Dissecting VILI from ARDS

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Collagen and Elastin

- Elastin $\approx 10\%$
- Collagen $\approx 2\%$

If empty zone (air) to full zone ratio $\approx 100:1$

Stress failure $\approx 100\text{cmH}_2\text{O}$
Collagen fiber network in rat lung

AE = alveolar entrances
(scale bar 100 μm)

Time course of ventilator induced lung injury

Stress-strain curve of healthy pigs

Specific Lung Elastance 5.8 cmH₂O

Strain index at 10mL/Kg

Alveolar diameter change %

V_T/Kg (mL)

0  5  10  15  20  25  30  35  40  45  50

0  10  20  30  40  50  60  70  80  90  100  110  120

man  rat  mouse  rabbit

Transpulmonary pressure (PL cmH₂O)

Resting  Biotrauma  Stress at rupture

%Total Lung Capacity

Specific Lung Elastance
~12 (cmH₂O)

Strain

Agostoni, Mead, Weibel, Gattinoni
Lung expansion/gas-free state

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

Voxel

$V_{gas}$

$\text{Gas fraction} = \frac{V_{gas0}}{V_{voxel}}$


Weighted gas ratio = $\frac{V_{gas1}}{V_{gas0}} \times \text{fraction of tissue}$
### 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(^{2/3})</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(^{2/3})</td>
<td>1.93 ± 0.42</td>
<td>1.97 ± 0.42</td>
<td>2.01 ± 0.55</td>
<td></td>
</tr>
</tbody>
</table>

*Courtesy of Dr. Cressoni*
Average ratio in normal subjects: $1.37 \pm 0.15$
How do stress and strain cause VILI?

Energy load into ventilatable lung structures
Tidal Strain

\[ P \Delta V = \text{Energy Input} \]

Dissipated

- Surface Tension
- Sliding EM
- Opening and Closing

Undissipated

- Elastic System

Continuous Strain

\[ \text{PEEP} \Delta V = \text{Energy Input} = 0 \]
Volume-Pressure curve and energy ($P\Delta V$)
Where is the energy dissipated?

- Gas motion (resistance etc.)
- Extracellular sliding (stress relaxation)
- Surface tension
- Opening/Closing
Degradation of 10% Vistanex 100 in cetane under laminar flow conditions. The data show a linear decrease of molecular weight with increasing shear stress, independent of the temperature. Reprinted with permission from ref 46. Copyright 1959, American Chemical Society, Washington, DC.

Healthy Pig
Constant VT, different PEEP

Dissipated Energy

- 1316 cmH₂O*mL
- 1160 cmH₂O*mL (-12%)
- 1478 cmH₂O*mL (+12%)
- 1960 cmH₂O*mL (+49%)
ARDS
Same plateau pressure, different PEEP
Protective effect of PEEP?

Number of pigs

ZEEP ALIVE
ZEEP DEAD
PEEP ALIVE
PEEP DEAD

95% ALIVE
ALL DEAD
≈50%

Protective effect of PEEP?
Conclusions

For VILI what matters is a tidal volume in a ventilatable lung

Tidal strain $\geq 1.5$ and total stress around 20 in man are possible thresholds.

The stress risers allow to reach the threshold locally and a multiplication of pressure is nearly 2

PEEP does not produce energy load and its positive effects may be due to the decreased tidal volume