ARDS
Measuring Respiratory Mechanics and Esophageal Pressure
Laurent Brochard
Toronto
Conflicts of interest

• Our clinical research laboratory has received research grants for clinical research projects from the following companies:
  – Maquet (NAVA)
  – Covidien (PAV+)
  – Air Liquide (Helium, CPR)
  – General Electric (FRC)
  – Philips (Sleep)
  – Fisher Paykel (Optiflow)
Background

• Mechanical factors appear to be the most relevant modifiable factors which can influence mortality in ARDS

• The “Baby lung” concept
Fifty Years of Research in ARDS
Respiratory Mechanics in Acute Respiratory Distress Syndrome

William R. Henderson¹, Lu Chen²,³, Marcelo B. P. Amato⁴, and Laurent J. Brochard²,³
Relationship between ventilatory settings and barotrauma in the acute respiratory distress syndrome
The “baby lung” became an adult

Fig. 1 A representative CT scan image of an ARDS patient showing that the ARDS lung can be modeled in one nearly normal region (having dimensions similar to those of a healthy baby) and a gasless region
Palv ≈ static Paw (at zero flow)
Prs = Paw – Pbs
P_L = Paw – Ppl
P_CW = Ppl - Pbs
$P_{tp} = P_{ao} - P_{pl} = 25 \text{ cm H}_2\text{O}$

$P_{tp} = P_{ao} - P_{pl} = 15 \text{ cm H}_2\text{O}$
PEEP = 10 cm H2O

\[ P_{tp} = P_{ao} - P_{pl} = \text{PEEPL} = 5 \text{ cm H2O} \]

\[ P_{tp} = P_{ao} - P_{pl} = \text{PEEPL} = -5 \text{ cm H2O} \]
Henderson, Chen L et al, AJRCCM 2017
Fifty Years of Research in ARDS
Respiratory Mechanics in Acute Respiratory Distress Syndrome

William R. Henderson\textsuperscript{1}, Lu Chen\textsuperscript{2,3}, Marcelo B. P. Amato\textsuperscript{4}, and Laurent J. Brochard\textsuperscript{2,3}
Pigs

Non-dependent sensor
Esophageal (absolute)

Dependent sensor

Expiratory Transpulmonary Pressure (cmH$_2$O)

PEEP (cmH$_2$O)

Yoshida and Grieco, manuscript submitted
Human cadavers

PEEP12

Expiratory Transpulmonary Pressure (cmH$_2$O)

Non-dependent sensor
Esophageal (absolute)
Dependent sensor

Yoshida and Grieco, manuscript submitted
End-expiratory absolute values

- Vertebral Pleural pressure
- Esophageal pressure
- Sternal Pleural pressure

Graph showing the comparison of pressures in dependent and non-dependent regions between supine and prone positions.
Transpulmonary plateau pressure calculated by elastance ratio

\[ PL = \text{Paw} \times \frac{\text{EL}}{\text{ERS}} \]
Elastance-derived $P_{L, plat}$ and 30-Day outcome (N=61)

**a**

$P_{L, plat}$ (cmH$_2$O)

- Survivors (N=42)
- Non-Survivors (N=19)

$P = 0.031$

**b**

30-day Mortality Rate (%)

- $\leq 20$ (N=29)
- $> 20$ (N=32)
What about spontaneous breathing?

15 cmH\textsubscript{2}O of peak transpulmonary swing (ΔPL) as an upper limit during spontaneous breathing

Yoshida AJRCCM 2013
Chen ATS 2015
Kassis ICM 2016
Yoshida AJRCCM 2017
Extremely high transpulmonary pressure in a spontaneously breathing patient with early severe ARDS on ECMO

Tommaso Mauri¹, Thomas Langer², Alberto Zanella¹, Giacomo Grasselli¹ and Antonio Pesenti¹,²* ID

<table>
<thead>
<tr>
<th>Volume</th>
<th>Pressure</th>
</tr>
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<tbody>
<tr>
<td>controlled</td>
<td>support</td>
</tr>
<tr>
<td>PEEP (cmH₂O)</td>
<td>15</td>
</tr>
<tr>
<td>Vt (ml/kg PBW)</td>
<td>4</td>
</tr>
<tr>
<td>RR (bpm)</td>
<td>10</td>
</tr>
<tr>
<td>Ppeak (cmH₂O)</td>
<td>37</td>
</tr>
<tr>
<td>ECMO GF (l/min)</td>
<td>6.5</td>
</tr>
<tr>
<td>VCO₂-NL (ml/min)</td>
<td>n.a.</td>
</tr>
<tr>
<td>VCO₂-ML (ml/min)</td>
<td>n.a.</td>
</tr>
<tr>
<td>VCO₂-ML/VCO₂-TOT (%)</td>
<td>n.a.</td>
</tr>
<tr>
<td>ΔPes (cmH₂O)</td>
<td>+2</td>
</tr>
<tr>
<td>P₄ (cmH₂O)</td>
<td>12</td>
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<tr>
<td>pH</td>
<td>7.42</td>
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<tr>
<td>PaO₂ (mmHg)</td>
<td>63</td>
</tr>
<tr>
<td>PaCO₂ (mmHg)</td>
<td>45</td>
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</table>

Feasibility of a Respiratory Mechanics Approach

Chen et al. Critical Care (2017) 21:84
DOI 10.1186/s13054-017-1671-8

Implementing a bedside assessment of respiratory mechanics in patients with acute respiratory distress syndrome

Lu Chen1,2, Guang-Qiang Chen1,2,3, Kevin Shore1, Orest Shklar4, Concetta Martins4, Brian Devenyi4, Paul Lindsay4, Heather McPhail4, Ashley Lanys2, Ibrahim Soliman1, Mazin Tuma1, Michael Kim1, Kerri Porretta4, Pamela Greco3, Hilary Every4, Chris Hayes1,2, Andrew Baker1,2, Jan O. Friedrich1,2 and Laurent Brochard1,2*
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<table>
<thead>
<tr>
<th>Ventilator Settings</th>
<th>Pre-measurement</th>
<th>Post-measurement</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;T&lt;/sub&gt;/PBW – ml/kg</td>
<td>6.5 [6.2-7.0]</td>
<td>6.4 [6.2-6.7]</td>
<td>0.006</td>
</tr>
<tr>
<td>PEEP – cmH&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>12 [10-14]</td>
<td>12 [10-14]</td>
<td>0.077</td>
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<tr>
<td>FiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.60 [0.50-0.70]</td>
<td>0.60 [0.50-0.70]</td>
<td>0.325</td>
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</table>

<table>
<thead>
<tr>
<th>Physiological Variables</th>
<th>Pre-measurement</th>
<th>Post-measurement</th>
<th>P Value</th>
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<tbody>
<tr>
<td>PaCO&lt;sub&gt;2&lt;/sub&gt; – mmHg</td>
<td>41 [38-50]</td>
<td>42 [38-50]</td>
<td>0.553</td>
</tr>
<tr>
<td>PaO&lt;sub&gt;2&lt;/sub&gt;/FiO&lt;sub&gt;2&lt;/sub&gt; – mmHg</td>
<td>146±60</td>
<td>162±69</td>
<td>0.020</td>
</tr>
<tr>
<td>P&lt;sub&gt;plat&lt;/sub&gt; – cmH&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>30±5</td>
<td>28±5</td>
<td>0.004</td>
</tr>
<tr>
<td>ΔP – cmH&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>18 [14-20]</td>
<td>15 [12-19]</td>
<td>0.023</td>
</tr>
<tr>
<td>OI&lt;sup&gt;8&lt;/sup&gt; – cmH&lt;sub&gt;2&lt;/sub&gt;O/mmHg</td>
<td>15.2±7.4</td>
<td>13.8±8.3</td>
<td>0.021</td>
</tr>
<tr>
<td>O/SI&lt;sup&gt;†&lt;/sup&gt; – mmHg/cmH&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>7.5 [5.4-11.5]</td>
<td>8.2 [5.9-14.7]</td>
<td>0.029</td>
</tr>
<tr>
<td>V&lt;sub&gt;D&lt;/sub&gt;/V&lt;sub&gt;T&lt;/sub&gt;, est</td>
<td>0.63±0.10</td>
<td>0.62±0.12</td>
<td>0.494</td>
</tr>
<tr>
<td>V&lt;sub&gt;E&lt;/sub&gt;, corr – L/min</td>
<td>13.0±3.2</td>
<td>12.8±3.3</td>
<td>0.421</td>
</tr>
</tbody>
</table>
Transpulmonary Pressure

- Contribution of the chest wall
- End expiratory value for recruitment
- End inspiratory value for safe ventilation
- Monitoring during SB
- Feasible in clinical practice
Thank You

brochardl@smh.ca
Mechanical Ventilation
From physiology to clinical practice

April 2018
Michener Institute, Toronto

Organized by the Interdepartmental Division of Critical Care Medicine,
University of Toronto
ARDS: “baby lung”

• Low compliance in ARDS: small lung not stiff lung

Gattinoni L and Pesenti A. The concept of « baby lung » ICM 2005
Compliance

- 100 ml/cmH2O
- 100 x units with 1 ml/cmH2O
- 30 units left
- C = 30 ml/cmH2O
Lung Volumes and Pressure-Volume Relations of the Respiratory System in Small Ventilated Neonates with Severe Respiratory Distress Syndrome

FRC$_z$, mL/kg

IC, mL/kg

$C_{rs\text{-}max}$, mL cmH$_2$O$^{-1}$ kg$^{-1}$

$C_{rs\text{-}max}/TLC$, cmH$_2$O$^{-1}$

Air ventilated  Severe RDS

C T Vilstrup, L J Björklund, O Werner and A Larsson. Pediatric Research 1996
Compliance and Delta P

- $C = \alpha \text{ FRC}$
- $C = \text{Vol} / \text{Elastic pressure}$
- $C = \text{Vt} / \text{Driving pressure (Pplat-PEEP)}$
- Driving pressure $\approx \text{Vt} / C$
- Driving pressure $\approx \text{Vt} / \alpha \text{ FRC}$
$\Delta P$: clinical data

![Graph showing the relationship between $\Delta P$ (cm of water) and Multivariate Relative Risk of Death in the Hospital. Median $V_T$ (10th–90th percentile) mg/kg of predicted body weight: 6.0 (5.9–7.5), 6.1 (5.8–9.2), 8.0 (5.7–12.1) with a P-value of 0.001.

![Graph showing the probability of hospital survival by driving pressure. Log-rank P = 0.02. Driving pressure, cm H$_2$O: ≤14 and >14.]

Amato NEJM 2015

Bellani JAMA 2016
ΔPEEP = 10
2. Reduce PEEP
3. Record expired Vt
4. Record Pplat
1. Reduce RR

Chen Crit Care 2017

Alveolar Derecruitment
Alveolar Recruitability

• A derecruited volume of at least 30% of Vt
• Validation study: our simplified method accurately predicts the best distinction of recruitable vs poorly or non recruitable patients using the reference method (multiple P-V curves) (Chen L, CCCF abstract 2016).
Diffuse airway closure and Airway Opening pressure

Chen AJRCCM 2017
Main Parameters

- Driving pressure
- PLplateau (elastance method)
- Recruitability
- AOP
- PeakPL (spontaneous breathing)
# ARDS Registry

**Recorder:** Brian, Orest  
**Date:** May 27, 2015  
**Dept:** ICU  
**Ventilator:** Servo-i

<table>
<thead>
<tr>
<th>Pt's Initial</th>
<th>Gender</th>
<th>DOB (year)</th>
<th>Height (cm)</th>
<th>PBW (kg)</th>
<th>FiO2 (%)</th>
<th>PaO2</th>
<th>PaCO2</th>
<th>VE (L/min)</th>
<th>P/F ratio</th>
<th>VE, corr</th>
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</thead>
<tbody>
<tr>
<td>RealCase</td>
<td>M</td>
<td>1959</td>
<td>178</td>
<td>73.3</td>
<td>0.6</td>
<td>69</td>
<td>46</td>
<td>13.9</td>
<td>115</td>
<td>16.0</td>
</tr>
</tbody>
</table>

## 1. IDENTIFICATION OF ARDS (Berlin definition)

- ✅ Risk factor in 1 week
- ✅ Bilateral opacities
- ✅ ARF not fully explained by cardiac failure or fluid overload

- ❌ 200 < PaO2/FiO2 ≤ 300
- ✅ 100 < PaO2/FiO2 ≤ 200
- ❌ PaO2/FiO2 ≤ 100

## 2. ASSESSMENT OF RESPIRATORY MECHANICS

<table>
<thead>
<tr>
<th>Mode</th>
<th>Vt (6ml/kg)</th>
<th>Vte</th>
<th>Flow</th>
<th>RR</th>
<th>PEEP</th>
<th>PEEPtot</th>
<th>Paw, peak</th>
<th>Paw, plat</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>439</td>
<td>442</td>
<td>60</td>
<td>30</td>
<td>10</td>
<td>11</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>square flow</td>
<td>ideal, ml</td>
<td>ml</td>
<td>L/min</td>
<td>bpm</td>
<td>cmH2O</td>
<td>cmH2O</td>
<td>cmH2O</td>
<td>cmH2O</td>
</tr>
</tbody>
</table>

## RESULTS (calculate automatically)

<table>
<thead>
<tr>
<th>PEEPi</th>
<th>Driving Pressure</th>
<th>Elastance, rs</th>
<th>Compliance, rs</th>
<th>Resistance, rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>29</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>cmH2O</td>
<td>cmH2O</td>
<td>cmH2O/L</td>
<td>ml/cmH2O</td>
<td>cmH2O/L/S</td>
</tr>
</tbody>
</table>

Comments:

- Bladder pressure at 1.00 15mmHg, Pga 20 mmHg
- Pentobarb loading dose 800mg, followed by 400mg/hr infusion.
hypercapnia. Bypass did not increase the risk of septicemia (approximately 20% in both groups) or decrease the incidence of pneumothorax (about 45%). Bypass was associated with decreased blood platelet and WBC concentrations, and increased mean daily blood and plasma infusion rates from approximately 1,000 to 2,500 mL. Bypass did prolong life for a short