Spontaneous Effort during Mechanical Ventilation

Brian Kavanagh
Hospital for Sick Children
University of Toronto
Conflicts of Interest

- Patent applied – Ventilation Device
- No other financial conflicts of interest with the subject matter of this talk
Spontaneous Breathing

$V_A/Q$ Matching
Mechanical Breaths

Paralyzed Diaphragm

Anterior

High V/Q

Low V/Q

Static Abdominal Pressure

Posterior

Putensen et al Curr Opin Crit Care 2002
In atelectasis, where does the injury occur?

Non-Dependent
(Aerated)

Dependent
(Atelectatic)
Atelectasis Causes Alveolar Injury in Nonatelectatic Lung Regions

Shinya Tsuchida, Doreen Engelberts, Vanya Peltekova, Natalie Hopkins, Helena Frndova, Paul Babyn, Colin McKeachie, Martin Post, Paul McLoughlin, and Brian P. Kavanagh
Spontaneous Breaths

*Contracting Diaphragm*

**Anterior**

**Posterior**

Match V/Q

Diaphragm Effort

Putensen *et al* Curr Opin Crit Care 2002
Pigs, Mild ARDS

APRV – No Spontaneous Effort

Wrigge et al Anesthesiology 2003
Pigs, Mild ARDS

BiPAP, APRV (0%)
Longer Term

Mild Disease, Recruited Lung

PaO$_2$/FiO$_2$
Spontaneous Breathing

Lung Perfusion
Airway pressure release ventilation improves pulmonary blood flow in infants after cardiac surgery*

Mark A. Walsh, MD; Michele Merat, MD; Gustavo La Rotta, MD; Pretha Joshi, MD; Vinay Joshi, MD; Tuyen Tran, RT; Steve Jarvis, RT; Christopher A. Caldarone, MD; Glen S. Van Arsdell, MD; Andrew N. Redington, MD; Brian P. Kavanagh, MD
Spontaneous Breathing

Global Injury
Global ...

\[ P_L = P_{aw} - P_{pl} \]
Global ‘Model’ of Spontaneous Effort

\[ P_{aw} = 0 \]

SB ✔

MV ✔

SB X

MV X
Mechanical + Spontaneous
= ‘Additive’ Pressures
Acute respiratory failure following pharmacologically induced hyperventilation: an experimental animal study


Sheep, ‘Spontaneous’ Hyperventilation (CSF Salicylate)

Data (mean ± SEM)

<table>
<thead>
<tr>
<th>Group</th>
<th>A</th>
<th>B</th>
<th>C</th>
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</thead>
<tbody>
<tr>
<td>VE (ml kg⁻¹ min⁻¹)</td>
<td>16</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Post-mortem delays (h)</td>
<td>32.3 ± 3</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Sedatives (N.)</td>
<td>8.4 ± 3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Hyperventilation injections (ml kg⁻¹ min⁻¹)</td>
<td>6.2 ± 2</td>
<td>9</td>
<td>h</td>
</tr>
<tr>
<td>PaO₂ (mmHg)</td>
<td>578 ± 200</td>
<td>168 ± 22</td>
<td>147 ± 23</td>
</tr>
<tr>
<td>PaCO₂ (mmHg)</td>
<td>60 ± 16</td>
<td>83 ± 12</td>
<td>84 ± 8</td>
</tr>
<tr>
<td>Alveolar-arterial difference (mmHg)</td>
<td>431 ± 139</td>
<td>227 ± 79</td>
<td>244 ± 42</td>
</tr>
<tr>
<td>Crs (ml cm H₂O⁻¹)</td>
<td>35.2 ± 7</td>
<td>34.6 ± 10</td>
<td>34 ± 6</td>
</tr>
<tr>
<td>Lung/body weight (×10⁻³)</td>
<td>19.5 ± 7</td>
<td>14.5 ± 2</td>
<td>13.7 ± 2</td>
</tr>
<tr>
<td>Surface tension (dynes cm⁻¹)</td>
<td>12.8 ± 6</td>
<td>11.5 ± 6</td>
<td>13.7 ± 2</td>
</tr>
<tr>
<td>Normal lungs (autopsy)</td>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Dead animals (N.)</td>
<td>–</td>
<td>–</td>
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</tbody>
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Spontaneous Effort can be Lethal ...
... Added Inspiratory Resistance

$^{99}$Tc-DTPA Lung Retention Scintigraphy

<table>
<thead>
<tr>
<th></th>
<th>2 min</th>
<th>10 min</th>
<th>20 min</th>
<th>40 min</th>
<th>60 min</th>
<th>80 min</th>
<th>90 min</th>
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</thead>
<tbody>
<tr>
<td><strong>ctr</strong></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
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<tr>
<td><strong>3 hrs IRB</strong></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
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<tr>
<td><strong>6 hrs IRB</strong></td>
<td><img src="image15.png" alt="Image" /></td>
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<td><img src="image20.png" alt="Image" /></td>
<td><img src="image21.png" alt="Image" /></td>
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</tbody>
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Retained ++
Retained +
Not Retained

Toumpanakis et al, AJRCCM 2010
Spontaneous Breathing
Synchrotny
Volume Preset, Low $V_T$, Spontaneous Effort

‘Negative-Pressure’ Edema

Kallet et al, Chest 1999
Double-Triggering

Increased Tidal Volume

Robinson et al, Resp Care 2013
Takeshi Yoshida MD PhD
Spontaneous breathing during lung-protective ventilation in an experimental acute lung injury model: High transpulmonary pressure associated with strong spontaneous breathing effort may worsen lung injury*

Takeshi Yoshida, MD; Akinori Uchiyama, MD, PhD; Nariaki Matsuura, MD, PhD; Takashi Mashimo, MD, PhD; Yuji Fujino, MD, PhD

$V_T$ 9 mL/Kg + Weak Effort
The Comparison of Spontaneous Breathing and Muscle Paralysis in Two Different Severities of Experimental Lung Injury*

Takeshi Yoshida, MD\textsuperscript{1,2}; Akinori Uchiyama, MD, PhD\textsuperscript{2}; Nariaki Matsuura, MD, PhD\textsuperscript{3}; Takashi Mashimo, MD, PhD\textsuperscript{2}; Yuji Fujino, MD, PhD\textsuperscript{2}
Early Paralysis Increases Survival

Impact in Severe ARDS

Papazian et al, N Engl J Med 2010
Spontaneous Breathing

Regional Injury
Spontaneous Effort Causes Occult Pendelluft during Mechanical Ventilation

Takeshi Yoshida¹,², Vinicius Torsani¹, Susimeire Gomes¹, Roberta R. De Santis¹, Marcelo A. Beraldo¹, Eduardo L. V. Costa³, Mauro R. Tucci¹, Walter A. Zin³, Brian P. Kavanagh⁴,⁵, and Marcelo B. P. Amato¹

40 yr, Male
- Pressure Control
- No Effort
Spontaneous Effort Causes Occult Pendelluft during Mechanical Ventilation

Takeshi Yoshida¹,², Vinicius Torsani³, Susimeire Gomes¹, Roberta R. De Santis¹, Marcelo A. Beraldo¹, Eduardo L. V. Costa¹, Mauro R. Tucci¹, Walter A. Zin³, Brian P. Kavanagh⁴,⁵, and Marcelo B. P. Amato¹

40 yr, Male
• Pressure Control
• Preserved Effort
Spontaneous Effort Causes Occult Pendelluft during Mechanical Ventilation

Takeshi Yoshida\textsuperscript{1,2}, Vinicius Torsani\textsuperscript{1}, Susimeire Gomes\textsuperscript{1}, Roberta R. De Santis\textsuperscript{1}, Marcelo A. Beraldo\textsuperscript{1}, Eduardo L. V. Costa\textsuperscript{1}, Mauro R. Tucci\textsuperscript{1}, Walter A. Zin\textsuperscript{3}, Brian P. Kavanagh\textsuperscript{4,5}, and Marcelo B. P. Amato\textsuperscript{1}
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In Spontaneous Effort ...

• $P_{es}$ Underestimates local $\Delta P_{pl}$

• Pressure is Local (not ‘general’)

$P_{pl}$, $P_{es}$ (cmH₂O)
Idealized Lung ...
Different Compliance Units ...

Equal Swing in ALL Ppl

IF Swing in Ppl Everywhere

- Maybe different extents
- Maybe different rates

None could ‘shrink’

Fluid-Like Behavior
‘Equal’ Compliance Units ...
Unequal Distribution of Swing in Ppl

-20
-10
-5
0
5
10
20

PEEP
-ΔP_{pl}

Can’t be the Same Swing in P_{pl}

Dependent Expand
Non-Dependent Contract

This is ‘Pendelluft’
- Not detected by P_{aw}
- Likely Injurious

Solid-Like Behavior
Spontaneous Breathing

Confounds Driving Pressure
Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.
Driving Pressure = \([P_{PLAT} - PEEP]\)

\[
P_{aw}
\]

\[
Time
\]

\[
\Delta P
\]

Spontaneous Effort ... \(P_{pl} < PEEP\)

True Driving Pressure = \([P_{PLAT} - P_{pl}]\)

*Underestimated*
Spontaneous Breathing

Exercising the Diaphragm
Diaphragm Biopsy, Brain Dead (*Ventilated*) Donors

Evolution of Diaphragm Thickness during Mechanical Ventilation
Impact of Inspiratory Effort

Ewan C. Goligher, Eddy Fan, Margaret S. Herridge, Alistair Murray, Stefannie Vorona, Debbie Brace, Nuttapol Rittayamai, Ashley Lanys, George Tomlinson, Jeffrey M. Singh, Steffen-Sebastian Bolz, Gordon D. Rubenfeld, Brian P. Kavanagh, Laurent J. Brochard, and Niall D. Ferguson

Atrophy

Exercise the Diaphragm

Ventilator Days

Activity

AJRCCM 2015
• Oxygenation
• Global vs. Local Injury
• Pulmonary Edema
• Dysynchrony
• Driving Pressure
• Diaphragm
Spontaneous Breathing During Mechanical Ventilation - Risks, Mechanisms & Management.

Yoshida T, Fujino Y, Amato MB, Kavanagh BP.

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Thank You

Brian.Kavanagh@utoronto.ca