Dynamic Lung Function and Monitoring

Peter C. Rimensberger
Pediatric and Neonatal ICU
Hôpital des Enfants
University Hospital of Geneva
My tools – and how I can use them

Physiologic response to my intervention: pO2, So2, Pco2, EtCO2

The ventilator as a monitoring device: Vt, Pressures, Curves and Loops, Calculated numbers (e.g. Cdyn)
Dynamic Lung Function and Monitoring

“Notion of Time”

- seconds
- minutes
- hours
- days
Non-invasive ventilation in ARDS


HFOV in ARDS

Metha S. Crit Care Med 2001; 29:1360–1369

Disease dynamics (?)
Position changes: supine ↔ prone

Recruitment Maneuver:
CPAP to 45 H2O for 20 seconds


Lapinsky SE Intensive Care Med 1999; 25:1297
The oxygen response (limitations)

P/F-ratio, oxygen delivery and Crs during PEEP steps

Lichtwarck-Aschoff M  AJRCCM 2000; 182:2125-32
The oxygenation response: Can it be used?

PEEP and Vt effects in ALI

"static" compliance:

\[ C_{st} = \frac{\text{tidal volume}}{\text{static PIP (Pplat) - PEEP}} \]

Burns D J Trauma 2001;51:1177-81
PEEP titration

Burns D J Trauma 2001;51:1177-81
Use of dynamic compliance for open lung positive end-expiratory pressure titration in an experimental study

F Suarez-Sipman
Crit Care Med 2007; 35:214–221
Constant $V_T$ : PaCO$_2$ and PaO$_2$

- PaCO$_2$
- PaO$_2$

Prevalent recruitment
Balance
Prevalent overdistention

L. Gattinoni, 2003
PEEP titration and the physiologic response

CO₂-response

Overdistention starts

Oxygenation

PEEP 10
PEEP 15
PEEP 20
PEEP 25
PEEP titration and the physiologic response

Steps of 5 cmH2O to 40/25

Overinflation starts

Pressure control ventilation

Overinflation ends
Physiologic response to pressure changes during HFO

CDP: 13

Overdistention

Collapse
$\text{O}_2$-improvement = Shunt improvement =

a) recruitment

b) flow diversion

\[ \text{PaO}_2, \text{PaCO}_2 \]

L. Gattinoni, 2003
Prevalent overinflation = dead space effect

PaO$_2$ and PaCO$_2$ increase

L. Gattinoni, 2003
Single breath CO$_2$-tracing

Phase I  CO$_2$-free = gas from airways

Phase II  Rapid S-shape upswing = washout of convective airway with alveolar gas

Phase III  Alveolar gas – called plateau but ascends gradually due to

a) sequential emptying of lung regions with different V/Q-ratios

b) within units V/Q mismatching secondary to incomplete gas mixing

c) the continual release of CO$_2$ into the alveoli during expiration
**CO₂ in ventilatory monitoring**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>etCO₂</td>
<td>endtidal value</td>
</tr>
<tr>
<td>FeCO₂</td>
<td>fraction of CO₂ in expired gas</td>
</tr>
<tr>
<td>VCO₂</td>
<td>minute elimination (“production”)</td>
</tr>
<tr>
<td>VTCO₂</td>
<td>tidal elimination</td>
</tr>
</tbody>
</table>

![Graph showing CO₂ levels over time]
Pressure – Flow – Time - Volume

$\Delta \text{Vol, max} = \Delta P \times \text{Crs}$

Volume change requires time to take place.

When a step change in pressure is applied, the instantaneous change in volume follows an exponential curve, which means that, formerly faster, it slows down progressively while it approaches the new equilibrium.

Time constant: $T = \text{Crs} \times \text{Rrs}$
Pressure – Flow – Time - Volume

Time constant: $T = Crs \times Rrs$
Patient-Ventilator Interaction - Monitoring

Flow termination and auto-PEEP
Control Modes

Support Modes

Flow termination criteria

Nilsestuen J  Respir Care 2005;50:202–232
Breath by Breath “Dynamics” Visualized

Digital sample rate of 12.2 Hz

Baumgardner JE AJRCCM 2002; 166:1556-62
Breath by Breath “Dynamics” Visualized

Delta change

Frequency change

Baumgardner JE AJRCCM 2002; 166:1556-62
Volume distribution

<table>
<thead>
<tr>
<th>PEEP (cmH₂O)</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deflation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After lavage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These functional EIT tomograms show the distribution of Vₐ in the chest cross-section.

Frerichs I, Dargaville P, Rimensberger PC  Intensive Care Med 2003
EIT to quantify Vt-distribution

Frerichs I, Dargaville P, Rimensberger PC  Intensive Care Med 2003; 29:2312-6
Regional «homogeneity» on the deflation limb

right lung nondependent region

- normal lung
- injured lung
- post surfactant lung

right lung dependent region

- normal lung
- injured lung
- post surfactant lung

Frerichs I, Dargaville P, Rimensberger PC (in preparation)
The basic tools, do I have them?  YES

To use them better you have to think “dynamic”

Look for trends and not for static numbers