Conventional Mechanical Ventilation (Overdistension intrinsic PEEP)

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Nicklaus Children’s Hospital
History

• The Greek physician Galen may have been the first to describe artificial ventilation: "If you take a dead animal and blow air through its larynx through a reed, you will fill its bronchi and watch its lungs attain the greatest distention”.

• Mechanical ventilators, in the form of negative-pressure ventilation, first appeared in the early 1800s.

• Positive-pressure devices started to become available around 1900

• Today's typical intensive care unit (ICU) ventilator did not begin to be developed until the 1940s
The first massive use of non-invasive ventilation (NIV) occurred during the 1952 Copenhagen poliomyelitis epidemic with the so-called iron lung
BEAR 3
RELATED RISKS OF INTUBATION

• Longer length of stay
• Infection, VAP, decubitus ulcers
• Increased mortality
• This means increased costs of patient care, worsened outcome
Pathogenic mechanisms of postoperative pulmonary dysfunction

- **Specific to cardiac surgery:**
  - Median sternotomy incision
  - Use of cardiopulmonary bypass (CPB)
  - Transfusion of blood product
  - Cooling for myocardial protection
  - Effects of general anesthesia
- **Alterations in lung mechanics:**
  - Reductions in vital capacity (VC)
  - Reduction of functional residual capacity (FRC)
  - Reduction of static and dynamic lung compliance
- **Anomalies in gas exchange:**
  - Widening of the alveolar-arterial oxygen gradient
  - Increased microvascular permeability in the lung
  - Increased pulmonary vascular resistance
  - Increased pulmonary shunt fraction
  - Intrapulmonary aggregation of leukocytes and platelets

Badenes et al; Crit Care Res Pract. 2015
Risk factors for hospital morbidity and mortality after the Norwood procedure: A report from the Pediatric Heart Network Single Ventricle Reconstruction trial

Sarah Tabbutt, MD, PhD, Nancy Ghanayem, MD, Chitra Ravishankar, MD, Lynn A. Sleeper, ScD, David S. Cooper, MD, MPH, Deborah U. Frank, MD, PhD, Minmin Lu, MS, Christian Pizarro, MD, Peter Frommelt, MD, Karen S. Goldberg, MD, Eric M. Graham, MD, Catherine Dent Krauwseski, MD, Wyman W. Lai, MD, Alan Lewis, MD, Joel A. Kirsh, MD, Lynn Mahony, MD, Richard G. Ohaye, MD, Janet Simsic, MD, Andrew J. Lodge, MD, Ellen Spurrer, MD, Mario Stylianou, PhD, and Peter Laussen, MD, for the Pediatric Heart Network Investigators

TABLE 2. Multivariable models for morbidity outcomes after the Norwood procedure

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of subjects with event</th>
<th>Time to event, days (median, range)</th>
<th>Odds ratio</th>
<th>95% CI</th>
<th>P</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catheter intervention (R² = 7%)</td>
<td>27</td>
<td>27 (5-126)</td>
<td>0.23</td>
<td>(0.05, 0.97)</td>
<td>.05</td>
<td>Ref</td>
</tr>
<tr>
<td>Preoperative ventilation for apnea/transport</td>
<td>4.02</td>
<td>(1.19, 13.6)</td>
<td>.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left atrial decompression</td>
<td>2.11</td>
<td>(1.04, 4.29)</td>
<td>.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regional cerebral perfusion</td>
<td>3.8</td>
<td>5 (1-157)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central nervous system injury (R² = 4%)</td>
<td>38</td>
<td>5 (1-157)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genetic abnormality</td>
<td>2.84</td>
<td>(1.29, 6.28)</td>
<td>.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>2.68</td>
<td>(1.27, 5.64)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Unknown</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Renal failure (R² = 26%)</td>
<td>46</td>
<td>3 (1-77)</td>
<td>10.2</td>
<td>(2.43, 42.4)</td>
<td>.002</td>
<td>Ref</td>
</tr>
<tr>
<td>Preoperative ventilation for apnea/transport</td>
<td>3.66</td>
<td>(1.66, 7.21)</td>
<td>&lt;.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart block</td>
<td>18.8</td>
<td>(5.05, 70)</td>
<td>&lt;.001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open sternum</td>
<td>7.61</td>
<td>(1.86, 31.2)</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, routine site</td>
<td>6.72</td>
<td>(1.02, 23.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, elective site</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No, elective site</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Surgeon Norwood volume</td>
<td>0.51</td>
<td>(0.06, 3.1)</td>
<td>.006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤50</td>
<td>0.51</td>
<td>(0.06, 1.99)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 to ≤100</td>
<td>0.00</td>
<td>(0.10, 2.93)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 to ≤150</td>
<td>0.20</td>
<td>(0.06, 2.11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Complications after the Norwood Operation: An Analysis of the STS Congenital Heart Surgery Database

Christoph P. Hornik, MD, Xia He, MS, Jeffrey P. Jacobs, MD, Jennifer S. Li, MD MHS, Robert D.B. Jaquiss, MD, Marshall L. Jacobs, MD, Sean M. O'Brien, PhD, Eric D. Peterson, MD MPH, and Sara K. Pasquali, MD.

Patient pre-operative factors associated with ≥1 post-operative complication

<table>
<thead>
<tr>
<th>Pre-operative factors</th>
<th>Unadjusted Odds Ratio (95% CI)</th>
<th>p-value</th>
<th>Adjusted Odds Ratio (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prolonged pre-op LOS*</td>
<td>0.98 (0.78–1.22)</td>
<td>0.82</td>
<td>0.84 (0.65–1.1)</td>
<td>0.2</td>
</tr>
<tr>
<td>Weight &lt; 2.5 kg</td>
<td>1.72 (1.30–2.27)</td>
<td>&lt;0.001</td>
<td>1.59 (1.22–2.08)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Female gender</td>
<td>1.08 (0.96–1.21)</td>
<td>0.18</td>
<td>1.02 (0.91–1.15)</td>
<td>0.71</td>
</tr>
<tr>
<td>Right dominant ventricle (vs left)</td>
<td>1.48 (1.13–1.93)</td>
<td>0.004</td>
<td>1.36 (1.01–1.82)</td>
<td>0.04</td>
</tr>
<tr>
<td>TAPVR</td>
<td>2.21 (1.08–4.55)</td>
<td>0.03</td>
<td>1.61 (0.84–3.08)</td>
<td>0.15</td>
</tr>
<tr>
<td>Non-cardiac/genetic abnormality</td>
<td>1.61 (1.28–2.04)</td>
<td>&lt;0.001</td>
<td>1.5 (1.19–1.91)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Shock</td>
<td>1.66 (1.17–2.35)</td>
<td>0.004</td>
<td>1.52 (1.08–2.15)</td>
<td>0.02</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>1.31 (0.91–1.87)</td>
<td>0.15</td>
<td>1.24 (0.84–1.82)</td>
<td>0.29</td>
</tr>
<tr>
<td>Mechanical circulatory support</td>
<td>4.51 (1.52–13.39)</td>
<td>0.007</td>
<td>4.0 (1.57–10.18)</td>
<td>0.003</td>
</tr>
<tr>
<td>Mechanical ventilatory support</td>
<td>1.37 (1.1–1.7)</td>
<td>0.004</td>
<td>1.28 (1.03–1.6)</td>
<td>0.03</td>
</tr>
<tr>
<td>Neurological deficit</td>
<td>1.81 (0.78–4.20)</td>
<td>0.17</td>
<td>1.33 (0.55–3.17)</td>
<td>0.53</td>
</tr>
</tbody>
</table>
## Post-operative complications and associated mortality

<table>
<thead>
<tr>
<th>Post-operative complications</th>
<th>Prevalence (n, %) n=2557</th>
<th>With complication</th>
<th>Without complication</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Renal Failure Requiring Permanent Dialysis</td>
<td>12 (0.5%)</td>
<td>91.7</td>
<td>21.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Cardiac Arrest</td>
<td>311 (12.2%)</td>
<td>67.5</td>
<td>15.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Acute Renal Failure Requiring Temporary Dialysis</td>
<td>141 (5.5%)</td>
<td>66.7</td>
<td>19.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mechanical Circulatory Support</td>
<td>365 (14.3%)</td>
<td>57.3</td>
<td>16.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Systemic Venous Obstruction</td>
<td>13 (0.5%)</td>
<td>53.9</td>
<td>22.0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pulmonary Vein Obstruction</td>
<td>2 (0.1%)</td>
<td>50.0</td>
<td>22.1</td>
<td>0.34</td>
</tr>
<tr>
<td>Transient Neurological Deficit</td>
<td>4 (0.3%)</td>
<td>50.0</td>
<td>20.8</td>
<td>0.15</td>
</tr>
<tr>
<td>Persistent Neurologic Deficit</td>
<td>83 (3.2%)</td>
<td>48.2</td>
<td>21.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Low Cardiac Output</td>
<td>415 (16.2%)</td>
<td>47.7</td>
<td>17.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Tracheostomy</td>
<td>19 (0.7%)</td>
<td>47.4</td>
<td>22.0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>55 (2.2%)</td>
<td>47.3</td>
<td>21.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Acidosis</td>
<td>280 (11.0%)</td>
<td>45.4</td>
<td>19.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Bleeding Requiring Reoperation</td>
<td>205 (8.0%)</td>
<td>44.4</td>
<td>20.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Pulmonary Hypertension</td>
<td>84 (3.3%)</td>
<td>39.3</td>
<td>21.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Unplanned Reoperation</td>
<td>303 (11.9%)</td>
<td>38.9</td>
<td>19.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mediastinitis</td>
<td>35 (1.4%)</td>
<td>34.3</td>
<td>22.0</td>
<td>0.08</td>
</tr>
<tr>
<td>Complete AV Block Requiring Temporary Pacemaker</td>
<td>71 (2.8%)</td>
<td>33.8</td>
<td>21.8</td>
<td>0.01</td>
</tr>
<tr>
<td>Sepsis</td>
<td>287 (11.2%)</td>
<td>33.7</td>
<td>20.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Seizure</td>
<td>110 (4.3%)</td>
<td>31.8</td>
<td>21.7</td>
<td>0.01</td>
</tr>
<tr>
<td>Pleural Effusion Requiring Drainage</td>
<td>150 (5.9%)</td>
<td>31.3</td>
<td>21.6</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Respiratory Insufficiency Requiring Intubation &gt; 7d</td>
<td>551 (21.6%)</td>
<td>30.0</td>
<td>20.0</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>492 (19.2%)</td>
<td>27.5</td>
<td>20.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Pericardial Effusion Requiring Drainage</td>
<td>50 (2.0%)</td>
<td>26.0</td>
<td>22.1</td>
<td>0.50</td>
</tr>
<tr>
<td>Chylothorax</td>
<td>159 (6.2%)</td>
<td>23.3</td>
<td>22.1</td>
<td>0.72</td>
</tr>
<tr>
<td>Respiratory Insufficiency Requiring Reintubation</td>
<td>334 (13.1%)</td>
<td>19.5</td>
<td>22.6</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Compliance curve of the lung with its lower and upper inflection points

- **Collapse**
- **Recruitment**
- **Overdistention**

**Alveoli**

- **Upper inflection point**
- **Volume-controlled continuous mandatory ventilation**
- **Mean lung volume**

**Lower inflection point**

**Volume (mL)**

**Pressure (cm H$_2$O)**
Mechanical ventilation strategy following Glenn and Fontan surgeries: On going challenge!

Hemodynamic response to positive end-expiratory pressure following right atrium-pulmonary artery bypass (Fontan procedure).

Williams DB, Kiernan PD, Metke MP, Marsh HM, Danielson GK

Doppler echocardiographic evaluation of pulmonary blood flow after the Fontan operation: the role of the lungs.

Penny DJ, Redington AN
Ventilation after BDCPA

The effects of carbon dioxide on oxygenation and systemic, cerebral, and pulmonary vascular hemodynamics after the bidirectional superior cavopulmonary anastomosis.

Hoskote A, et al
Ventilation after BDCPA

We have demonstrated that after the BCPA systemic oxygenation, Qp, Qs, and cerebral blood flow increased and SVRI decreased at CO$_2$ tensions of 45 and 55 mm Hg compared with 35 mm Hg.
Intraoperative use of low volume ventilation to decrease postoperative mortality, mechanical ventilation, lengths of stay and lung injury in patients without ALI

- 12 randomized controlled trials (RCTs) that evaluated the effect of low tidal volumes (defined as < 10 mL/kg) on any of our selected outcomes in adult participants undergoing any type of surgery
- Low tidal volumes should be used preferentially during surgery
- They decrease the need for postoperative ventilatory support (invasive and non-invasive)

Guay J, Ochroch EA. Cochrane Database Syst Rev. 2015 Dec 7;(12)
Fast-tracking in pediatric cardiac surgery - The current standing

Table 1: Results from current literature on the feasibility of fast-tracking in surgery for CHD

<table>
<thead>
<tr>
<th>Author, Year published</th>
<th>Type of study</th>
<th>Patients enrolled</th>
<th>Findings</th>
</tr>
</thead>
</table>
| Neroti et al., 2002[4] | Retrospective | 901 (s, c)       | - 73% extubated in OR  
|                        |               |                  | - Younger age, lower weight were factors for prolonged MV  
| Vrticla et al., 2000[6] | Retrospective | 201 (s, c)       | - 87% extubated in OR  
|                        |               |                  | - Fast-tracking in surgery for CHD is feasible and safe  
| Davis et al., 2004[7]  | Retrospective | 219 (<36 mos) (s, c) | - 47% extubated within 24hrs  
|                        | Multivariate analysis | | |
| Heinle et al., 1997[8] | Retrospective | 56 (< 90 days)   | - 50% of neonates and young infants extubated in OR or within 3 hrs on ICU  
|                        |               |                  | - 3 patients required reintubation  
|                        |               |                  | - Patients extubated early had shorter ICU/hospital stay  
|                        |               |                  | - 41% extubated in OR  
|                        |               |                  | - Mild respiratory acidosis immediately following early extubation well tolerated  
|                        |               |                  | - No patient reintubated  
| Kloth et al., 2002[9]  | Retrospective | 102 (> 2 mos) (s, c) | |
|                        |               |                  | |
| Mittnacht et al., 2008[10] | Retrospective | 224 (> 1 month <18 years) (s, c) | - 79% in OR  
|                        |               |                  | - No patient reintubated  

mos = month of age, hrs = hours, wks = weeks, PHT = pulmonary hypertension, S = simple cases (e.g. ASD, VSD), C = complex cases (e.g. TOF, AV canal, Fontan), MV = Mechanical ventilation.
Fast-tracking in pediatric cardiac surgery - The current standing

- Fewer ventilator associated complications such as:
  - Accidental extubation
  - Laryngotracheal trauma
  - Mucous plugging of endotracheal tube
  - Pulmonary hypertensive crisis from endotracheal suctioning
  - Barotrauma from positive pressure ventilation

- Ventilator associated pulmonary infections and atelectasis
- Reduced requirements of sedatives (and associated hemodynamic compromise)
- More rapid patient mobilization
- Earlier ICU discharge
- Decreased length of hospital stay
- Reduced costs (ventilator associated, as well as length of ICU/hospital stay)
- Reduced parental stress

Alexander JC Mittnacht, Ingrid Hollinger
Department of Anesthesiology, The Mount Sinai Medical Center, New York, NY, USA

Year: 2010 | Volume: 13 | Issue: 2 | Page: 92
# Ventilation Modes

## Mode of Ventilation | Other Names | Characteristics/Theoretical Benefits/Disadvantages
--- | --- | ---
**Volume Modes**
Assist-control ventilation | CMV with assist | Ventilator delivers preset volume; breaths can be either assist or control but of the same volume; may induce hyperinflation and respiratory alkalosis at high respiratory rates
SIMV |  | Mandatory breaths synchronized to coincide with spontaneous inspiration; guaranteed backup rate; cardiac output can decrease in patients with LV dysfunction because of increased afterload with unsupported spontaneous inspiratory efforts
**Pressure Modes**
PCV |  | Ventilator delivers set target pressure at a set respiratory rate; protects from barotrauma; volume delivered subject to lung compliance
PSV |  | Patients’ inspiratory effort assisted to a preset level; patient triggered, pressure limited, and flow cycled
CPAP | EPAP | Pressures set to remain constant during respiratory cycle while patients are allowed to breathe spontaneously
APRV | BiPap | Clinician set to level CPAP and time spent at each level (inspiratory and expiratory time); CPAP or pressure high and release pressure or pressure low; patients can breathe spontaneously at both levels; potential for hemodynamic compromise in preload-dependent conditions

## Dual Modes
- **PRVC**
  - AutoFlow (Dräger Medical AG & Co. KGaA, Germany)
  - Adaptive pressure control
  - Closed-loop, pressure-controlled mode; patient or time triggered with tidal volume as the variable selected by operator; maintains a more stable tidal volume as lung compliance varies while protecting from barotrauma
- **ASV**
  - Delivers pressure-controlled breaths using automatically calculated optimal settings (tidal volume and frequency) based on patients’ ideal body weight and percentage of minute volume ventilation; aims to minimize work of breathing while encouraging spontaneous breaths
- **PAV**
  - Pressure-controlled output by the ventilator is adjusted to perform accordingly to patients’ effort; maximizes ventilator-patient synchrony and reduces work of breathing
- **NAVA**
  - Electrical activity of diaphragm (Edi) is captured, fed back to ventilator, and breath assistance is delivered proportionally and in synchrony with patients’ Edi signal[^14-18]
What is the daily practice of mechanical ventilation in pediatric intensive care units?  
A multicenter study
<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 4</th>
<th>Day 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Acute on CPD&lt;sup&gt;a&lt;/sup&gt;</td>
<td>ARDS</td>
</tr>
<tr>
<td>Ventilatory parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidal volume (ml/kg)</td>
<td>11 (9, 13)</td>
<td>11 (10, 14)</td>
<td>11 (10, 14)</td>
</tr>
<tr>
<td>Respiratory rate (bpm)</td>
<td>25 (20, 30)</td>
<td>25 (20, 32)</td>
<td>24 (22, 30)</td>
</tr>
<tr>
<td>Patients with PEEP (n, %)</td>
<td>549 (83%)</td>
<td>46 (71%)</td>
<td>15 (95%)</td>
</tr>
<tr>
<td>Applied PEEP (cm H&lt;sub&gt;2&lt;/sub&gt;O)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4 (2, 5)</td>
<td>4 (3, 5)</td>
<td>8 (5, 10)</td>
</tr>
<tr>
<td>Peak pressure (cm H&lt;sub&gt;2&lt;/sub&gt;O)</td>
<td>24 (20, 28)</td>
<td>28 (23, 30)</td>
<td>36 (23, 40)</td>
</tr>
<tr>
<td>Blood arterial gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.39 (7.34, 7.45)</td>
<td>7.39 (7.32, 7.45)</td>
<td>7.40 (7.36, 7.45)</td>
</tr>
<tr>
<td>PaCO&lt;sub&gt;2&lt;/sub&gt; (mm Hg)</td>
<td>39 (32, 46)</td>
<td>48 (38, 60)</td>
<td>37 (32, 52)</td>
</tr>
<tr>
<td>Ratio PaO&lt;sub&gt;2&lt;/sub&gt; to FiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>221</td>
<td>126</td>
<td>88</td>
</tr>
<tr>
<td>FiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(125, 364)</td>
<td>(92, 204)</td>
<td>(65, 181)</td>
</tr>
</tbody>
</table>
High tidal volumes in mechanically ventilated patients increase organ dysfunction after cardiac surgery

• In the multivariate analysis, high and traditional tidal volumes were independent risk factors for organ failure, multiple organ failure, and prolonged stay in the intensive care unit

Lellouche et al; Anesthesiology 2012 May;116(5):1072-82, Centre de Recherche, Quebec, Canada
High vs Low Vt  “baby lung”

• It took until the end of the 20th century till the effects of the size of tidal volumes were examined in clinical trials with shocking results

• The ARMA trial showed an absolute reduction in mortality of 10 % when lower tidal volumes were compared with conventional in patients with ARDS

Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network. 
Ventilation with Lower Tidal Volumes as Compared with Traditional Tidal Volumes for Acute Lung Injury and the Acute Respiratory Distress Syndrome

The Acute Respiratory Distress Syndrome Network
VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

The Acute Respiratory Distress Syndrome Network

Results of ARDSnet Tidal Volume Trial

**Table 4. Main Outcome Variables.**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>GROUP RECEIVING LOWER TIDAL VOLUMES</th>
<th>GROUP RECEIVING TRADITIONAL TIDAL VOLUMES</th>
<th>P VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death before discharge home and breathing without assistance (%)</td>
<td>31.0</td>
<td>39.8</td>
<td>0.007</td>
</tr>
<tr>
<td>Breathing without assistance by day 28 (%)</td>
<td>65.7</td>
<td>55.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>No. of ventilator-free days, days 1 to 28</td>
<td>12±11</td>
<td>10±11</td>
<td>0.007</td>
</tr>
<tr>
<td>Baro-trauma, days 1 to 28 (%)</td>
<td>10</td>
<td>11</td>
<td>0.43</td>
</tr>
<tr>
<td>No. of days without failure of nonpulmonary organs or systems, days 1 to 28</td>
<td>15±11</td>
<td>12±11</td>
<td>0.006</td>
</tr>
</tbody>
</table>

9% absolute risk reduction in mortality = NNT ~ 10
More recent trials suggest that even patients without acute respiratory distress syndrome benefit from the use of lower tidal volumes

Association between use of lung-protective ventilation with lower tidal volumes and clinical outcomes among patients without acute respiratory distress syndrome: a meta-analysis.
Serpa Neto A, Cardoso SO, Manetta JA, Pereira VG, Espósito DC, Pasqualucci Mde O, Damasceno MC, Schultz MJ


Ventilator-associated lung injury in patients without acute lung injury at the onset of mechanical ventilation.
Prone Positioning in Severe Acute Respiratory Distress Syndrome

Claude Guérin, M.D., Ph.D., Jean Reignier, M.D., Ph.D.,
Jean-Christophe Richard, M.D., Ph.D., Pascal Beuret, M.D., Arnaud Gacouin, M.D.,
Thierry Boulay, M.D., Emmanuelle Mercier, M.D., Michel Badet, M.D.,
Alain Mercat, M.D., Ph.D., Olivier Baudin, M.D., Marc Clavel, M.D.,
Delphine Chatellier, M.D., Samir Jaber, M.D., Ph.D., Sylvène Rosselli, M.D.,
Jordi Mancebo, M.D., Ph.D., Michel Sirodot, M.D., Gilles Hilbert, M.D., Ph.D.,
Christian Bengler, M.D., Jack Richet, M.D., Marc Ghainnier, M.D., Ph.D.,
Frédérique Baye, M.D., Gaël Bourdin, M.D., Véronique Leray, M.D.,
Raphaële Girard, M.D., Loredana Baboi, Ph.D., and Louis Ayyaz, M.D.,
for the PROSEVA Study Group

DOI: 10.1056/NEJMoa1214103

Severe ARDS:
• PF ratio < 150
• $\text{PaO}_2 \geq 60$
• PEEP $\geq 5$
• $V_t \sim 6 \text{ ml/kg}$

At least 16 hours/day in prone position

Figure 2. Kaplan–Meier Plot of the Probability of Survival from Randomization to Day 90.
High Level Positive End Expiratory Pressure (PEEP) in Acute Respiratory Insufficiency*

R. R. Kirby, M.D.,** J. B. Downs, M.D.;† J. M. Civetta, M.D.;‡
J. H. Modell, M.D., F.C.C.P.;§ F. J. Dannemiller, M.D., F.C.C.P.;||
E. F. Klein, M.D.;* and M. Hodges¶

Twenty-eight patients developed severe, progressive acute respiratory insufficiency despite aggressive application of conventional respiratory therapy. Application of increased PEEP (18 torr or greater) resulted in a significant decrease in QA/QT. Selection of the optimal level of PEEP for each patient required serial determinations of QA/QT and measurement of cardiovascular response. The overall survival rate was 61 percent. Acute respiratory insufficiency was a proximate cause of death in only one patient. Four of the patients (14 percent) developed a pneumothorax following institution of high PEEP therapy. Cardiac output was not affected adversely at any level of PEEP up to 32 torr (44 cm H₂O). We conclude that high levels of PEEP can be therapeutic for patients with refractory respiratory failure when combined with intermittent mandatory ventilation and careful cardiovascular monitoring. As with any therapy, the optimum dose should be tailored to each patient according to his needs and response.
Pathophysiologic consequences from the increase in lung volume and alveolar pressure

- If end-expiratory lung volume exceeds predicted functional residual capacity causes dynamic hyperinflation.
- Respiratory compliance decreases.
- The respiratory muscles progressively operate in an unfavorable part of their length-tension curve.
- Alveolar ventilation will depend on increased work of breathing.
• Lower Inflection Point
  • Alveolar closing pressure below this
  • Apply enough PEEP

• Upper Inflection Point
  • Risk for over distention above
  • Limit pressure/volume

Khemani, Bart, Newth 2007
Positive end-expiratory pressure
Luciano Gattinoni\textsuperscript{a,b}, Eleonora Carlesso\textsuperscript{b}, Luca Brazzi\textsuperscript{a,b} and Pietro Caironi\textsuperscript{a,b}

\textsuperscript{a}Dipartimento di Anestesia, Rianimazione (Intensiva e Subintensiva) e Terapia del Dolore, Fondazione IRCCS – Ospedale Maggiore Policlinico Mangiagalli Regina Elena' di Milano and \textsuperscript{b}Dipartimento di Anestesiologia, Terapia Intensiva e Scienze Dermatologiche, Università degli Studi, Milan, Italy

Correspondence to Professor Luciano Gattinoni, MD, FRCP, Dipartimento di Anestesiologia, Terapia Intensiva e Scienze Dermatologiche, Fondazione IRCCS – Ospedale Maggiore Policlinico, Mangiagalli, Regina Elena’ di Milano, Via Francesco Sforza 35, 20122 Milan, Italy
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Current Opinion in Critical Care 2010, 16:39–44

Purpose of review
In the last 2 years, several reports have dealt with recruitment/positive end-expiratory pressure (PEEP) selection. Most of them confirm previous results and few add new information.

Recent findings
It has been definitely confirmed that opening pressures are different throughout the acute respiratory distress syndrome lung parenchyma, ranging from 5–10 up to 30–40 cmH\textsubscript{2}O. The highest opening pressures are required to open the most dependent lung regions. It has been found that in 2 s, most of the recruitable lung regions may be open when a proper pressure is applied. The best way to assess recruitment is computed tomography scanning, whereas lung mechanics are a reasonable bedside surrogate. Impedance tomography has been increasingly tested, whereas gas exchange is the less reliable indicator of recruitment. A large outcome
• The two largest outcome studies so far concluded suggested that higher PEEP should be preferred to lower PEEP in the most severe ARDS patients

• Individual PEEP selection should be applied for considering the expiratory phase of the pressure – volume curve
iPEEP or auto PEEP

- Dynamic hyperinflation
- First described by Bergman in 1972 and Jonson et al in 1975
- Its clinical implications and measurement technique during mechanical ventilation were further described by Pepe and Marini in 1982
Auto PEEP mechanism
Measurement of Air Trapping, Intrinsic Positive End-Expiratory Pressure, and Dynamic Hyperinflation in Mechanically Ventilated Patients

Lluís Blanch MD PhD, Francesca Bernabé MD, and Umberto Lucangelo MD

Respir Care 2005;50(1):110–123
Dynamic hyperinflation is affected by

- VT
- I:E ratio, expiratory time
- Resistance
- Compliance
- **External factors**: 
  - High minute ventilation
  - Increased equipment expiratory resistance (e.g., a mucus-narrowed endotracheal tube)
Pulsus Paradoxicus (>10 mmHg)
Auto-PEEP contributes to hypoxemia and hypercapnia

• Possibly as a result of inhomogeneous distribution of inspired gas between lung units with different time constants
• Decreasing pulmonary blood flow to overdistended alveoli
• Increase gap ETCO2/PaO2
Experimental animal receiving manual (bag) ventilation during cardiopulmonary resuscitation

Respir Care 2005;50(1):110–123
Mechanisms involved in the development of auto-PEEP

F. LAGHI, A. GOYAL Minerva Anestesiol 2012;78:201-21
• Dynamic hyperinflation affects tidal ventilation, increases airways resistance, and causes intrinsic positive end-expiratory pressure (auto-PEEP)

• Auto-PEEP can be identified in passively breathing patients by observation of real-time ventilator flow and pressure graphics

• In spontaneously breathing patients, auto-PEEP is measured by simultaneous recordings of esophageal and flow waveforms
Hemodynamic Effects of Auto-PEEP

• May be equal to or worse than the effects of a similar degree of PEEP applied to a patient with normal lungs
• Increased mean intrathoracic pressure decreases venous return and reduces the preload of both ventricles
• Decreases LV compliance and may increase RV afterload because of high pulmonary vascular resistance
• Increase in intrathoracic pressure may falsely increase pulmonary capillary wedge pressure and right-atrial pressure which can lead to mistakes in hemodynamic management
• Non hemodynamic consequences are patient-ventilator asynchrony and increased WOB

Respir Care 2005;50(1):110–123
Gracias!

Special thanks to Daniel Bolivar for helping me with the animations