BASIC MODES OF MECHANICAL VENTILATION:

Niall D. Ferguson, MD, FRCPC, MSc
Head of Critical Care Medicine
University Health Network & Sinai Health System
Professor, Departments of Medicine & Physiology,
Institute of Health Policy, Management and Evaluation
Interdepartmental Division of Critical Care Medicine
University of Toronto
Outline

How ventilators work
How basic modes work
General ventilation targets
How to set PEEP
Ventilators blow gas to deliver volume and generate pressure

\[ C = \frac{\Delta V}{\Delta P} \]
Ventilators blow gas to deliver volume and generate pressure

\[ C = \frac{\Delta V}{\Delta P} \]

Ventilators target either volume or pressure.

One is set (Independent).

The other becomes the dependent variable.
Ventilators target either Volume or Pressure. One is set (independent) and the other becomes the dependent variable.

\[ C = \frac{\Delta V}{\Delta P} \]

**Volume Control**
- Set tidal volume → Airway pressures depend on patient

**Pressure Control**
- Set driving pressure → Tidal volume depends on patient
Ventilator modes have 3 key elements

3 key elements of conventional modes

- Trigger
- Limit
- Cycle
Ventilator modes have 3 key elements:

- Trigger
  - Machine Initiated (Time)
  - Patient Initiated (Pressure/Flow)

- Limit
  - Volume
  - Pressure

- Cycle
  - Volume
  - Time
  - Flow
Ventilator modes have 3 key elements

VC (A/c) - Volume-cycled Assist Control Ventilation

Trigger: Patient or Timer
Limit: Volume
Cycle: Volume
Ventilator modes have 3 key elements

**PC - Pressure Control** (really assist-control)

**Trigger:** Patient or Time

**Limit:** Pressure

**Cycle:** Time
Ventilator modes have 3 key elements
Ventilator modes have 3 key elements

PS - Pressure Support Ventilation

Trigger: Patient
Limit: Pressure
Cycle: Flow (\% Peak Inspiratory Volume)
Ventilator modes have 3 key elements
Ventilator modes have 3 key elements

PS - Pressure Support Ventilation

Trigger: Patient
Limit: Pressure
Cycle: Flow (\% Peak Insp V)
Ventilators target either Volume or Pressure. One is set (independent), the other becomes the dependent variable.

\[ C = \frac{\Delta V}{\Delta P} \]
Which is better – Volume or Pressure Control?

VC vs PC

VC

- Direct control of $V_t$
- Only indirect control if $\Delta P$
- If patient worsens, $\Delta P$ may be inappropriately
- Spontaneous breathing likely to lead to desensitizing

PC

- Direct control of $A_P$
- Only indirect control of $V_t$
- If patient improves, $V_t$ may be inappropriately
- Spontaneous breathing can lead to larger $V_t$
Ventilator Targets

Ventilation - target "acceptable" gas exchange - often accept $PaCO_2 > 45$ as long as pH OK (> 7.25)

- $V_t$ 6 ml/kg PBW (4-8)
- $\Delta P < 15$ cm H$_2$O
- $P_{plat} < 30$ cm H$_2$O
Ventilator Targets

Oxygenation
- \( F_\text{IO}_2 \) - immediate response
- PEEP

- target lowest that keeps
  \( P_{\text{AO}} 70-90 \) (Sp\( \text{O}_2 92-98\%\))

- more complicated
  affects both oxygenation & hemodynamics
Starting Ventilation for Respiratory Failure

1. Start at PEEP = 10, Set $V_t$ 6ml/kg; titrate $FiO_2$ to $SpO_2$
   
   1. Reassess
      
      2. $SpO_2 < 90\%$ or $FiO_2 > 0.6$?
      
         1. Try 4 PEEP to 15
      
      2. $P_{PLAT} > 30$ or $\Delta P > 15$?
         
         1. Try $V_t$ as tolerated by $pH$
Everything we know about the ARDS clinical phenotype we learned in 1967

**TABLE III—EFFECT OF POSITIVE END-EXPIRATORY PRESSURE IN PATIENT 11 WITH VIRAL PNEUMONIA**

<table>
<thead>
<tr>
<th></th>
<th>No retard (30 l./min.)</th>
<th>Retard (15 l./min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{1}O_{2}$ (mm. Hg)</td>
<td>560 (mm. Hg)</td>
<td>560 (mm. Hg)</td>
</tr>
<tr>
<td>$P_{2}O_{2}$ (mm. Hg)</td>
<td>42 (mm. Hg)</td>
<td>141.5 (mm. Hg)</td>
</tr>
<tr>
<td>$S_{a}O_{2}$ (%)</td>
<td>78 (74)</td>
<td>98 (98)</td>
</tr>
<tr>
<td>$P_{3}CO_{2}$ (mm. Hg)</td>
<td>31 (33)</td>
<td>39.5 (35)</td>
</tr>
<tr>
<td>pH</td>
<td>7.436 (7.435)</td>
<td>7.370 (7.405)</td>
</tr>
<tr>
<td>Blood-pressure (mm. Hg)</td>
<td>120/8 (mm. Hg)</td>
<td>120/84 (mm. Hg)</td>
</tr>
<tr>
<td>Time (min.)</td>
<td>0 (55 min.)</td>
<td>30 min. (65 min.)</td>
</tr>
</tbody>
</table>

Oxygenation improvement with PEEP
OPTIMUM END-EXPIRATORY AIRWAY PRESSURE IN PATIENTS WITH ACUTE PULMONARY FAILURE

PETER M. SUTER, M.D., H. BARRIE FAIRLEY, M.B., B.S., F.F.A.R.C.S., AND MICHAEL D. ISENBERG, M.D.

Abstract To determine whether in the management of pulmonary failure, the maximum compliance produced by positive end-expiratory pressure coincides with optimum lung function, 15 normovolemic patients requiring mechanical ventilation for acute pulmonary failure were studied. The end-expiratory pressure resulting in maximum oxygen transport (cardiac output times arterial oxygen content) and the lowest dead-space fraction both resulted in the greatest total static compliance. This end-expiratory pressure varied between 0 and 15 cm of water and correlated inversely with functional residual capacity at zero end-expiratory pressure (r = −0.72, p < 0.005). Mixed venous oxygen tension increased between zero end-expiratory pressure and the end-expiratory pressure resulting in maximum oxygen transport, but then decreased at higher end-expiratory pressures.

When measurements of cardiac output or of true mixed venous blood are not available, compliance may be used to indicate the end-expiratory pressure likely to result in optimum cardiopulmonary function. (N Engl J Med 292:284-289, 1975)
Set PEEP (cm of H₂O) in ARDS – Means & %age
Set PEEP

8.4  7.4  8.3  10.1
Atelectasis Causes Alveolar Injury in Nonatelectatic Lung Regions

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


IL-6 Stain
Setting PEEP

Defined range
• Low PEEP arm of ExPress (5-9 cm H\textsubscript{2}O)
Plateau pressure limit
• High PEEP arm of ExPress (28-30 cm H\textsubscript{2}O)

PEEP-FiO\textsubscript{2} Table
• Higher vs. Lower – ARMA, LOVS, ALVEOLI
Pressure/Volume measurements
Transpulmonary pressure limit
Decremental PEEP titration
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*

High Stretch
- $V_T$: 11.8
- $P_{PLAT}$: 32–34
- RR: 18
- $V_{MIN}$: 13
- PEEP: 8

Mortality 40%

Low Stretch
- $V_T$: 6.2 ml/kg
- $P_{PLAT}$: 25 cm H$_2$O
- RR: 29
- $V_{MIN}$: 13 L/min
- PEEP: 9 cm H$_2$O

Mortality 31%*  

*p=0.005

Table 1 ARDSNet table of $\text{FiO}_2$ and PEEP values to keep $\text{SpO}_2 \geq 88\%$ or $\text{PaO}_2 \geq 55\text{ mmHg}$

<table>
<thead>
<tr>
<th>$\text{FiO}_2$</th>
<th>30%</th>
<th>40%</th>
<th>40%</th>
<th>50%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>90%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEEP</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>18-24</td>
</tr>
</tbody>
</table>
Table 2. Allowable PEEP Ranges at Specified Levels of FiO₂

<table>
<thead>
<tr>
<th>Fraction of Inspired Oxygen (FiO₂)</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control PEEP ranges, cm H₂O</td>
<td>5</td>
<td>5-8</td>
<td>8-10</td>
<td>10</td>
<td>10-14</td>
<td>14</td>
<td>14-18</td>
<td>18-24</td>
</tr>
<tr>
<td>Lung open ventilation PEEP ranges, cm H₂O</td>
<td>5-10</td>
<td>10-18</td>
<td>18-20</td>
<td>20</td>
<td>20</td>
<td>20-22</td>
<td>22</td>
<td>22-24</td>
</tr>
<tr>
<td>After protocol change</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: PEEP, positive end-expiratory pressure.

*Both ventilation strategies included a protocol for reducing PEEP when plateau pressure exceeded the assigned plateau pressure limit or when mean arterial pressure decreased to less than 60 mm Hg, whether or not this occurred in the setting of an increase in PEEP.*
Higher vs Lower Positive End-Expiratory Pressure in Patients With Acute Lung Injury and Acute Respiratory Distress Syndrome: Systematic Review and Meta-analysis

Matthias Briel, MD, MSc

In-hospital time to death

Patients with ARDS

Patients without ARDS

ICU Mortality: RR 0.85 (0.76-0.94)

Hosp Mortality: RR 0.90 (0.81-1.0)

HR, 0.85 (95% CI, 0.73-0.99); P = .03

HR, 1.32 (95% CI, 0.87-2.00); P = .20

JAMA. 2010;303(9):865-873
Lung Recruitment in Patients with the Acute Respiratory Distress Syndrome

Luciano Gattinoni, M.D., F.R.C.P., Pietro Caironi, M.D., Massimo Cressoni, M.D., Davide Chiumello, M.D., V. Marco Ranieri, M.D., Michael Quintel, M.D., Ph.D., Sebastiano Russo, M.D., Nicolò Patroniti, M.D., Rodrigo Cornejo, M.D., and Guillermo Bugedo, M.D.

Higher Percentage of Potentially Recruitable Lung
Lung Recruitment in Patients with the Acute Respiratory Distress Syndrome

Luciano Gattinoni, M.D., F.R.C.P., Pietro Caironi, M.D., Massimo Cressoni, M.D., Davide Chiumello, M.D., V. Marco Ranieri, M.D., Michael Quintel, M.D., Ph.D., Sebastiano Russo, M.D., Nicolò Patroniti, M.D., Rodrigo Cornejo, M.D., and Guillermo Bugedo, M.D.

Lower Percentage of Potentially Recruitable Lung

5 cm of water

45 cm of water
Use of dynamic compliance for open lung positive end-expiratory pressure titration in an experimental study

(Crit Care Med 2007; 35:214–221)

Fernando Suarez-Sipmann, MD; Stephan H. Böhm, MD; Gerardo Tusman, MD; Tanja Pesch; Oliver Thamm; Hajo Reissmann, MD; Andreas Reske, MD; Anders Magnusson, MD, PhD; Göran Hedenstierna, MD, PhD
Bedside Selection of Positive End-Expiratory Pressure in Mild, Moderate, and Severe Acute Respiratory Distress Syndrome*  


Davide Chiumello, MD1,2; Massimo Cressoni, MD2; Eleonora Carlesso, MSc2; Maria L. Caspani, MD1; Antonella Marino, MD2; Elisabetta Gallazzi, MD2; Pietro Caironi, MD1,2; Marco Lazzerini, MD3; Onnen Moerer, MD4; Michael Quintel, MD4; Luciano Gattinoni, MD, FRCP1,2

Only PEEP by O2 gave higher PEEP with increasing severity & recruitability
Subphenotypes in acute respiratory distress syndrome: latent class analysis of data from two randomised controlled trials

Carolyn S Calfee, Kevin Delucchi, Polly E Parsons, B Taylor Thompson, Lorraine B Ware, Michael A Matthay, and the NHLBI ARDS Network

ARMA & ALVEOLI Trials
Latent Class Modeling

<table>
<thead>
<tr>
<th></th>
<th>Phenotype 1 (n=404)</th>
<th>Phenotype 2 (n=145)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low PEEP (n=202)</td>
<td>High PEEP (n=202)</td>
</tr>
<tr>
<td>Mortality at 90 days</td>
<td>33 (16%)</td>
<td>48 (24%)</td>
</tr>
<tr>
<td>Ventilator-free days</td>
<td>20 (10–25)</td>
<td>21 (3–24)</td>
</tr>
<tr>
<td>Organ failure free-days</td>
<td>22 (11–26)</td>
<td>22 (9–26)</td>
</tr>
</tbody>
</table>

Data are n (%) or median (IQR). *p value for interaction between positive end-expiratory pressure (PEEP) assignment and phenotype.

Table 5: Differences in response to PEEP strategy by phenotype (ALVEOLI cohort only)
Oxygenation Response to Positive End-Expiratory Pressure Predicts Mortality in Acute Respiratory Distress Syndrome
A Secondary Analysis of the LOVS and ExPress Trials

Ewan C. Goligher\textsuperscript{1,2,3,4}, Brian P. Kavanagh\textsuperscript{1,5,6}, Gordon D. Rubenfeld\textsuperscript{1,2,7}, Neill K. J. Adhikari\textsuperscript{1,2,7}, Ruxandra Pinto\textsuperscript{7}, Eddy Fan\textsuperscript{1,2,4}, Laurent J. Brochard\textsuperscript{1,2,8}, John T. Granton\textsuperscript{1,2,4}, Alain Mercat\textsuperscript{9}, Jean-Christophe Marie Richard\textsuperscript{10}, Jean-Marie Chretien\textsuperscript{11}, Graham L. Jones\textsuperscript{12}, Deborah J. Cook\textsuperscript{12,13}, Thomas E. Stewart\textsuperscript{1,2,4}, Arthur S. Slutsky\textsuperscript{1,2,4}, Maureen O. Meade\textsuperscript{12,13}, and Niall D. Ferguson\textsuperscript{1,2,3,4}

Am J Respir Crit Care Med Vol 190, Iss 1, pp 70–76, Jul 1, 2014
Summary – Take Home Points

- Ventilators target either pressure or volume… the other is then dependent on patient mechanics
- Remember volume–pressure relationship (Compliance)
- Apply standard principles of lung–protection and target acceptable gas exchange
- Setting PEEP is as complicated as you want to make it
n.ferguson@utoronto.ca
@nialldeferguson

October 4-7, 2020
Sheraton Centre Hotel, Toronto
www.criticalcarecanada.com