolar recruitment

Probes

- Curvilinear probe
- Probe 5-10 MHz Lung periphery
- Probe 4-5 MHz Deep Lung
- Phased array probe 3 MHz
  Hemodynamic monitoring
- Linear probe 7.5 MHz
  Vascular application
- Convex probe 3.5 MHz
  Lung and hemodynamic applications

Image quality
1 to 17 cm
Lung imaging for titration of mechanical ventilation
The role of lung ultrasound

Luecke T, Corradi F, Pelosi P  Curr Opinion in Anaesthesiology, 2011 ( Ahead of Print)
Lung imaging for titration of mechanical ventilation
The role of lung ultrasound

Luecke T, Corradi F, Pelosi P  Curr Opinion in Anaesthesiology, 2011 (Ahead of Print)
Bedside Ultrasound Assessment of PEEP–induced Lung Recruitment


(A) PEEP-induced Lung Recruitment (ml)

\[ \text{rho} = 0.88; \ p < 0.0001 \]

(C) PEEP-induced Change in PaO\(_2\) (%)

\[ \text{rho} = 0.63; \ p < 0.05 \]
LUNG ULTRASOUND PROTOCOL

Pelosi P, Corradi F
Anesthesiology 2012 (Ahead of Print)
How to perform a PEEP trial in most severe ARDS patients?

PEEP to achieve the “best” Cst,rs

$V_T \ 6 \text{ ml/Kg IBW}$

How to perform a PEEP trial in most severe ARDS patients?

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Use of computed tomography scanning to guide lung recruitment and adjust PEEP in ALI/ARDS

Thanks

Royal Library, British Museum, London, UK