BASIC MODES OF MECHANICAL VENTILATION:

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UHN Toronto General, Toronto Western, Princess Margaret, Toronto Rehab

Mount Sinai Hospital
Sinai Health System
Joseph & Wolf Lebovic Health Complex

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Outline

How ventilators work

How basic modes work

General ventilation targets

How to set PEEP

Ventilators blow gas to deliver volume and generate pressure

$$C = \frac{\Delta V}{\Delta P}$$

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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

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$$C = \frac{\Delta V}{\Delta P}$$

Volume Control

↳ set tidal volume → Airway Pressures depend on patient

Pressure Control

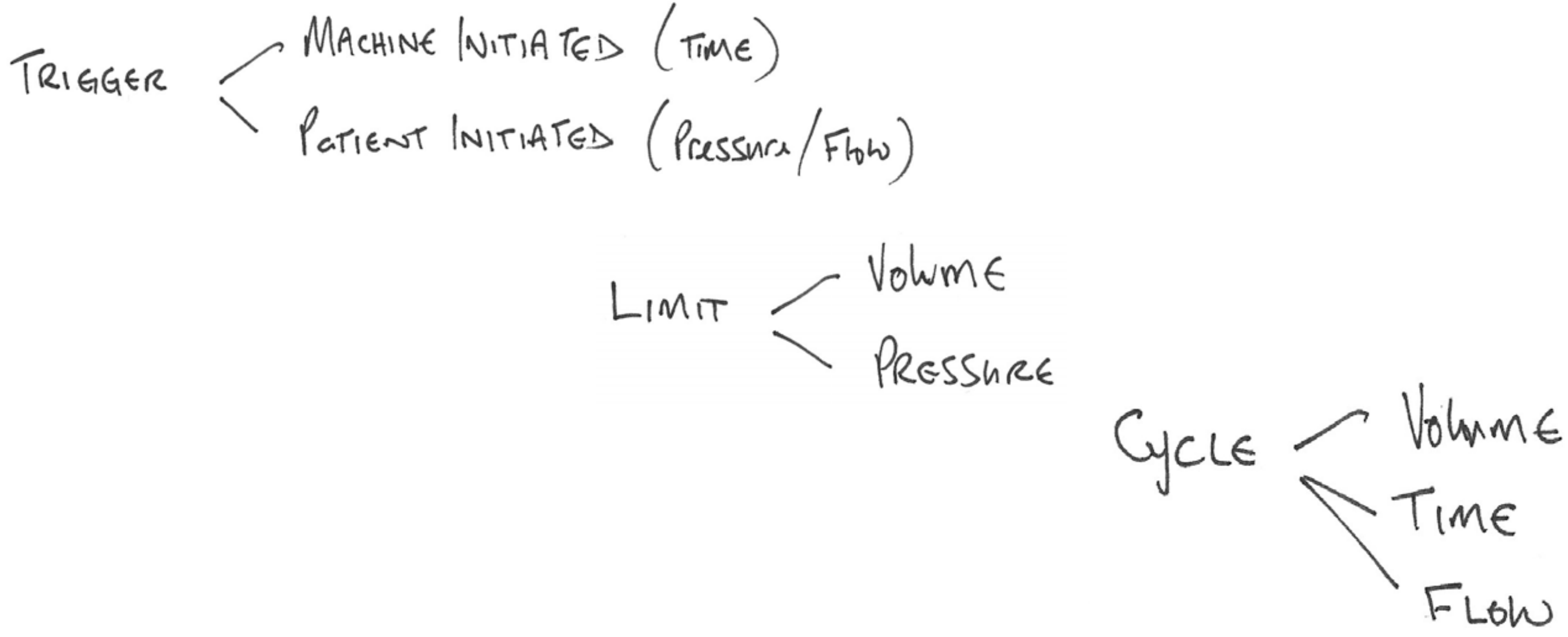
↳ set driving pressure → Tidal Volume depends on patient

Ventilator modes have 3 key elements

3 key elements of conventional modes

- TRIGGER
- LIMIT
- CYCLE

Ventilator modes have 3 key elements



Ventilator modes have 3 key elements

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

TRIGGER: Patient or Time
LIMIT: Volume
CYCLE: Volume

Ventilator modes have 3 key elements

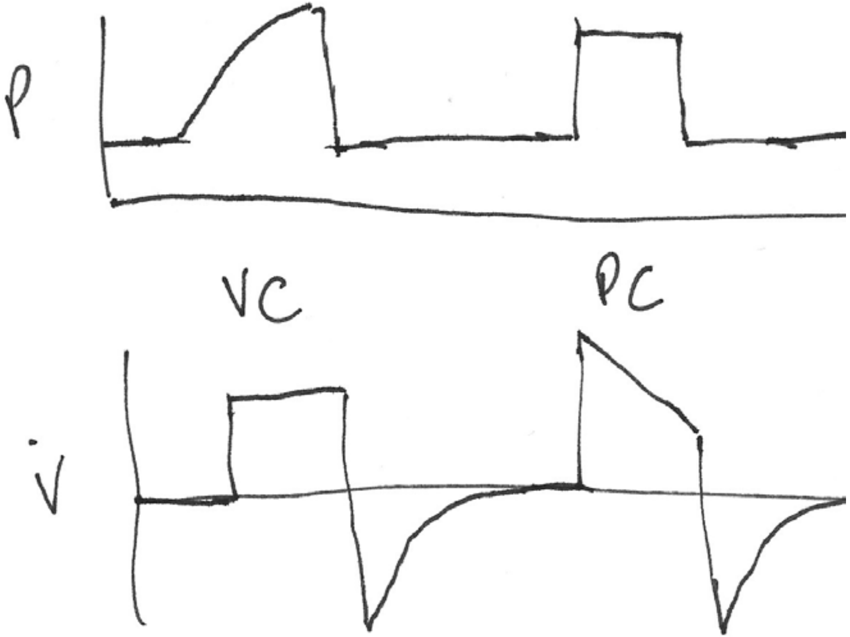
PC – PRESSURE CONTROL (really assist-control)

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 Insp $\dot{V}$)

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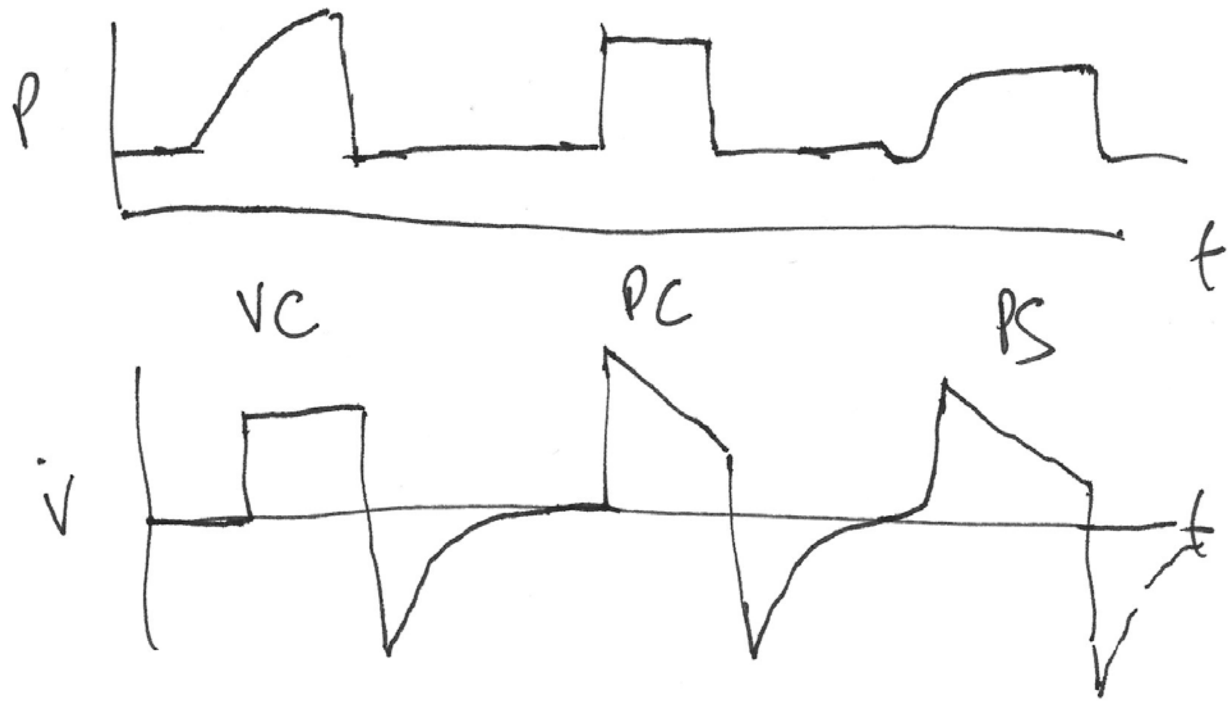
Ventilator modes have 3 key elements



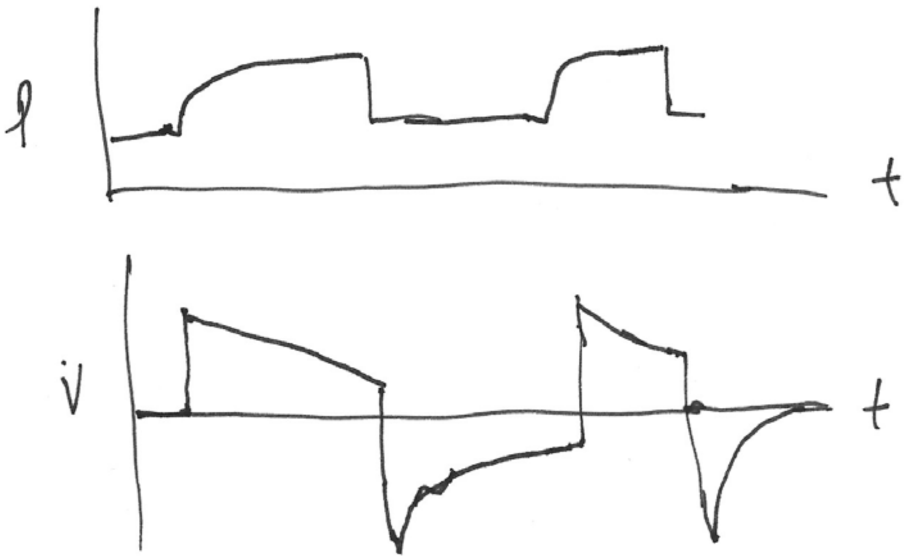
Ventilator modes have 3 key elements

PS – PRESSURE SUPPORT VENTILATION

TRIGGER: PATIENT

LIMIT: PRESSURE

CYCLE: FLOW (% PEAK INSP V̇)



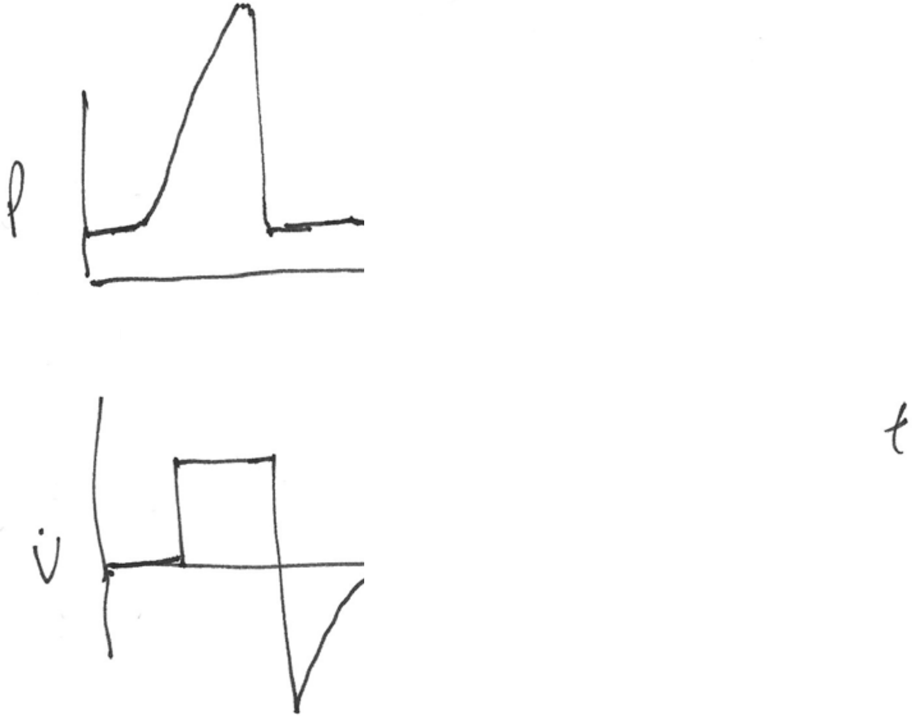
Ventilators target either VOLUME or PRESSURE

ONE is set (INDEPENDENT)

↳ The other becomes the DEPENDENT variable

$$C = \frac{\Delta V}{\Delta P}$$

Pneumothorax → ↓ C



Which is better – Volume or Pressure Control?

VC	vs	PC
• Direct control of V_T		• Direct Control ΔP
• Only indirect control of ΔP		• Only indirect control of V_T
• If patient C worsening ΔP may ↑ inadvertently		• If patient C improving V_T may ↑ inadvertently
• Spontaneous breathing likely to lead to double-triggers		• Spontaneous breathing can lead to larger V_T

Ventilator Targets

Ventilation — target "acceptable" gas exchange — often accept $PaCO_2$ > (N) as long as pH ok (>7.25)

- V_T 6 ml/kg PBW (4-8)
- ΔP < 15 cm H_2O
- P_{PLAT} < 30 cm H_2O

Ventilator Targets

Oxygenation — · FiO_2 — immediate response
- └ target lowest that keeps PaO_2 70-90 (SpO_2 92-98%)

· PEEP
- └ more complicated
  - · affects both oxygenation & hemodynamics

Starting Ventilation for Respiratory Failure

For Respiratory Failure

- Start at PEEP = 10, Set V_T 6 ml/kg ; titrate F_iO_2 to SpO_2
    - ↳ REASSESS
        - $SpO_2 < 90\%$ or $F_iO_2 > 0.6$?
            - ↳ Try ↑ PEEP to 15
        - $P_{PLAT} > 30$ or $\Delta P > 15$?
            - ↳ 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

—	No retard (30 l./min.)	Retard (15 l./min.)
P_{IO_2} (mm. Hg)	560 (mm. Hg)	560 (mm. Hg)
P_{aO_2} (mm. Hg)	42 (mm. Hg)	141·5 (mm. Hg)
S_{aO_2} (%)	78 (74)	98 (98)
P_{aCO_2} (mm. Hg)	31 (33)	39·5 (35)
pH	7·436 (7·435)	7·370 (7·405)
Blood-pressure (mm. Hg)	120/ ? (mm. Hg)	120/84 (mm. Hg)
Time (min.)	0 (55 min.)	30 min. (65 min.)

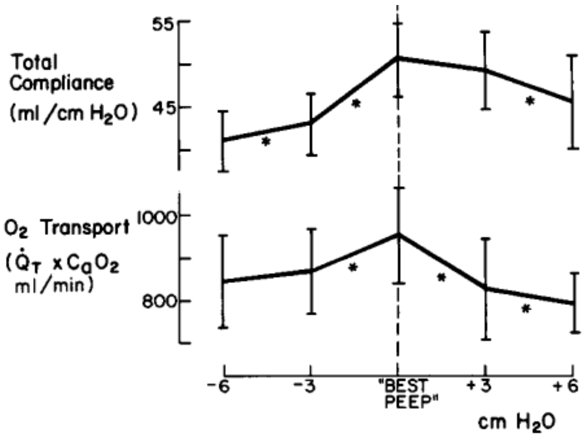
Oxygenation improvement with PEEP

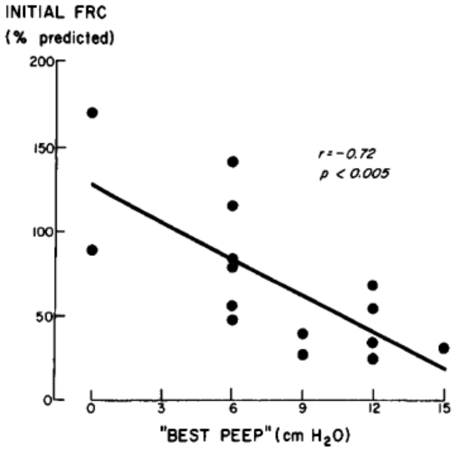
OPTIMUM END-EXPIRATORY AIRWAY PRESSURE IN PATIENTS WITH ACUTE PULMONARY FAILURE

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)



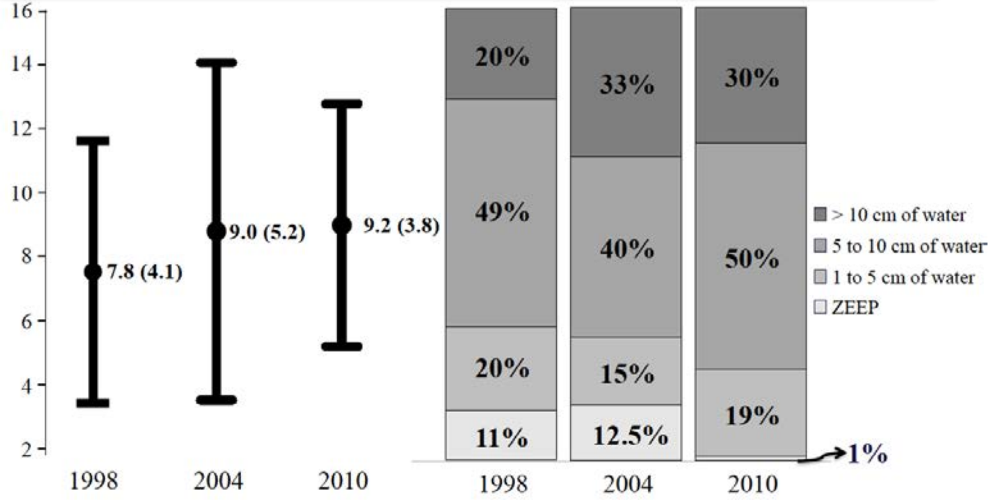


Evolution of Mortality over Time in Patients Receiving Mechanical Ventilation

Am J Respir Crit Care Med Vol 188, Iss. 2, pp 220–230, Jul 15, 2013

Andrés Esteban[1], Fernando Frutos-Vivar[1], Alfonso Muriel[2], Niall D. Ferguson[3], Oscar Peñuelas[1], Victor Abraira[2], Konstantinos Raymondos[4], Fernando Rios[5], Nicolas Nin[1], Carlos Apezteguía[5], Damian A. Violi[6], Arnaud W. Thille[7], Laurent Brochard[8], Marco González[9], Asisclo J. Villagomez[10], Javier Hurtado[11], Andrew R. Davies[12], Bin Du[13], Salvatore M. Maggiore[14], Paolo Pelosi[15], Luis Soto[16], Vinko Tomicic[17], Gabriel D'Empaire[18], Dimitrios Matamis[19], Fekri Abroug[20], Rui P. Moreno[21], Marco Antonio Soares[22], Yaseen Arabi[23], Freddy Sandi[24], Manuel Jibaja[25], Pravin Amin[26], Younsuck Koh[27], Michael A. Kuiper[28], Hans-Henrik Bülow[29], Amine Ali Zeggwagh[30], and Antonio Anzueto[31]

Set PEEP (cm of H_2O) in ARDS – Means & %age



Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

Epidemiology, Patterns of Care, and Mortality for Patients With Acute Respiratory Distress Syndrome in Intensive Care Units in 50 Countries

JAMA February 23, 2016 Volume 315, Number 8

Giacomo Bellani, MD, PhD; … R; Andres Esteban, MD, PhD;
Luciano Gattinoni, MD, FR… Marco Ranieri, MD;
Gordon Rubenfeld, MD, M… Sc; Antonio Pesenti, MD;
for the LUNG SAFE Investi…

Table 3. Baseline Characteristics of Patients With Acute Respiratory Distress Syndrome Treated With Invasive Ventilation by Severity Category at Diagnosis

Parameter	All (N = 2377)	Mild (n = 714)	Moderate (n = 1106)	Severe (n = 557)	P Value[a]
Age, median (IQR), y	61 (61-62)	61 (60-63)	62 (62-63)	57 (55-58)	<.001
No longer meet ARDS criteria after 24 h, No. (%) [95% CI]	486 (17.3) [15.9-18.7]	190 (26.6) [23.4-30.0]	152 (13.7) [11.8-15.9]	71 (12.8) [10.1-15.8]	<.001
Severity of illness, mean (95% CI), SOFA score[b]					
Day 1	10.1 (9.9-10.2)	8.8 (8.6-9.1)	10.2 (9.9-10.4)	11.4 (11.1-11.8)	<.001
Day 1 nonpulmonary[c]	6.9 (6.7-7.0)	6.7 (6.4-7.0)	6.9 (6.7-7.1)	7.0 (6.7-7.4)	.34
Worst	11.1 (10.9-11.3)	10.3 (10.0-10.6)	11.8 (11.5-12.0)	13.0 (12.6-13.3)	<.001
Worst nonpulmonary	8.0 (7.8-8.2)	8.0 (7.7-8.3)	8.7 (8.4-8.9)	9.0 (8.4-8.9)	<.001
Ventilator settings, first day of ARDS					

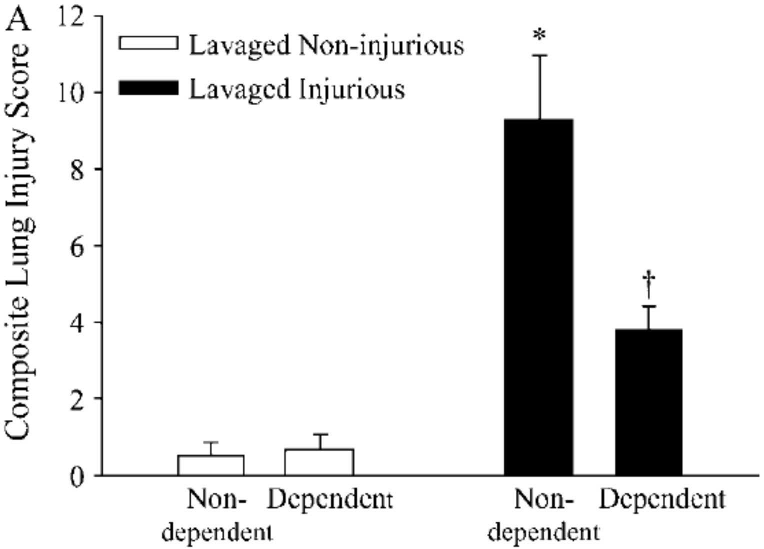
Set PEEP 8.4 7.4 8.3 10.1

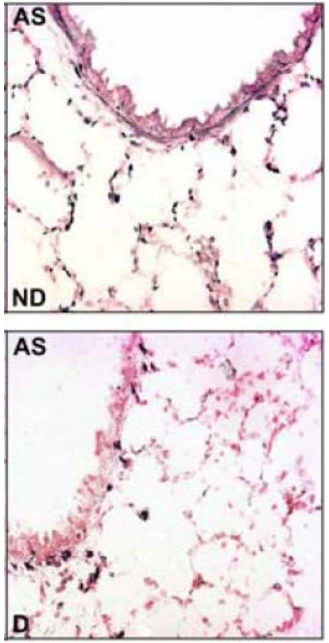
Parameter	All (N = 2377)	Mild (n = 714)	Moderate (n = 1106)	Severe (n = 557)	P Value[a]
Total respiratory rate, mean (95% CI), 1/min	20.8 (21.5-21.2)	19.5 (19.0-19.9)	20.7 (20.3-21.1)	22.7 (21.5-23.8)	<.001
VT, mean (95% CI), mL/kg PBW	7.6 (7.5-7.7)	7.8 (7.6-7.9	7.6 (7.5-7.7)	7.5 (7.3-7.6)	.02
Control vent mode	7.5 (7.4-7.6)	7.6 (7.5-7.8)	7.4 (7.3-7.6)	7.4 (7.2-7.6)	.06
Spontaneous vent mode	7.9 (7.8-8.1)	7.9 (7.7-8.2)	8.0 (7.7-8.2)	7.7 (7.4-8.1)	.55
P value (control vs spont mode)	<.001	.049	<.001	.053	
Set PEEP, mean (95% CI), cm H_2O	8.4 (8.3-8.6)	7.4 (7.2-7.6)	8.3 (8.1-8.5)	10.1 (9.8-10.4)	<.001
Peak pressure, mean (95% CI), cm H_2O[d]	27.0 (26.7-27.4)	24.7 (24.1-25.4)	26.9 (26.5-27.4)	30.3 (29.6-30.9)	<.001
Patients in whom P_{PLAT} measured, No. (%)					
Among all invasively ventilated patients, No. (%) [95% CI]	954 (40.1) [38.2-42.1]	260 (36.4) [32.9-40.1]	463 (41.9) [38.9-44.8]	231 (41.5) [37.3-45.7]	.05
Among patients with controlled ventilation, No. (%) [95% CI]	756 (48.5) [46.0-51.0]	198 (46.1) [41.3-51.0]	363 (49.8) [46.1-53.5]	195 (48.5) [43.5-53.5]	.49
P_{PLAT}, mean (95% CI), cm H_2O[e]	23.2 (22.6-23.7)	20.5 (19.8-21.3)	23.1 (22.6-23.7)	26.2 (25.2-27.1)	<.001
Standardized minute ventilation, mean (95% CI), l/min[f]	10.8 (10.6-11.0)	9.3 (9.1-9.6)	10.7 (10.5-11.0)	12.8 (12.3-13.3)	<.001
Spontaneous ventilation, No. (%) [95% CI]	723 (30.4 [8.6-32.3]	260 (36.4) [32.9-40.0]	336 (30.4) [29.7-35.3]	127 (22.8) [19.3-26.5]	<.001

Atelectasis Causes Alveolar Injury in Nonatelectatic Lung Regions

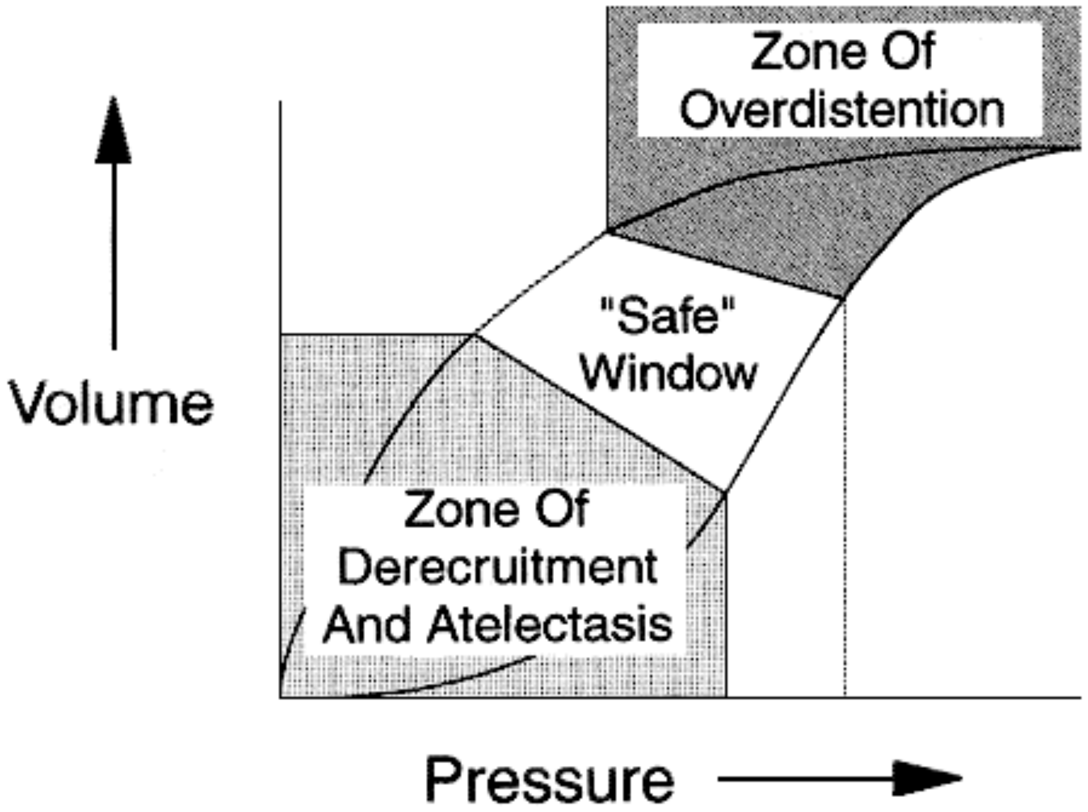
Am J Respir Crit Care Med Vol 174. pp 279–289, 2006

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





IL-6 Stain


Zone Of Overdistention
"Safe" Window
Zone Of Derecruitment And Atelectasis
Volume
Pressure

Setting PEEP

Defined range

- Low PEEP arm of ExPress (5-9 cm H_2O)

Plateau pressure limit

- High PEEP arm of ExPress (28-30 cm H_2O)

PEEP-FiO_2 Table

- **Higher vs. Lower – ARMA, LOVS, ALVEOLI**

Pressure/Volume measurements

Transpulmonary pressure limit

Decremental PEEP titration

VOLUME 342 MAY 4, 2000 NUMBER 18

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_2O
- RR: 29
- V_{MIN}: 13 L/min
- PEEP: 9 cm H_2O

Mortality 31%*

*p=0.005

Table 1 ARDSNet table of FiO_2 and PEEP values to keep $SpO_2 \geq 88\%$ or $PaO_2 \geq 55$ mmHg

FiO_2	30%	40%	40%	50%	50%	60%	70%	70%	70%	80%	90%	90%	90%	100%
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24

Ventilation Strategy Using Low Tidal Volumes, Recruitment Maneuvers, and High Positive End-Expiratory Pressure for Acute Lung Injury and Acute Respiratory Distress Syndrome

A Randomized Controlled Trial

JAMA. 2008;299(6):637-645

Table 2. Allowable PEEP Ranges at Specified Levels of FIO_2[a]

	Fraction of Inspired Oxygen (FIO_2)							
	0.3	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
Control PEEP ranges, cm H_2O	5	5-8	8-10	10	10-14	14	14-18	18-24
Lung open ventilation PEEP ranges, cm H_2O								
After protocol change	5-10	10-18	18-20	20	20	20-22	22	22-24

Abbreviation: PEEP, positive end-expiratory pressure.

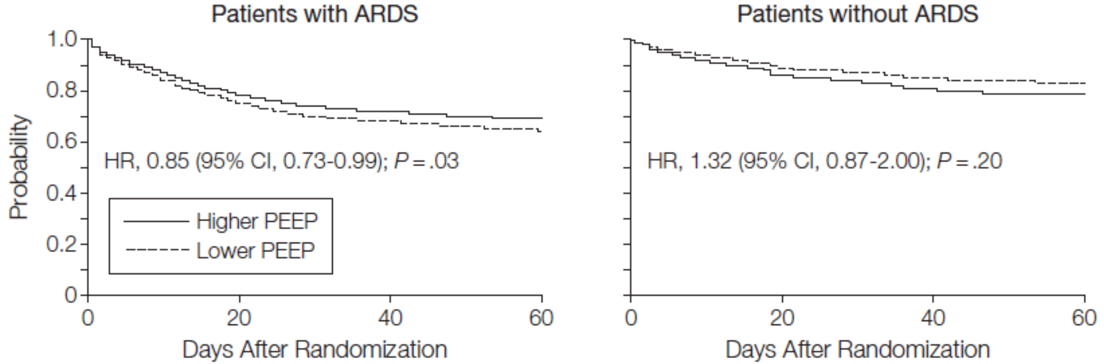
[a] Both ventilation strategies included a protocol for reducing PEEP when plateau pressure exceeded the assigned plateau pressure limit or when mean arterial pressure decreased to less than 60 mm Hg, whether or not this occurred in the setting of an increase in PEEP.

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



No. at risk								
Higher PEEP	949	760	693	666	183	158	148	144
Lower PEEP	939	723	649	619	219	196	186	183

ICU Mortality: RR 0.85 (0.76-0.94)

Hosp Mortality: RR 0.90 (0.81-1.0)

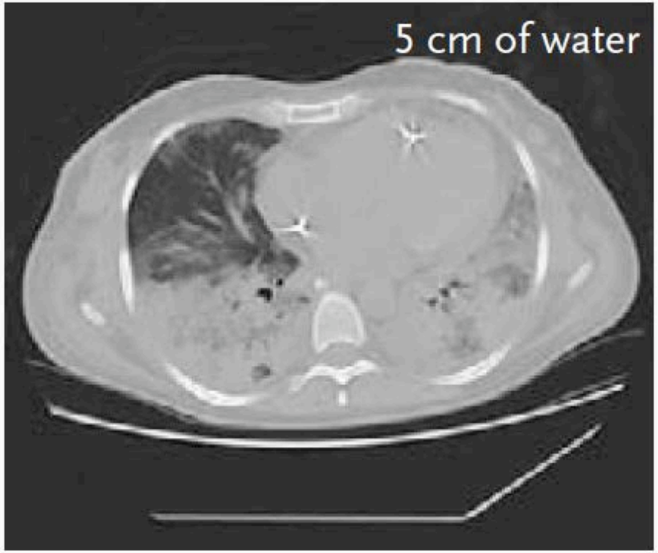
JAMA. 2010;303(9):865-873

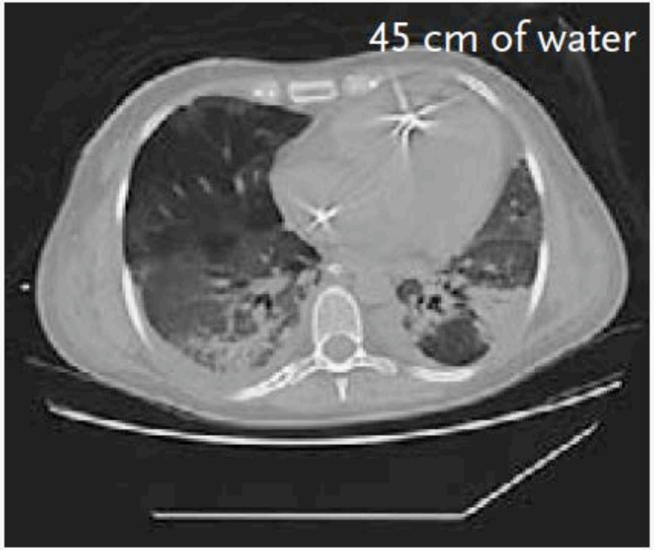
N Engl J Med 2006;354:1775-86.

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





N Engl J Med 2006;354:1775-86.

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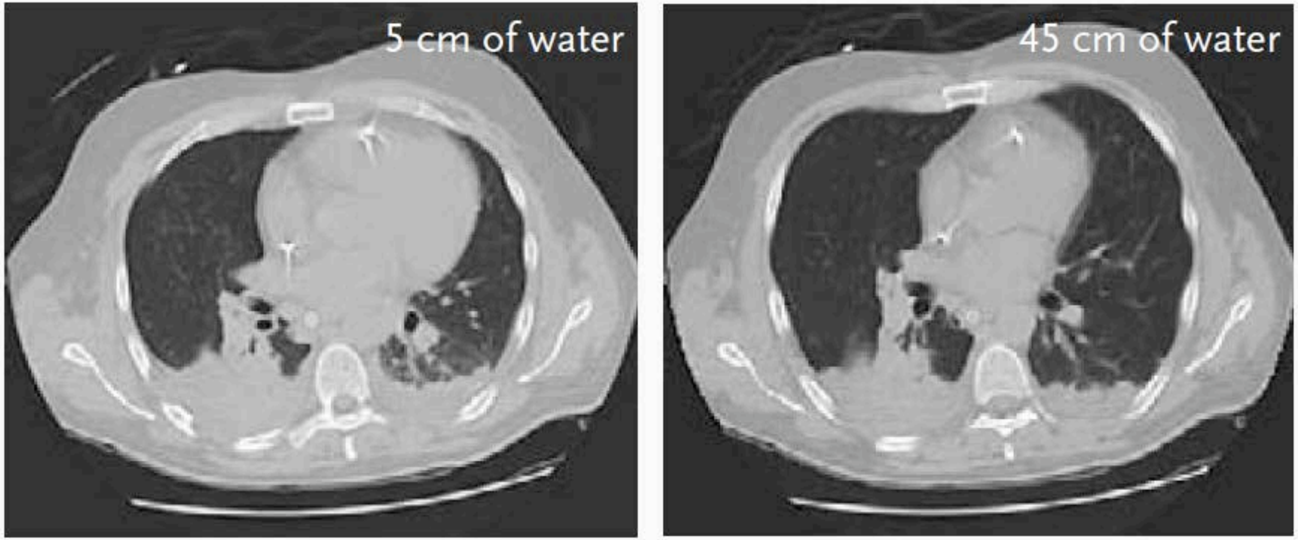
Luciano Gattinoni, M.D., F.R.C.P., Pietro Caironi, M.D., Massimo Cressoni, M.D., Davide Chiumello, M.D., V. Marco Ranieri, M.D., Michael Quintel, M.D., Ph.D., Sebastiano Russo, M.D., Nicolò Patroniti, M.D., Rodrigo Cornejo, M.D., and Guillermo Bugedo, M.D.

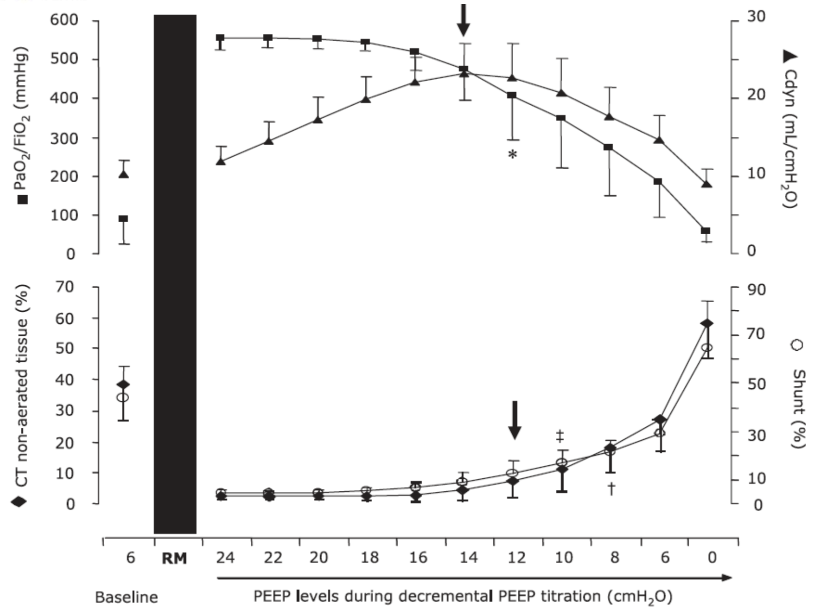
Lower Percentage of Potentially Recruitable Lung



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



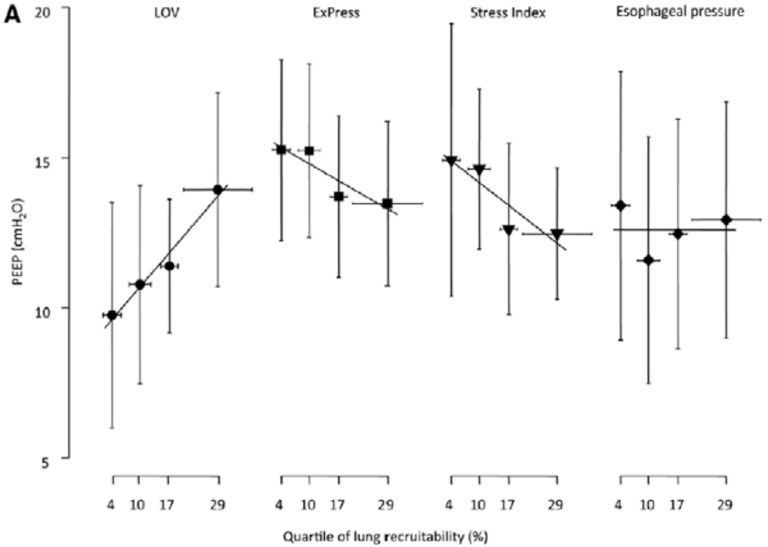
Bedside Selection of Positive End-Expiratory Pressure in Mild, Moderate, and Severe Acute Respiratory Distress Syndrome*

Crit Care Med 2014; 42:252–264

Davide Chiumello, MD[1,2]; Massimo Cressoni, MD[2]; Eleonora Carlesso, MSc[2]; Maria L. Caspani, MD[1]; Antonella Marino, MD[2]; Elisabetta Gallazzi, MD[2]; Pietro Caironi, MD[1,2]; Marco Lazzerini, MD[3]; Onnen Moerer, MD[4]; Michael Quintel, MD[4]; Luciano Gattinoni, MD, FRCP[1,2]

Only PEEP by O_2 gave

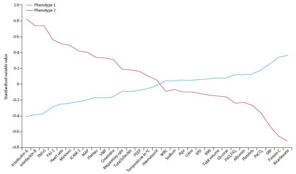
higher PEEP with increasing severity & recruitability



Subphenotypes in acute respiratory distress syndrome: latent class analysis of data from two randomised controlled trials

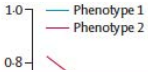
Lancet Respir Med 2014; 2: 611–20

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



	Phenotype 1 (n=404)		Phenotype 2 (n=145)		
	Low PEEP (n=202)	High PEEP (n=202)	Low PEEP (n=71)	High PEEP (n=74)	p value*
Mortality at 90 days	33 (16%)	48 (24%)	36 (51%)	31 (42%)	0·049
Ventilator-free days	20 (10–25)	21 (3–24)	2 (0–21)	4·5 (0–20)	0·018
Organ failure free-days	22 (11–26)	22 (9–26)	4 (0–18)	6·5 (0–21)	0·003

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

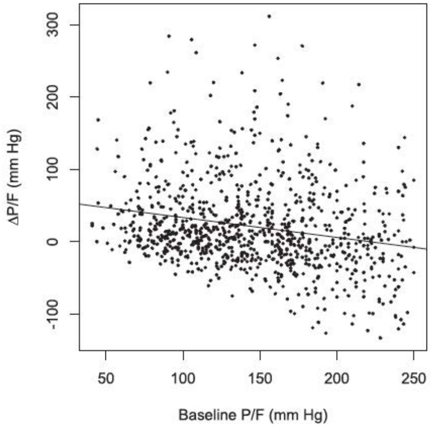
Table 5: **Differences in response to PEEP strategy by phenotype (ALVEOLI cohort only)**

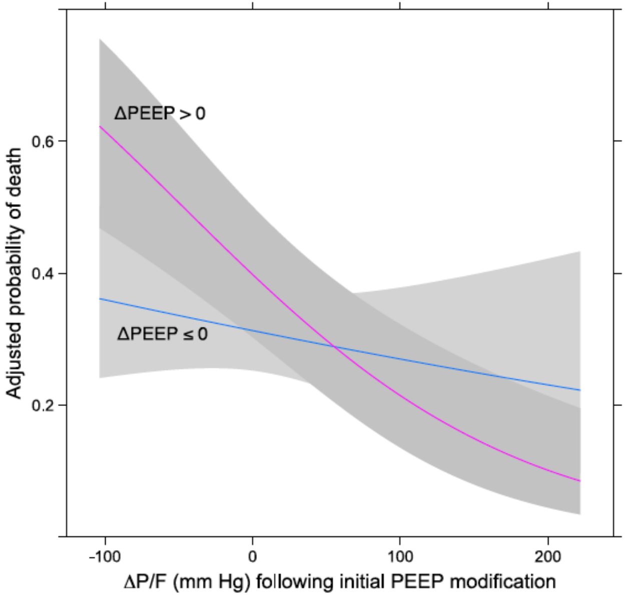
Oxygenation Response to Positive End-Expiratory Pressure Predicts Mortality in Acute Respiratory Distress Syndrome

A Secondary Analysis of the LOVS and ExPress Trials

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

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