Lung and Diaphragm-Protective Ventilation
What, Why, and How?

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Disclosures

- Conflicts of Interest
  - Equipment from Timpel
  - Equipment and personal fees from Getinge
Modern Mechanical Ventilation Saves Lives

<table>
<thead>
<tr>
<th>Group</th>
<th>Period of admission</th>
<th>No. of cases</th>
<th>Died</th>
<th>Died within three days</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>July 21–Aug. 25</td>
<td>31</td>
<td>27 (87%)</td>
<td>19 (70%)</td>
</tr>
<tr>
<td>II</td>
<td>Aug. 26–Sept. 8</td>
<td>50</td>
<td>26 (52%)</td>
<td>7 (27%)</td>
</tr>
<tr>
<td>III</td>
<td>Sept. 8–Sept. 23</td>
<td>50</td>
<td>24 (48%)</td>
<td>8 (33%)</td>
</tr>
<tr>
<td>IV</td>
<td>Sept. 23–Oct. 5</td>
<td>50</td>
<td>19 (38%)</td>
<td>10 (53%)</td>
</tr>
<tr>
<td>V</td>
<td>Oct. 6–Oct. 21</td>
<td>50</td>
<td>13 (26%)</td>
<td>7 (54%)</td>
</tr>
<tr>
<td>VI</td>
<td>Oct. 21–Nov. 6</td>
<td>50</td>
<td>18 (36%)</td>
<td>10 (55%)</td>
</tr>
<tr>
<td>Total II–VI</td>
<td></td>
<td>250</td>
<td>100 (40%)</td>
<td>42 (42%)</td>
</tr>
</tbody>
</table>
Protective Mechanical Ventilation Saves Lives

Webb & Tierney *ARRD* 1974

ARDSNet *NEJM* 2000
Prolonged Mechanical Ventilation Leads to Disability

Hodgson et al *Intensive Care Med* 2017

Unroe et al *Ann Intern Med* 2011
The Diaphragm and ICU Outcomes

P = .04

Baseline diaphragm thickness
- >50th Percentile (2.3 mm)
- ≤50th Percentile (2.3 mm)

No. at risk
- >2.3 mm: 88
- ≤2.3 mm: 105

Duration of Follow-up, d
- 0: 88
- 7: 34
- 14: 13
- 21: 8

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The Diaphragm and ICU Outcomes

Log-rank $P = .09$

Baseline diaphragm thickness
- $>50\text{th Percentile (2.3 mm)}$
- $\leq 50\text{th Percentile (2.3 mm)}$

<table>
<thead>
<tr>
<th>Duration of Follow-up, d</th>
<th>No. at risk $&gt;2.3 \text{ mm}$</th>
<th>No. at risk $\leq 2.3 \text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>87</td>
<td>102</td>
</tr>
<tr>
<td>15</td>
<td>54</td>
<td>76</td>
</tr>
<tr>
<td>30</td>
<td>29</td>
<td>47</td>
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<tr>
<td>45</td>
<td>21</td>
<td>28</td>
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<tr>
<td>60</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>75</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>90</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

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Ventilator-Induced Diaphragm Dysfunction

Abnormalities of diaphragmatic muscle in neonates with ventilated lungs.

Knisely AS¹, Leal SM, Singer DB.

47 days of MV

3 days of MV
Diaphragm Myotrauma

Goligher et al. AJRCCM 2015
Diaphragm Myotrauma Associated with Delayed Liberation from Ventilation
Lung and Diaphragm-Protective Ventilation

- Mechanical Ventilation
  - Volutrauma
    - Homeostasis
      - Clinical outcomes
      - Myotrauma

Lung-protective ventilation & ECLS
Minimizing lung stress/strain

Diaphragm-protective ventilation & ECLS
Monitoring/optimizing respiratory effort & synchrony
Diaphragmatic myotrauma: a mediator of prolonged ventilation and poor patient outcomes in acute respiratory failure

Ewan C Goligher, Laurent J Brochard, W Darlene Reid, Eddy Fan, Olli Saarela, Arthur S Slutsky, Brian P Kavanagh, Gordon D Rubenfeld, Niall D Ferguson
Over-assistance Myotrauma: Disuse Atrophy

Diaphragm

Pectoralis major

Under-Assistance Myotrauma: Load-Induced Injury

Reid et al. J Appl Phys 1994
Eccentric Myotrauma

Concentric

Eccentric

Gea et al. *Arch Bronchopneumol* 2009
Eccentric Myotrauma

Reverse triggering

Premature cycling
Myotrauma: Clinical Investigation
Inspiratory Effort and Outcome

![Graph showing duration of mechanical ventilation (days) against mean diaphragm thickening fraction over first 3 days of MV. The graph includes a target window indicated by arrows.](Goligher et al AJRCCM 2018)
Diaphragmatic myotrauma: a mediator of prolonged ventilation and poor patient outcomes in acute respiratory failure

Ewan C Goligher, Laurent J Brochard, W Darlene Reid, Eddy Fan, Olli Saarela, Arthur S Slutsky, Brian P Kavanagh, Gordon D Rubenfeld, Niall D Ferguson

Goligher et al Lancet Respir Med 2019
Diaphragm-Protective Ventilation in 2019

Optimize respiratory effort

- Over-assistance and disuse atrophy
- Under-assistance and load-induced injury

Myotrauma risk

Patient inspiratory effort

+ Flow & Vt (AC-VC), Pressure (AC-PC)
+ Sedation

Optimize patient-ventilator synchrony

- Eccentric contractions due to premature cycling and reverse triggering
- Ineffective efforts and over-assistance due to delayed cycling

Myotrauma risk

Before patient Ventilator cycling After patient

Sedation, Flow & Vt (AC-VC), I:E ratio (AC-PC), $E_{sens}$ (PSV)

Goligher Intensive Care Med 2019
Lung and Diaphragm-Protective Ventilation

Mechanical Ventilation -> Volutrauma -> Homeostasis -> Clinical outcomes

Myotrauma

Lung-protective ventilation & ECLS
Minimizing lung stress/strain

Diaphragm-protective ventilation & ECLS
Monitoring/optimizing respiratory effort & synchrony
Excess Lung Stress

\[ P_L = P_{\text{airway}} - P_{\text{pleural}} \]

Inhomogeneous Lung Stress
Challenge: Managing Respiratory Drive

- P-SILI

  - Respiratory drive & effort

  - Myotrauma
LDPV: How

- Ventilation targets
- Monitoring
- Methods for controlling respiratory drive and effort
LDPV Goals

Position Statements

• No single universally applicable one-size-fits-all setting for optimal mechanical ventilation
• Protecting the lung should be prioritized over protecting the diaphragm
• Respiratory effort should be monitored routinely
LDPV Goals

Proposed LDPV Goals
• Limit cyclic lung stress
• Limit regional cyclic lung stress
• Maintain low-normal respiratory effort
• Avoid breath stacking dyssynchrony
• Aim for expiratory synchrony
Monitoring for LDPV Strategy

- Flow
- $P_{aw}$
- $P_{es}$
- $P_L$

- Respiratory effort
- Risk of myotrauma
- Risk of excess regional lung stress

- Cyclic lung stress
- Risk of volutrauma
Challenge: Managing Respiratory Drive

- Ventilator flow & pressure
- P-SILI
- ECLS
- Respiratory drive & effort
- Sedation
- Myotrauma
Lung and Diaphragm-Protective Ventilation

- Mechanical Ventilation
- ECLS
- Sedation
- Volutrauma
- Homeostasis
- Myotrauma
- Lung-protective ventilation & ECLS
  - Minimizing lung stress/strain
- Clinical outcomes
  - Diaphragm-protective ventilation & ECLS
    - Monitoring/optimizing respiratory effort & synchrony
Questions?

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