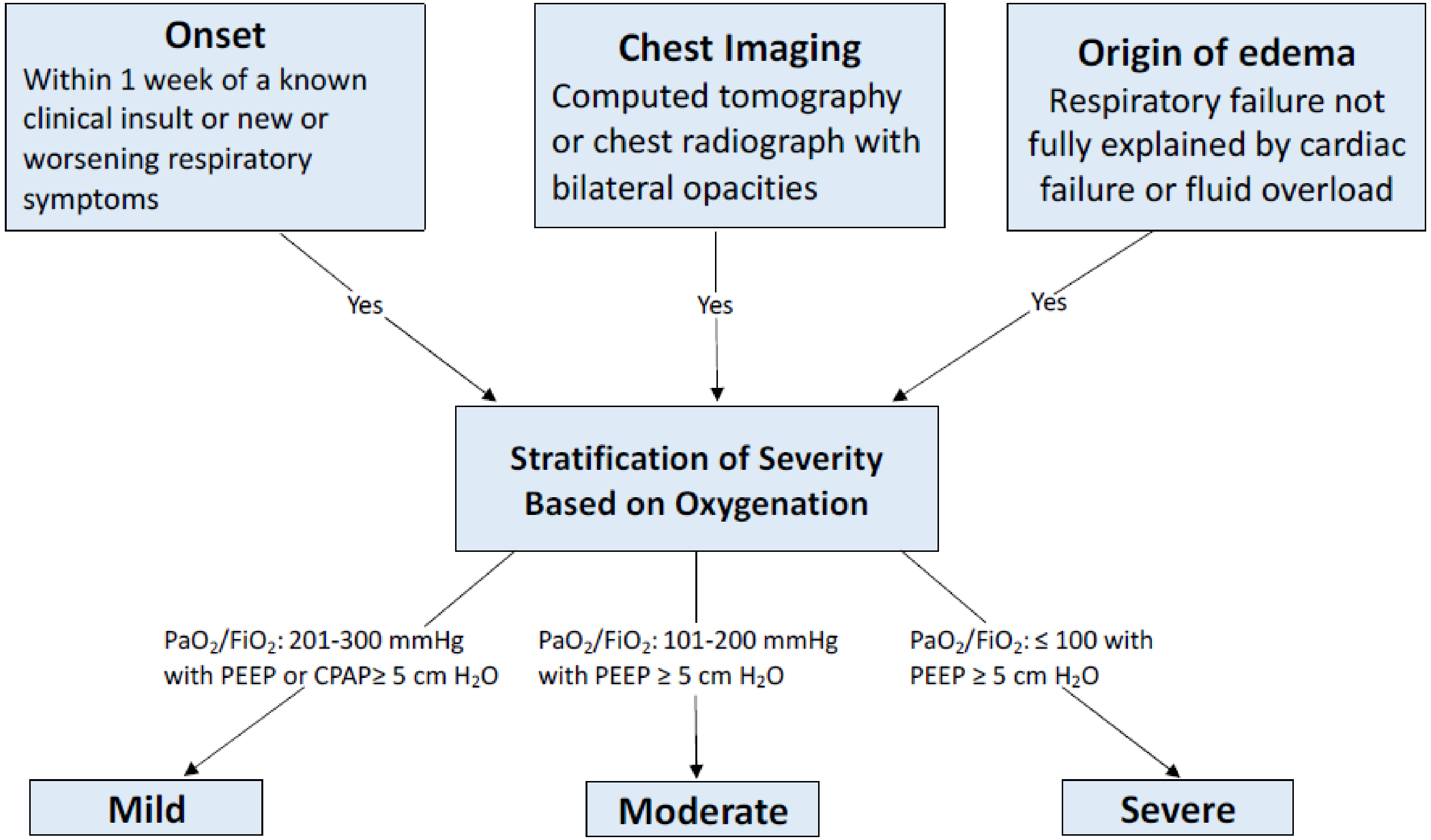
Current Strategy for Mechanical Ventilation

박태선

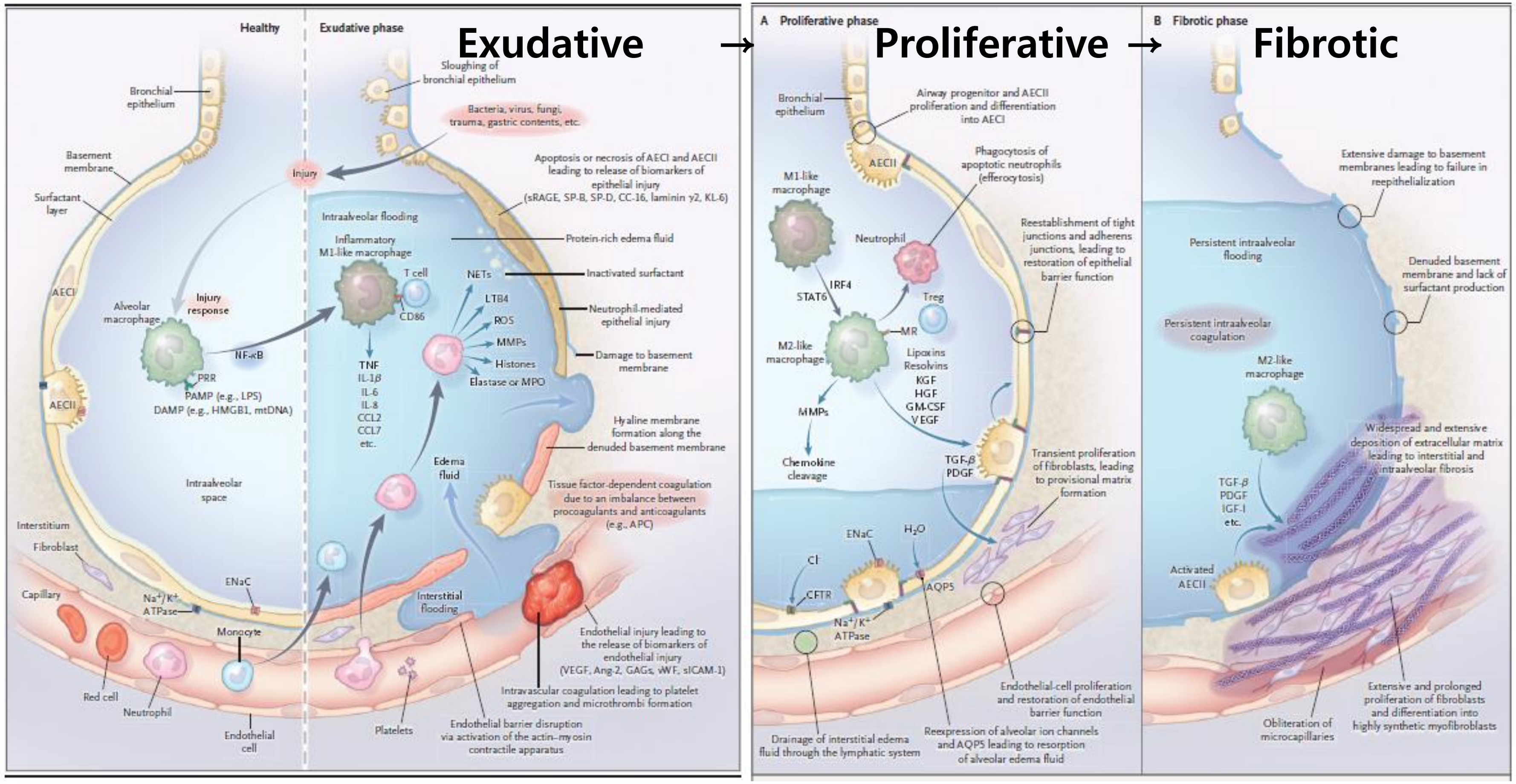
한양의대 내과

The Berlin Definition of ARDS



JAMA. 2012;307(23):2526.

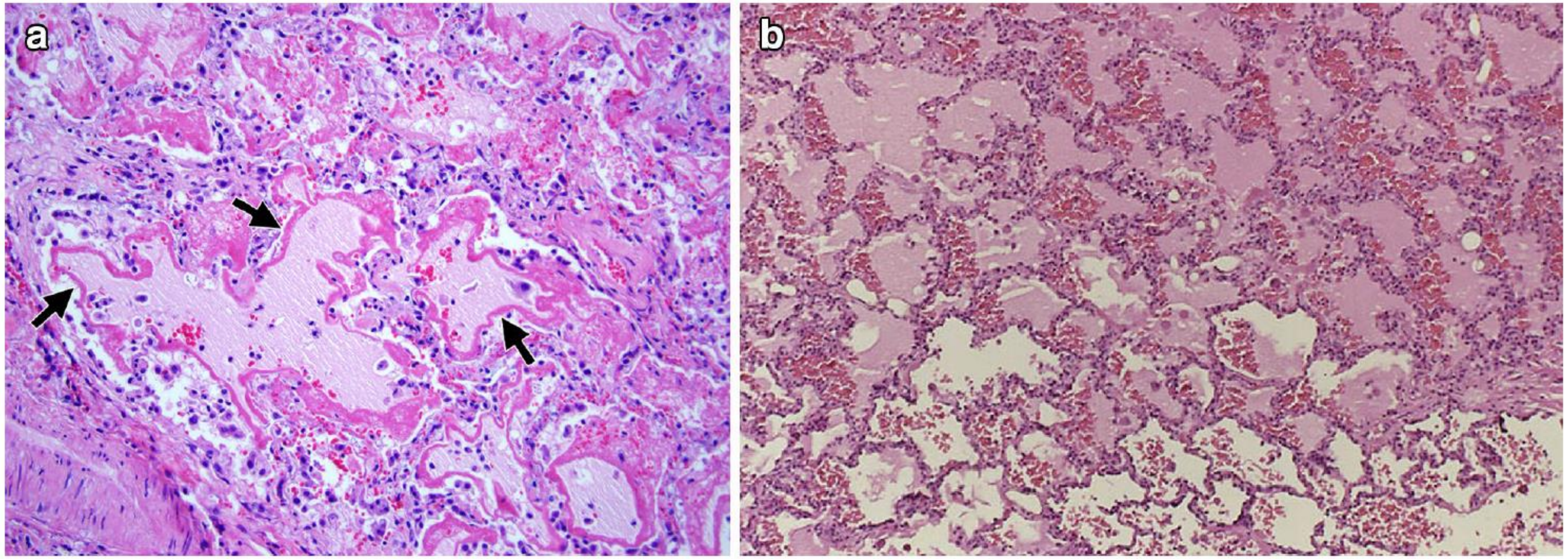
Pathophysiology of ARDS – Alveolus



N Engl J Med 2017;377:562.

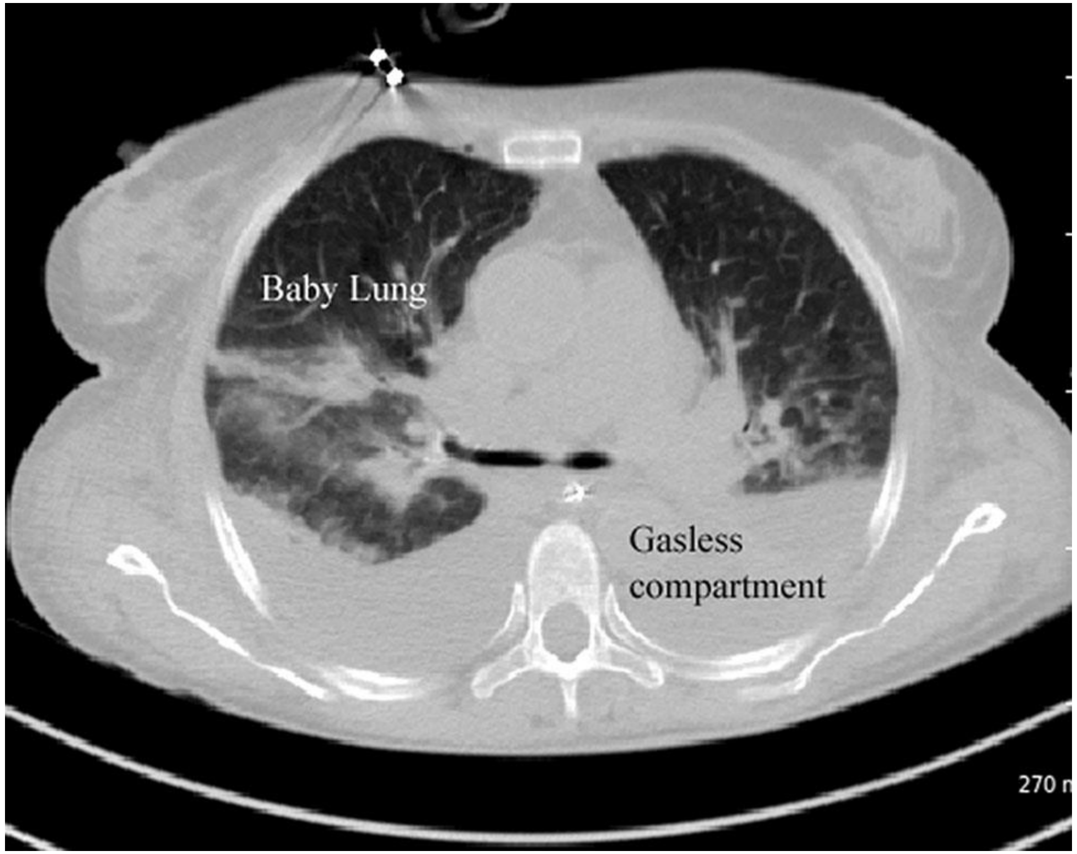
Diffuse Alveolar Damage

open lung biopsies or autopsies have found that only approximately one-half of the patients with ARDS also have DAD



Intensive Care Med 2016;42(5):674.
Ann Am Thorac Soc. 2017;14(6):844.

The "Baby Lung"– not Stiff but Small



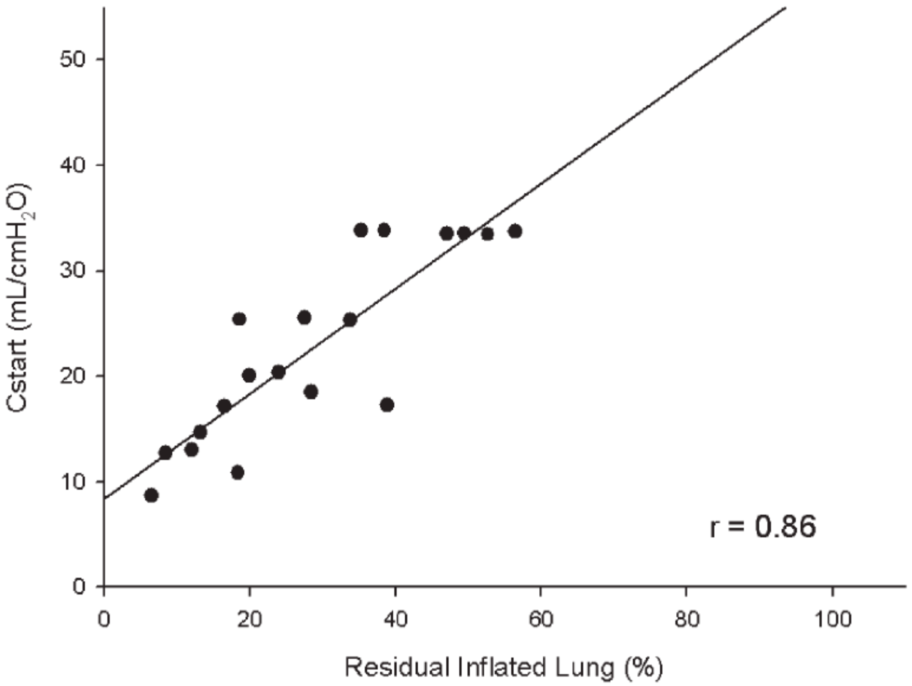
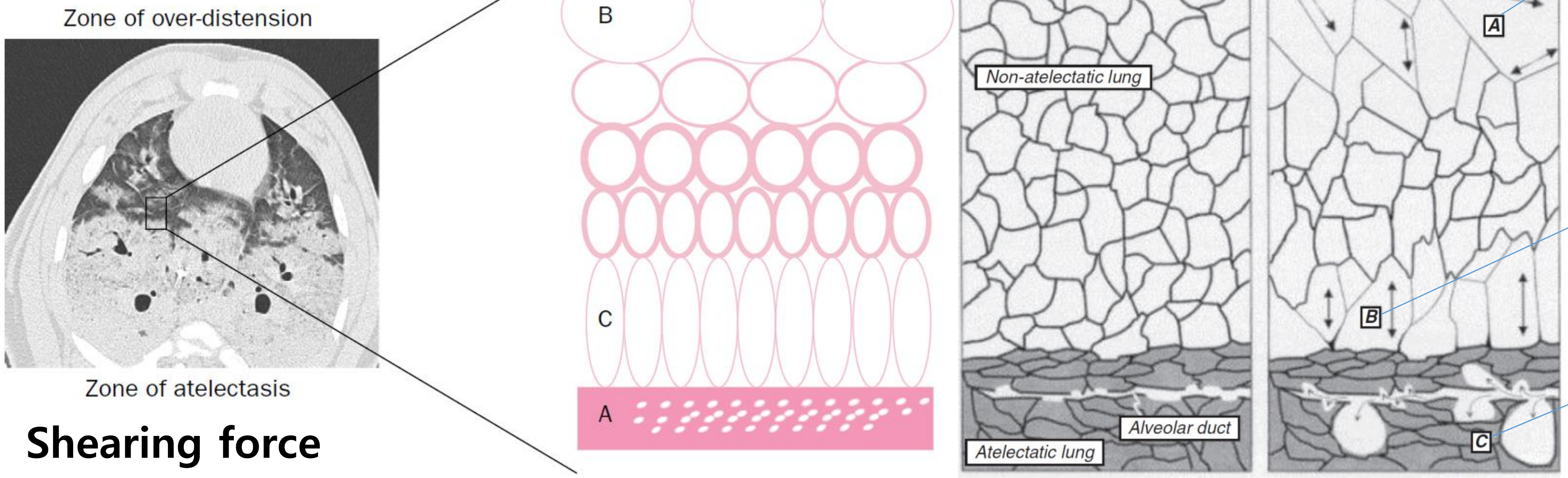


Fig. 2 Starting compliance (*Cstart*) as a function of residual inflated lung expressed as percentage of the expected normal lung volume. (Redrawn from Gattinoni et al. [22])

Intensive Care Med 2016;42(5):663.
Intensive Care Med 2005;31(6):776.

Regional Inhomogeneity in ARDS

Stretch injury



Shearing force

End-expiration End-inspiration

Overdistension
Stretched

Excessive stress
between atelectatic
and aerated alveoli

Repeated
opening and closure

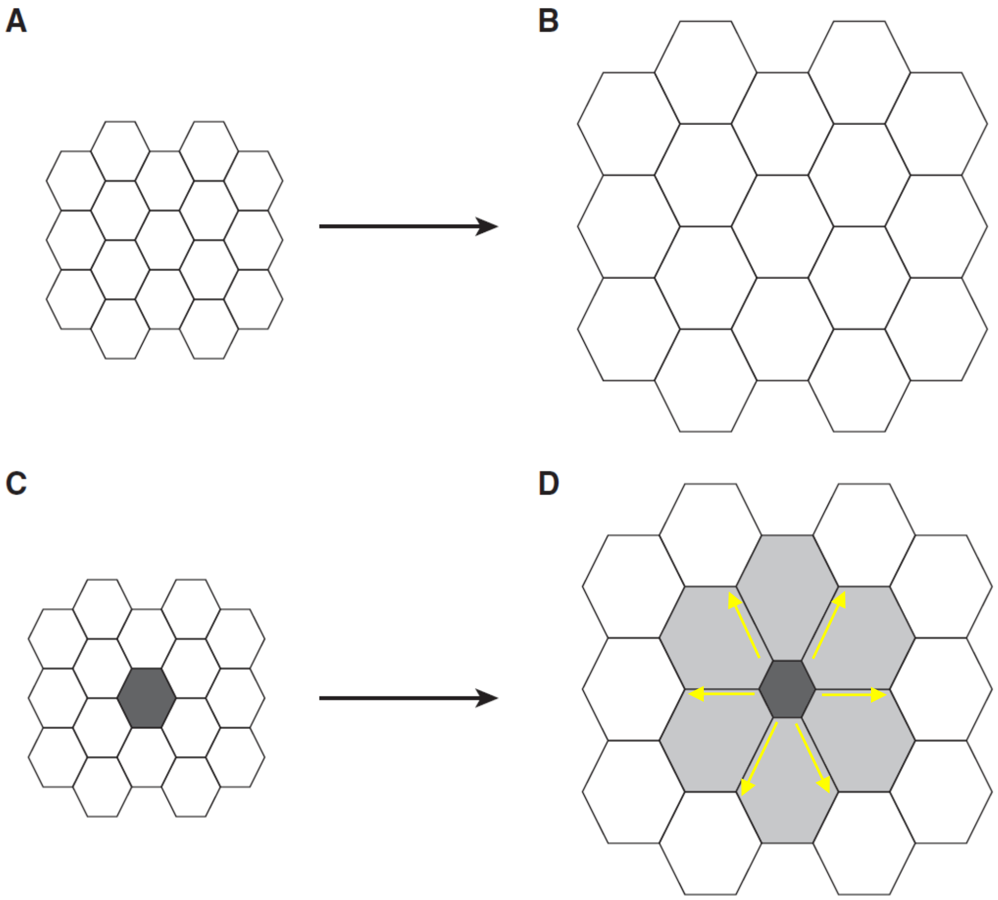
heterogenous mechanical properties of aveoli

Lancet 2003;361(9354):332.
Clin Chest Med 2000;21(3):491.

Stress is Raised in Inhomogeneous Lung

Normal lung

Inhomogeneous Lung

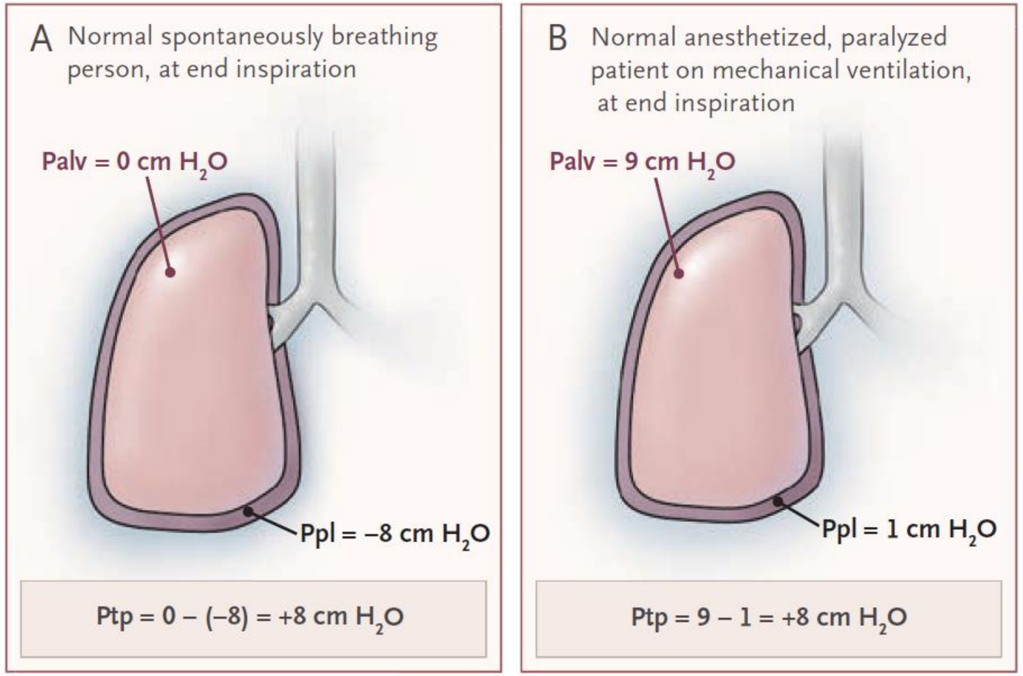


A stress raiser: a collapsed or consolidated portion that does not participate in ventilation

Am J Respir Crit Care Med. 2019;199(1):128.

Stress and Transpulmonary Pressure

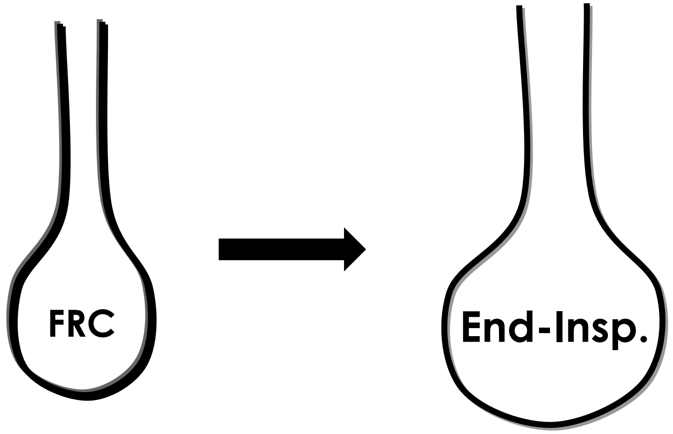
- Stress: the distending force of lung to generate tidal volume
- The difference between **airway (P_{AW})** and **pleural pressure (P_{PL})**
- Surrogate: **plateau pressure**



N Engl J Med 2013;369:2126.

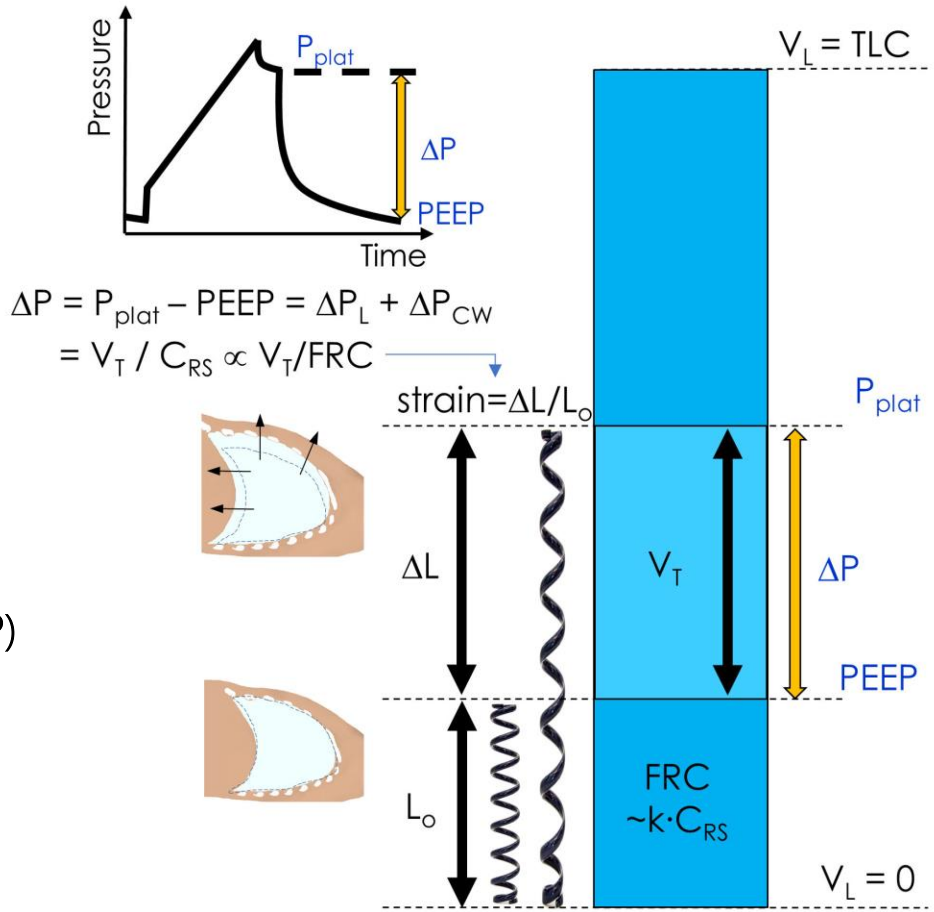
Strain and Driving Pressure

- **Strain**
  - A change in the dimension of a structure from its original dimension.
  - **ΔV/FRC**
    - Ratio of volume change(ΔV) to the functional residual capacity (FRC)



Surrogate: **Driving Pressure** (Plateau Pressure – PEEP)

ΔP is Proportional to Lung Strain.



Driving pressure (ΔP)
Plateau pressure (P_{plat})
Positive end-expiratory pressure (PEEP)
Transpulmonary pressure (ΔP_L)
Trans-chest wall pressure (ΔP_{cw})
Respiratory system compliance (C_{RS})
Tidal volume (V_T)

Anesthesiology. 2019;131(1):155.

Ventilator-Induced Lung Injury

Volutrauma
Damage caused by over-distension. Sometimes called high volume or high end-inspiratory volume injury

Atelectotrauma
Lung injury associated with repeated recruitment and collapse, theoretically prevented by using a level of positive end-expiratory pressure greater than the lower inflection point of the pressure volume curve.[12] Sometimes called low volume or low end-expiratory volume injury

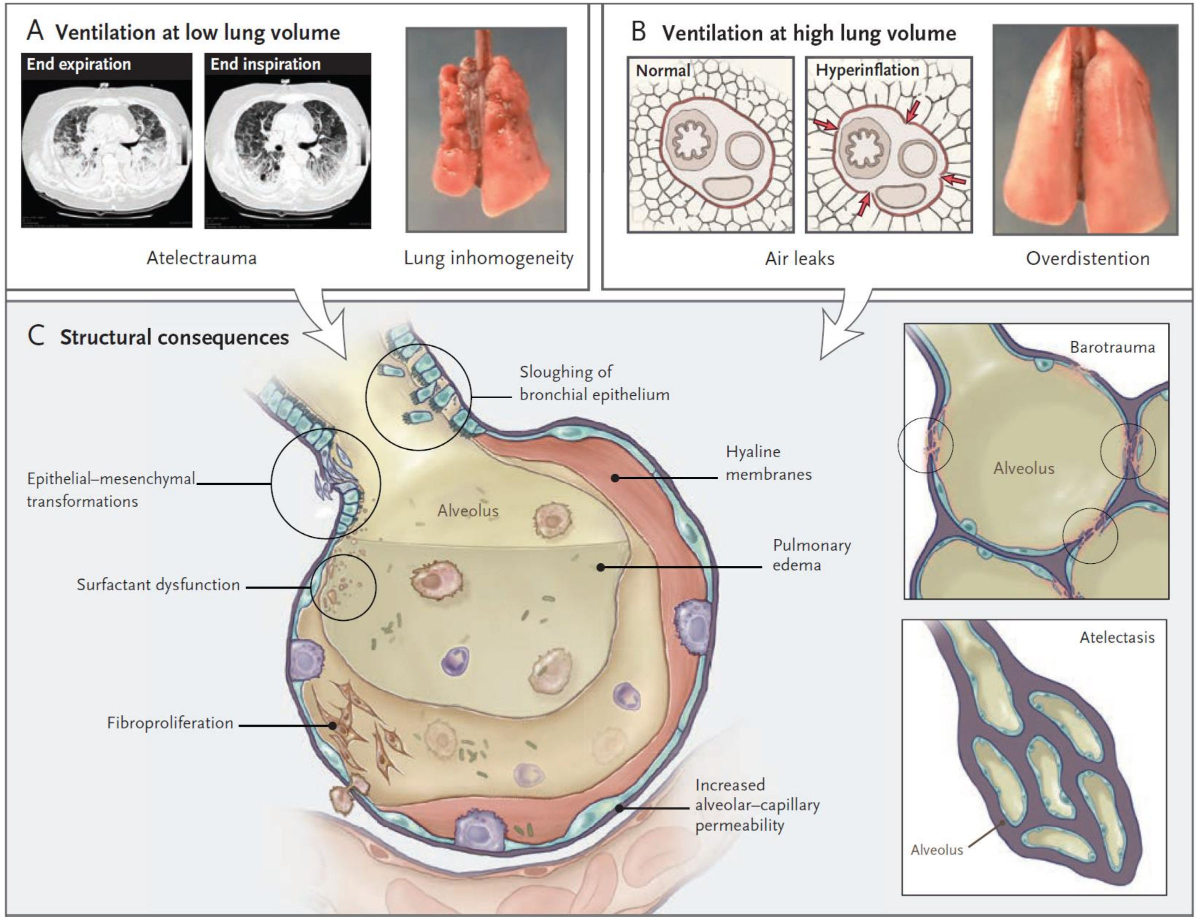
Biotrauma
Pulmonary and systemic inflammation caused by the release of mediators from lungs subjected to injurious mechanical ventilation

Oxygen toxic effects
Damage caused by a high concentration of inspired oxygen. The oxygen concentration: toxic effect relationship for damaged lung is not known

Barotrauma
High pressure induced lung damage

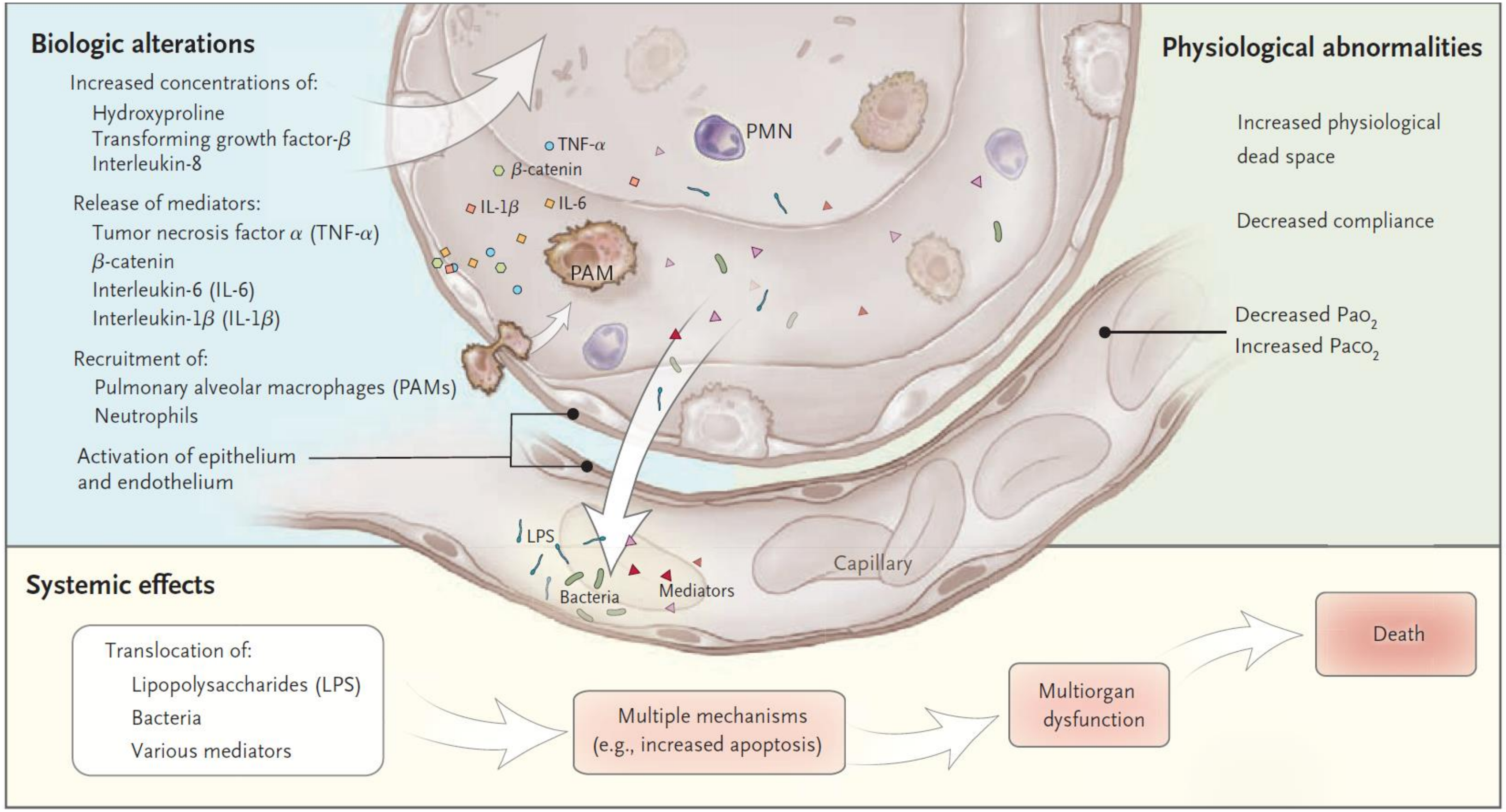
Lancet. 2003;361(9354):332.

Physical Forces in VILI



N Engl J Med 2013;369:2126.

Biologic Forces in VILI



N Engl J Med 2013;369:2126.

Mechanical Ventilation in ARDS

- **ARDS:** not a single disease entity, but a syndrome
  - Treat underlying cause of ARDS
  - Supportive care
- **MV:** the cornerstone of treatment in ARDS
  - Gas exchange↑, work of breathing↓: buy time to recover
  - Understanding of the pathophysiological abnormalities of ARDS
  - Strategy to mimimize lung injury: **reduce stress and strain**

MV Strategies in Patients with ARDS

- Lung Protective Ventilation
- Optimal PEEP
- Driving Pressure
- Recruit Maneuvers
- Prone Positioning

Lung Protective Ventilation

- The mainstay of ventilatory management of ARDS
- **Lower tidal volume (4-8 mL/kg of predicted body weight)**
- **Lower inspiratory pressure (plateau pressure $<30cmH_20$)**

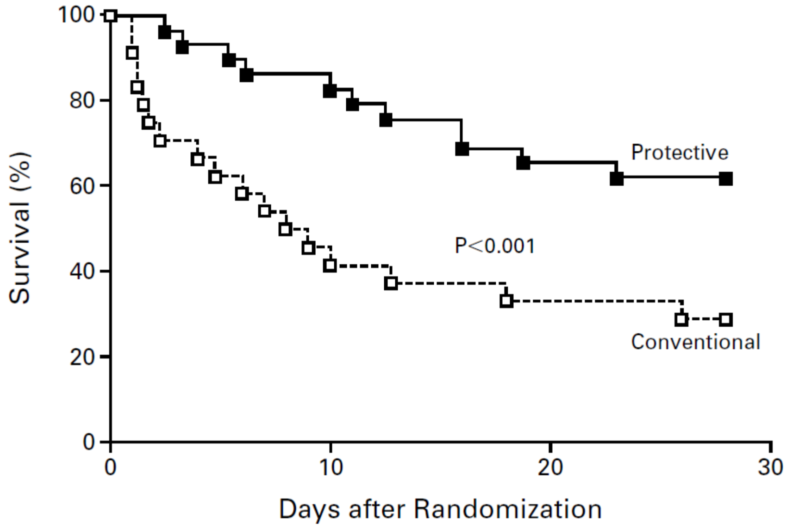
Am J Respir Crit Care Med. 2017;195(9):1253.

Protective Ventilation Strategy

EFFECT OF A PROTECTIVE-VENTILATION STRATEGY ON MORTALITY IN THE ACUTE RESPIRATORY DISTRESS SYNDROME

TABLE 2. Study Outcomes According to the Intention-to-Treat Analysis.

Outcome	Protective Ventilation (N=29)	Conventional Ventilation (N=24)	P Value: Isolated Comparisons	P Value: Comparisons Corrected for Multiple Testing*
Primary end point — no. (%)				
Mortality at 28 days	11 (38)	17 (71)	<0.001†	<0.001
Secondary end points — no. (%)				
In-hospital death	13 (45)	17 (71)	0.09‡	0.37
Barotrauma	2 (7)§	10 (42)¶	0.004‡	0.02
Weaning at 28 days	19 (66)	7 (29)	0.001†	0.005
Other outcomes				
Death in the intensive care unit — no. (%)	11 (38)	17 (71)	0.03‡	
Death after weaning — no.	4	0	>0.10‡	
Nosocomial pneumonia — no.	17	11	>0.10‡	
Use of paralyzing agents for >24 hr — no.	17	8	0.10‡	
Neuropathy after extubation — no.	2	0	>0.10‡	
Dialysis required — no.	7	5	>0.10‡	
Packed red cells infused — ml/patient/day	230	309	0.25‖	
Cause of in-hospital death — no.**				
Progressive respiratory failure	1	6		
Refractory septic shock	6	7		
Accidental extubation	2	1		
Gastric hemorrhage	2	1		
Cerebral nocardiosis	1	0		
Accidental hemothorax	1	0		
Ventricular fibrillation	0	1		
Intracranial hemorrhage	0	1		



No. at Risk				
Protective	29	25	20	18
Conventional	24	11	9	7

NEJM 1998;338(6):347-54.

ARMA Trial

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*

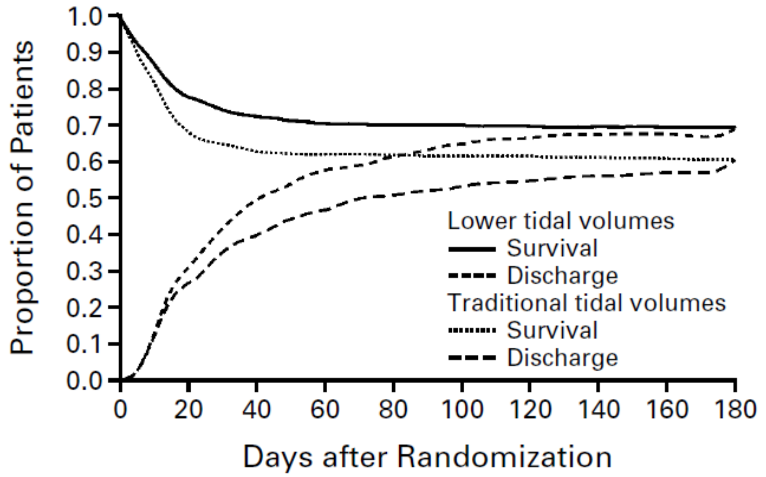


Figure 1. Probability of Survival and of Being Discharged Home and Breathing without Assistance during the First 180 Days after Randomization in Patients with Acute Lung Injury and the Acute Respiratory Distress Syndrome.

The status at 180 days or at the end of the study was known for all but nine patients. Data on these 9 patients and on 22 additional patients who were hospitalized at the time of the fourth interim analysis were censored.

TABLE 4. MAIN OUTCOME VARIABLES.*

VARIABLE	GROUP RECEIVING LOWER TIDAL VOLUMES	GROUP RECEIVING TRADITIONAL TIDAL VOLUMES	P VALUE
Death before discharge home and breathing without assistance (%)	31.0	39.8	0.007
Breathing without assistance by day 28 (%)	65.7	55.0	<0.001
No. of ventilator-free days, days 1 to 28	12±11	10±11	0.007
Barotrauma, days 1 to 28 (%)	10	11	0.43
No. of days without failure of nonpulmonary organs or systems, days 1 to 28	15±11	12±11	0.006

*Plus–minus values are means ±SD. The number of ventilator-free days is the mean number of days from day 1 to day 28 on which the patient had been breathing without assistance for at least 48 consecutive hours. Barotrauma was defined as any new pneumothorax, pneumomediastinum, or subcutaneous emphysema, or a pneumatocele that was more than 2 cm in diameter. Organ and system failures were defined as described in the Methods section.

NEJM 2000;342:1301.

ARDS Network Ventilation Protocol

- 10 center trial of 861 patients with ALI/ARDS prospectively randomized to **6** vs **12** ml/kg PBW*
- PEEP based on FiO_2, with PaO_2 goal of 55-80 mmHg.
- P_{Plat} Goal ≤ **30** cm H_20
- pH Goal : 7.30-7.45

*PBW = 50 + 0.91 [Ht (cm)-152.4] (male)

PBW = 45.5 + 0.91 [Ht (cm)-152.4] (female)

NEJM 2000;342:1301.

Timing of Low Tidal Volume Ventilation and Intensive Care Unit Mortality in Acute Respiratory Distress Syndrome
A Prospective Cohort Study

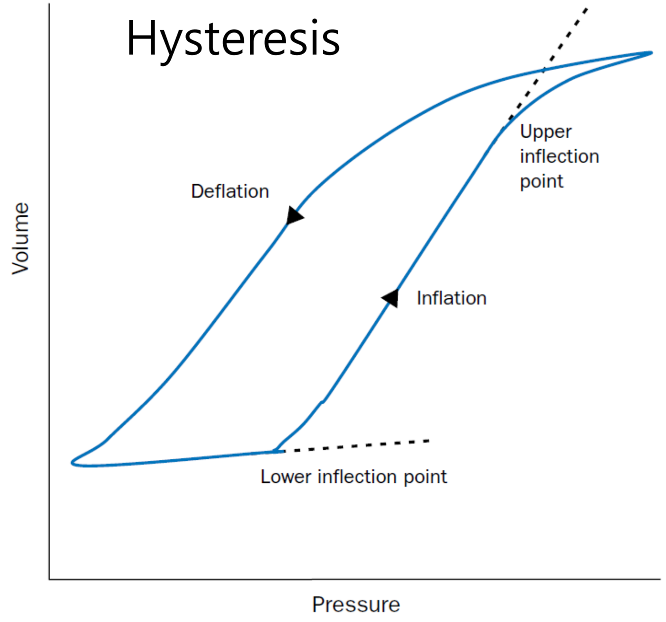
Main Results: An increase of 1 ml/kg PBW in initial tidal volume was associated with a 23% increase in ICU mortality risk (adjusted hazard ratio, 1.23; 95% confidence interval [CI], 1.06–1.44; P = 0.008)

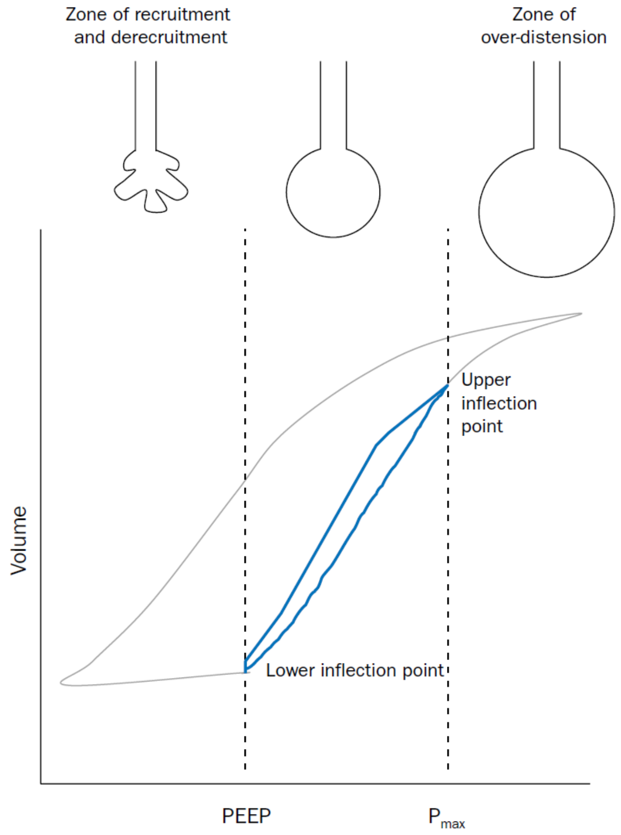
Conclusions: Higher tidal volumes shortly after ARDS onset were associated with a greater risk of ICU mortality compared with subsequent tidal volumes.

Am J Respir Crit Care Med. 2015;15;191(2):177.

Adjustment of PEEP

- No single PEEP strategy has proven to be ideal.





"double-edeged sword"

Lancet. 2003;361(9354):332.

PEEP – Clinical Trials

- **ALVEOLI** (NEJM 2004): higher vs. lower PEEP
- **EXPRESS** (JAMA 2008): high-PEEP, low-tidal volume strategy
- **LOVS** (JAMA 2008): high PEEP, low tidal volume, and recruit maneuvers

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 JULY 22, 2004 VOL. 351 NO. 4

Higher versus Lower Positive End-Expiratory Pressures in Patients with the Acute Respiratory Distress Syndrome

The National Heart, Lung, and Blood Institute ARDS Clinical Trials Network*

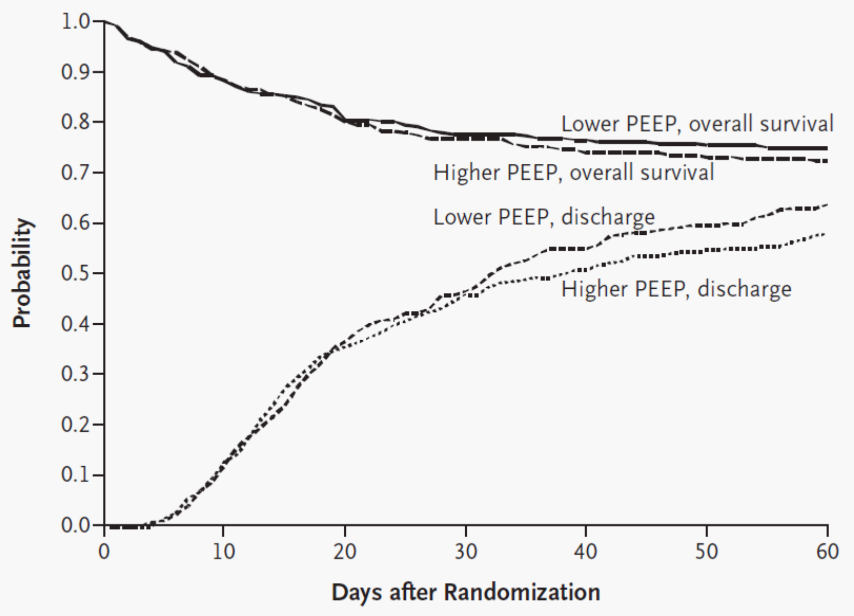


Figure 1. Probabilities of Survival and of Discharge Home While Breathing without Assistance, from the Day of Randomization (Day 0) to Day 60 among Patients with Acute Lung Injury and ARDS, According to Whether Patients Received Lower or Higher Levels of PEEP.

Table 1. Summary of Ventilator Procedures in the Lower- and Higher-PEEP Groups.*

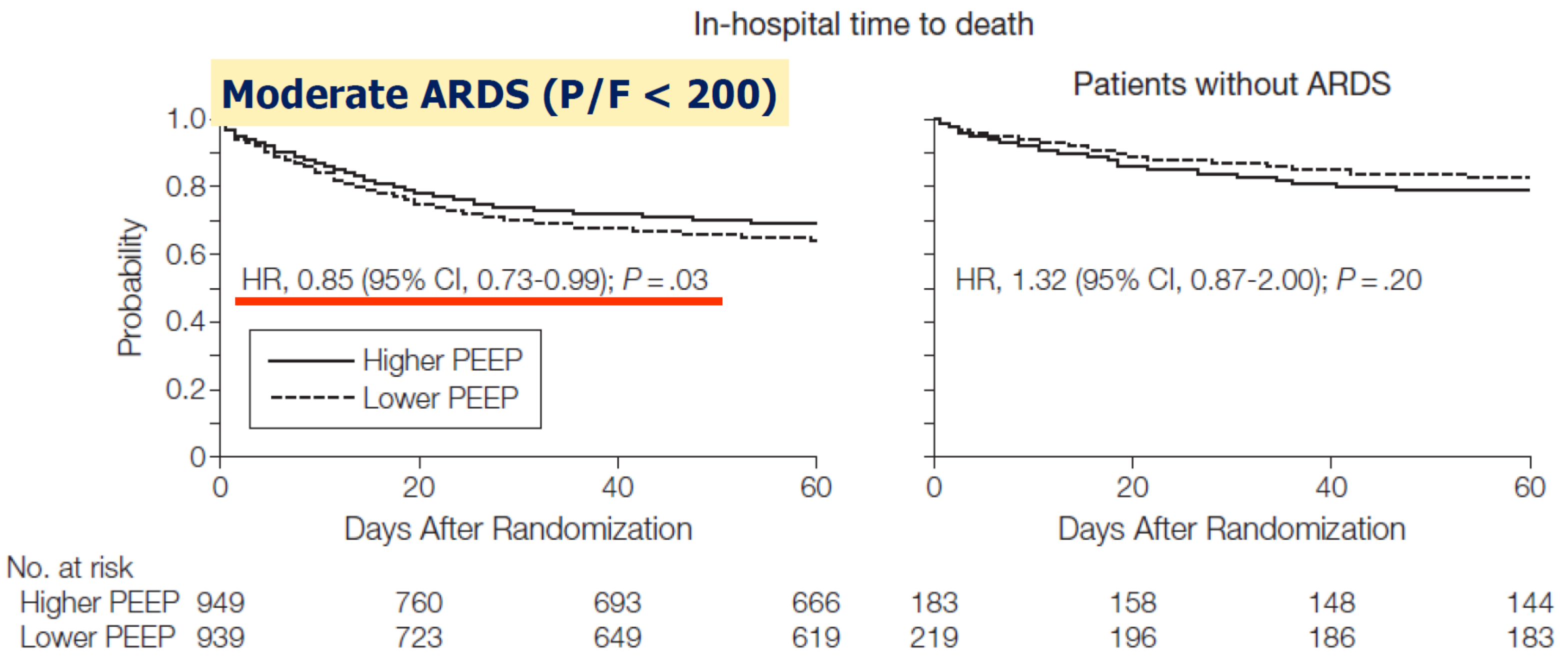
Procedure	Value													
Ventilator mode	Volume assist/control													
Tidal-volume goal	6 ml/kg of predicted body weight													
Plateau-pressure goal	≤30 cm of water													
Ventilator rate and pH goal	6–35, adjusted to achieve arterial pH ≥7.30 if possible													
Inspiration:expiration time	1:1–1:3													
Oxygenation goal														
PaO_2	55–80 mm Hg													
SpO_2	88–95%													
Weaning	Weaning attempted by means of pressure support when level of arterial oxygenation acceptable with PEEP ≤8 cm of water and FiO_2 ≤0.40													
Allowable combinations of PEEP and FiO_2†														
Lower-PEEP group														
FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18–24
Higher-PEEP group (before protocol changed to use higher levels of PEEP)														
FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5–0.8	0.8	0.9	1.0	
PEEP	5	8	10	12	14	14	16	16	18	20	22	22	22–24	
Higher-PEEP group (after protocol changed to use higher levels of PEEP)														
FiO_2	0.3	0.3	0.4	0.4	0.5	0.5	0.5–0.8	0.8	0.9	1.0				
PEEP	12	14	14	16	16	18	20	22	22	22–24				

Higher vs. Lower PEEP

	LOV	Express	ALVEOLI
Country	Canada, Australia, S.A	France	USA (ARDS network)
No of patients	983	767	549
Inclusion criteria	ALI (PaO_2/FiO_2<250)	ALI (PaO_2/FiO_2<300)	ALI (PaO_2/FiO_2<300)
Mean PEEP level (D1)			
High PEEP (cmH_2O)	15.6	15.8	14.7
Low PEEP (cmH_2O)	10.1	8.4	8.9
1˚ outcome	All-cause mortality	28D mortality	Mortality before discharge
	36.4% vs 40.4%	31.2% vs 27.8%	27.5% vs 24.9%
Significant outcome	Refractory hypoxemia	Ventilator free days	-
	Use of rescue Tx	Oxygenation	

Higher vs Lower Positive End-Expiratory Pressure in Patients With Acute Lung Injury and Acute Respiratory Distress Syndrome

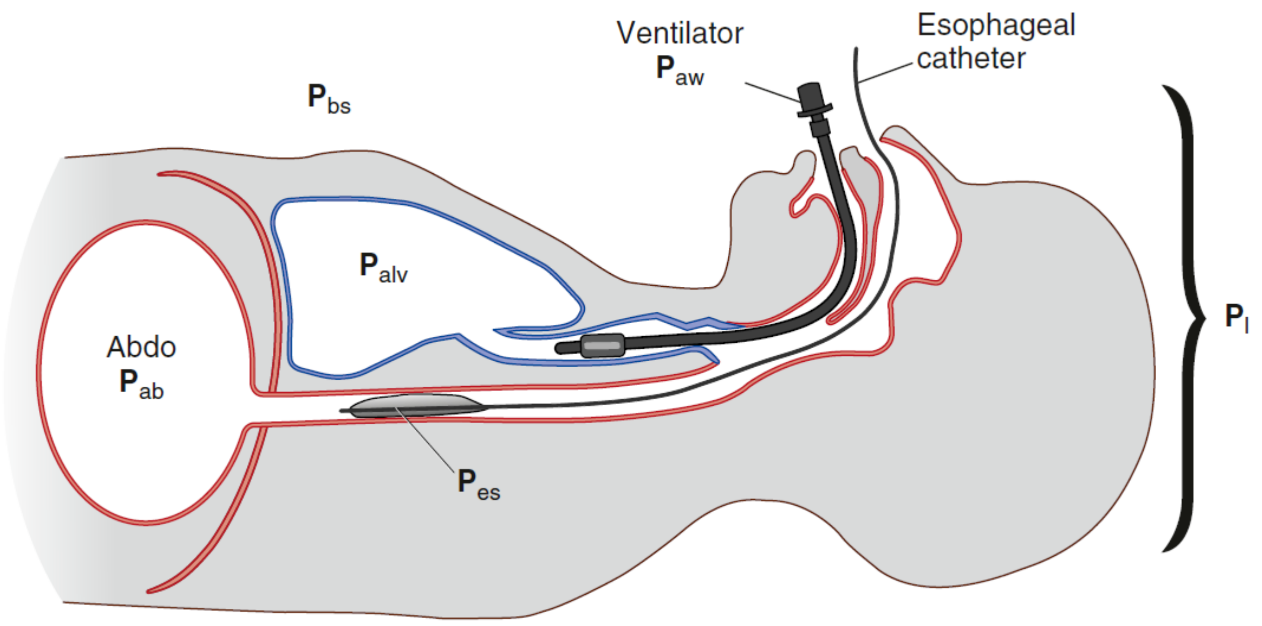
Systematic Review and Meta-analysis



Conclusion: Treatment with higher vs lower levels of PEEP was not associated with improved hospital survival. However, higher levels were associated with improved survival among the subgroup of patients with ARDS.

JAMA 2010;303:865

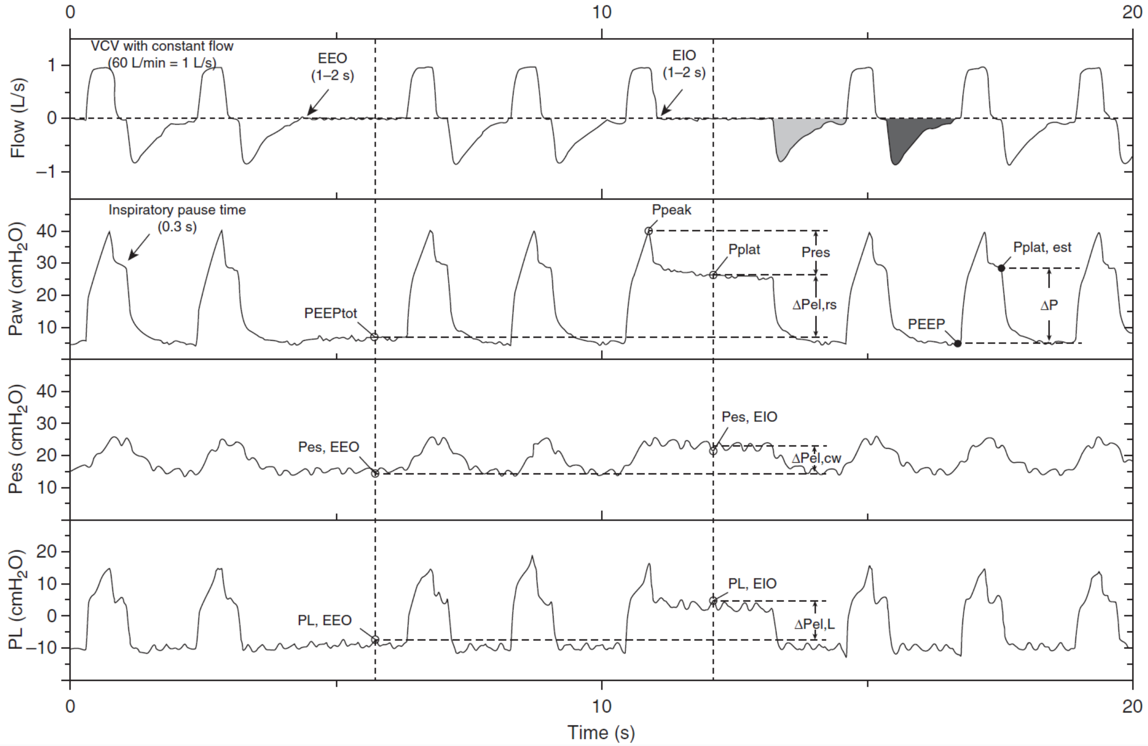
Esophageal Pressure Guided PEEP



Transpulmonary pressure (P_L)

= Airway pressre (P_{aw}) – Esophageal pressure (P_{es})

Am J Respir Crit Care Med. 2017;196(7):822.



Esophageal-Pressure–Guided Group

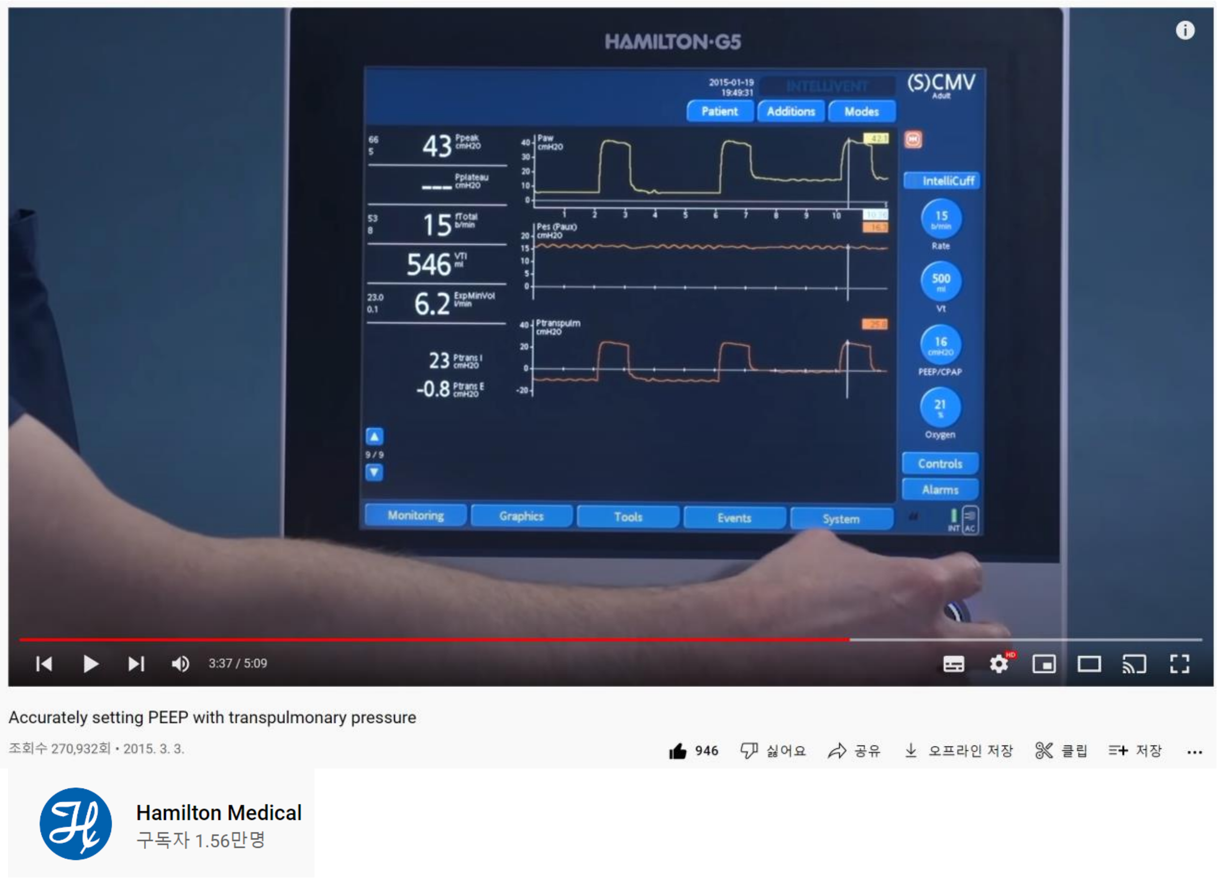
FiO_2	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0
P_{Lexp}	0	0	2	2	4	4	6	6	8	8	10	10

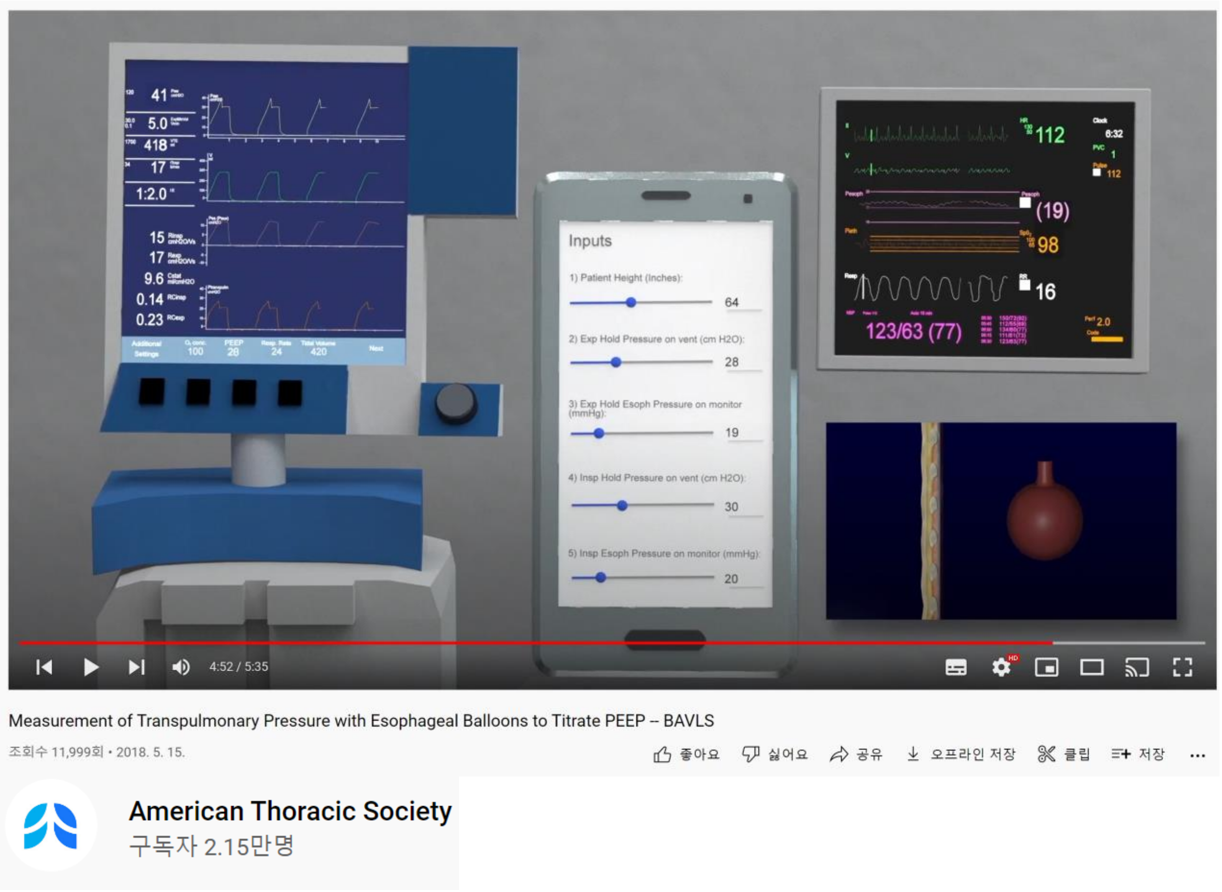
Control Group

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	20–24

PEEP levels were set to achieve a transpulmonary pressure of 0 to 10 cm of water at end expiration, according to a sliding scale based on the partial pressure of arterial oxygen (PaO_2) and the fraction of inspired oxygen (FiO_2)

Am J Respir Crit Care Med. 2017;196(7):822.





https://youtu.be/GH1rtU-1hJc

https://youtu.be/RpjEmUgSwwI

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812 NOVEMBER 13, 2008 VOL. 359 NO. 20

Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

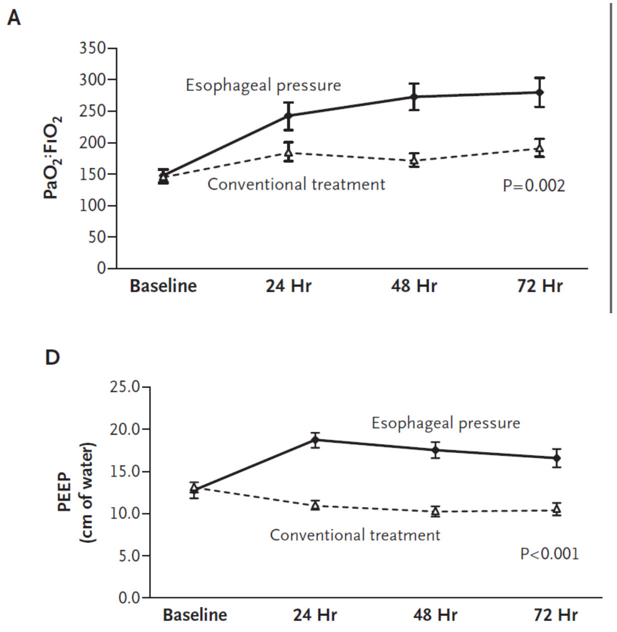


Table 4. Clinical Outcomes.*

Outcome	Esophageal-Pressure–Guided (N=30)	Conventional Treatment (N=31)	P Value
28-Day mortality — no. (%)	5 (17)	12 (39)	0.055
180-Day mortality — no. (%)	8 (27)	14 (45)	0.13
Length of ICU stay — days			0.16
Median	15.5	13.0	
Interquartile range	10.8–28.5	7.0–22.0	
No. of ICU-free days at 28 days			0.96
Median	5.0	4.0	
Interquartile range	0.0–14.0	0.0–16.0	
No. of ventilator-free days at 28 days			0.50
Median	11.5	7.0	
Interquartile range	0.0–20.3	0.0–17.0	
No. of days of ventilation among survivors			0.71
Median	12.0	16.0	
Interquartile range	7.0–27.5	7.0-20.0	

JAMA | Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

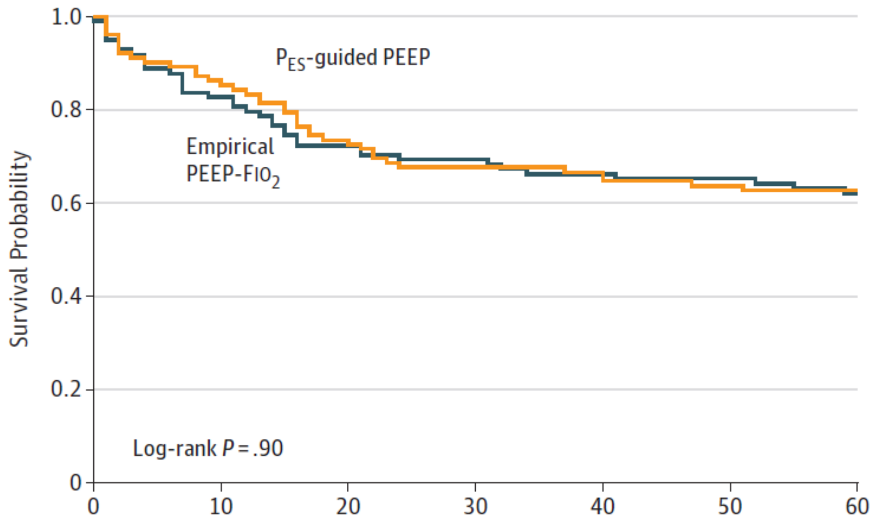
Effect of Titrating Positive End-Expiratory Pressure (PEEP) With an Esophageal Pressure–Guided Strategy vs an Empirical High PEEP-FIO_2 Strategy on Death and Days Free From Mechanical Ventilation Among Patients With Acute Respiratory Distress Syndrome

A Randomized Clinical Trial

EPVent-2 Study Group

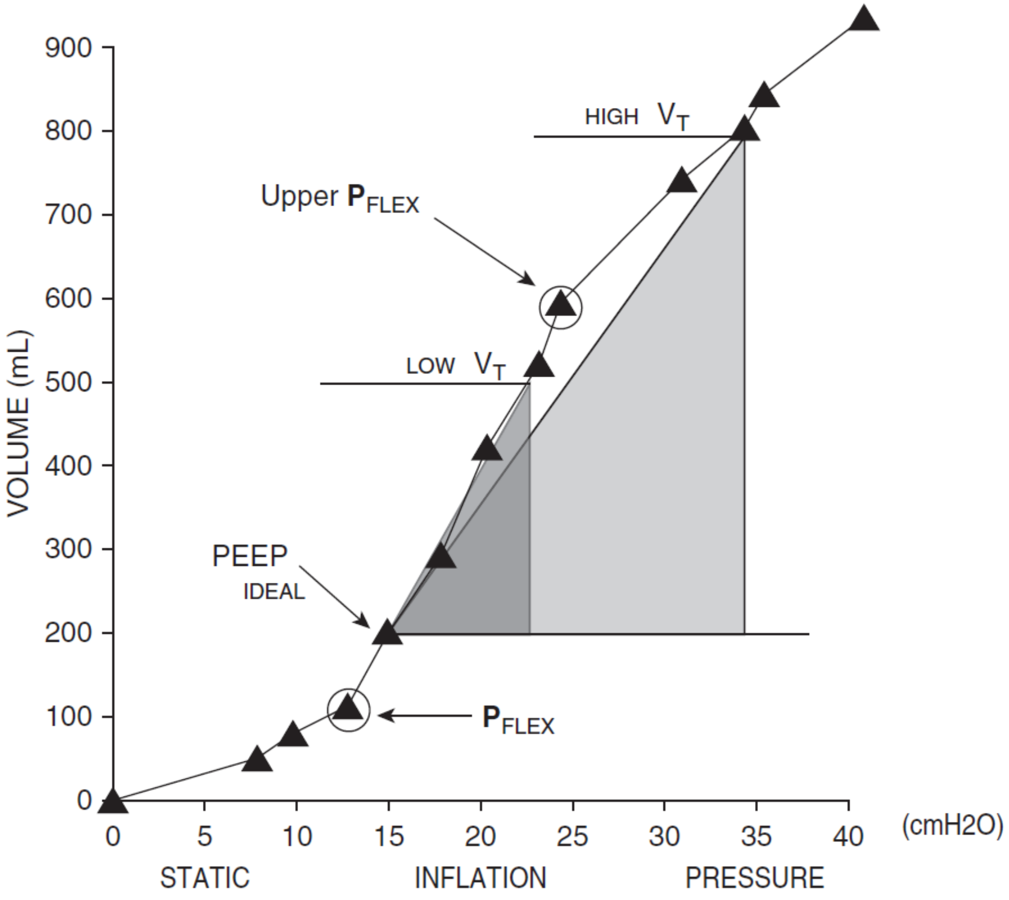
Table 3. Patient Outcomes[a]

Variable	P_{ES}-Guided PEEP (n = 102)	Empirical PEEP-FIO_2 (n = 98)	Absolute Difference, % (95% CI)[b]	P Value[c]
Primary End Point				
Probability of more favorable outcome, a ranked composite incorporating death and days free from mechanical ventilation among survivors, % (95% CI)[d]	49.6 (41.7 to 57.5)	50.4 (42.5 to 58.3)	NR[e]	.92
Secondary Clinical End Points				
Mortality through day 28, No. (%)	33 (32.4)	30 (30.6)	1.7 (−11.1 to 14.6)	.88
Days free from mechanical ventilation among survivors through day 28, median (IQR)	22 (15 to 24)	21 (16.5 to 24)	0 (−1 to 2)	.85
Mortality through day 60, No./total No. (%)	38/101 (37.6)	37/98 (37.8)	−0.1 (−13.6 to 13.3)	>.99
Mortality through 1 y, No./total No. (%)	44/100 (44.0)	44/96 (45.8)	−1.8 (−15.8 to 12.1)	.89
Ventilator-free days through day 28, median (IQR)[f]	15.5 (0 to 23)	17.5 (0 to 23)	0 (0 to 0)	.93
ICU length of stay through day 28, median (IQR), d	10 (6 to 17)	9.5 (5 to 14)	1 (−1 to 3)	.24
Hospital length of stay through day 28, median (IQR), d	16 (9 to 26)	15 (8 to 24)	0 (−1 to 3)	.58
Hospital length of stay through day 60, median (IQR), d	16 (9 to 26)	15 (8 to 24)	1 (−2 to 4)	.47
Rescue therapy administered, No. (%)[g]	4 (3.9)	12 (12.2)	−8.3 (−15.8 to -0.8)	.04
Prone positioning, No. (%)	1 (1.0)	3 (3.1)	−2.1 (−6.0 to 1.8)	.36
Inhaled pulmonary vasodilator, No. (%)	3 (2.9)	10 (10.2)	−7.3 (−14.1 to −0.4)	.046
Extracorporeal membrane oxygenation, No. (%)	1 (1.0)	3 (3.1)	−2.1 (−6.0 to 1.8)	.36
Recruitment maneuvers, No. (%)	1 (1.0)	1 (1.0)	0.0 (−2.8 to 2.7)	>.99
Safety End Points				
Shock-free days, median (IQR)[f]	14 (0 to 21)	17 (0 to 21)	0 (−2 to 0)	.47
Acute kidney injury requiring renal replacement therapy in the first 28 d, No./total, No. (%)[h]	21/100 (21.0)	32/96 (33.3)	−12.3 (−24.7 to 0.0)	.056
Pneumothorax, No. (%)	3 (2.9)	2 (2.0)	0.9 (−3.4 to 5.2)	>.99
Bronchopleural fistula, No.	0	0	0	
Barotrauma, No. (%)[i]	6 (5.9)	5 (5.1)	0.8 (−5.5 to 7.1)	>.99



JAMA. 2019;321(9):846.

Ideal PEEP – Low V_T and Best C_{stat}



Am J Respir Crit Care Med. 2017;195(11):1429.

Driving Pressure

- $\Delta P = P_{plat} - PEEP$
- Pressure needed to overcome elastic recoil of respiratory system as V_T is inflated.
    - Reflect pressure load due to tidal ventilation
- **Strain** = $\Delta V/FRC \fallingdotseq \Delta V/ C_{RS}$

The NEW ENGLAND JOURNAL of MEDICINE

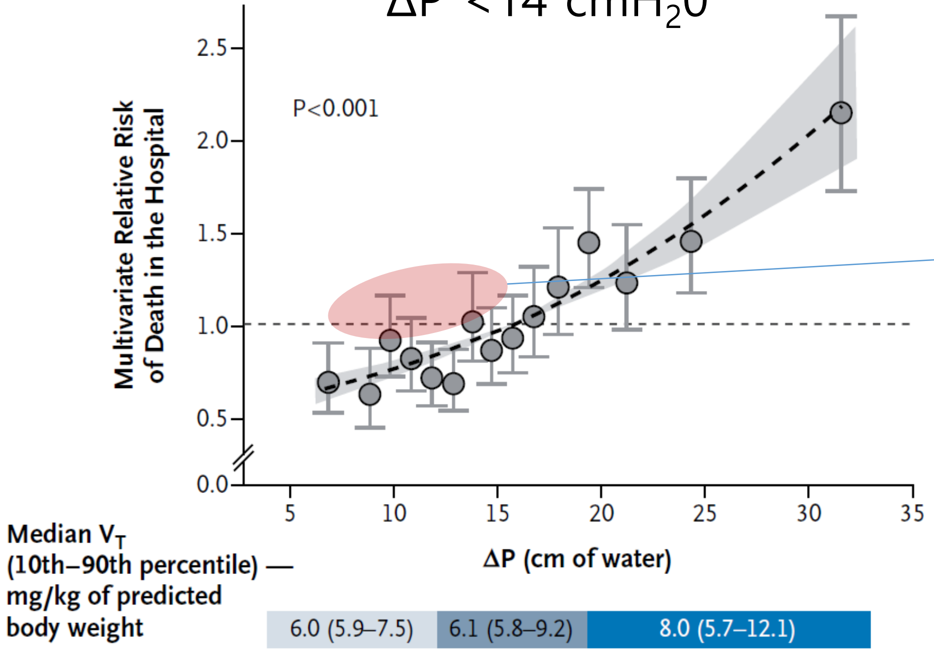
SPECIAL ARTICLE

Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

3562 patients with ARDS enrolled in nine previously reported randomized trial.

ΔP as an independent variable associated with survival.

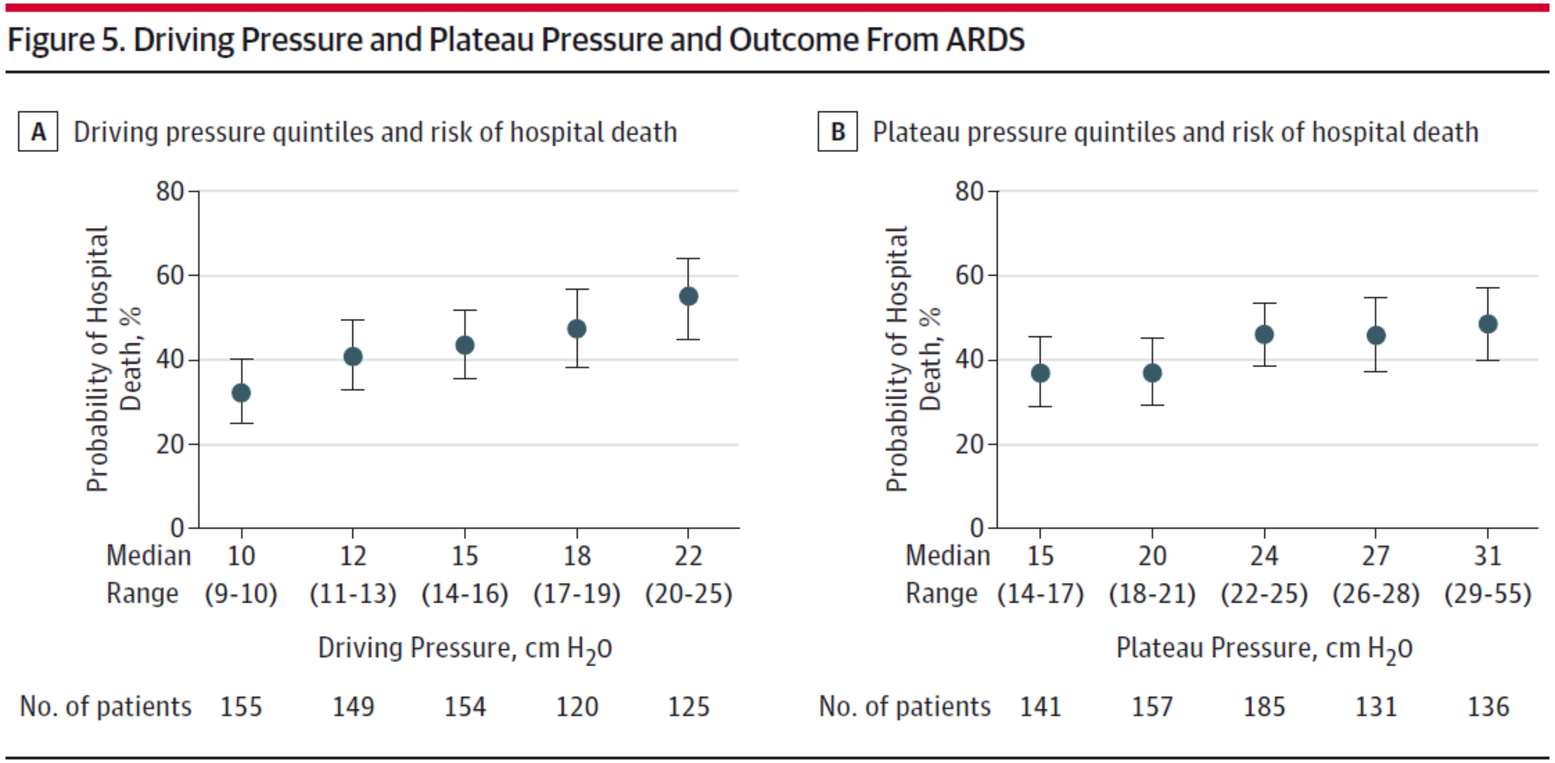
ΔP <14 cmH_20



Even below the median driving pressure of 14 cm H_2O, there is still a significant risk of death in the hospital!

N Engl J Med 2015;372:747-55.

Driving Pressure and Risk of Death in LUNG-SAFE Study



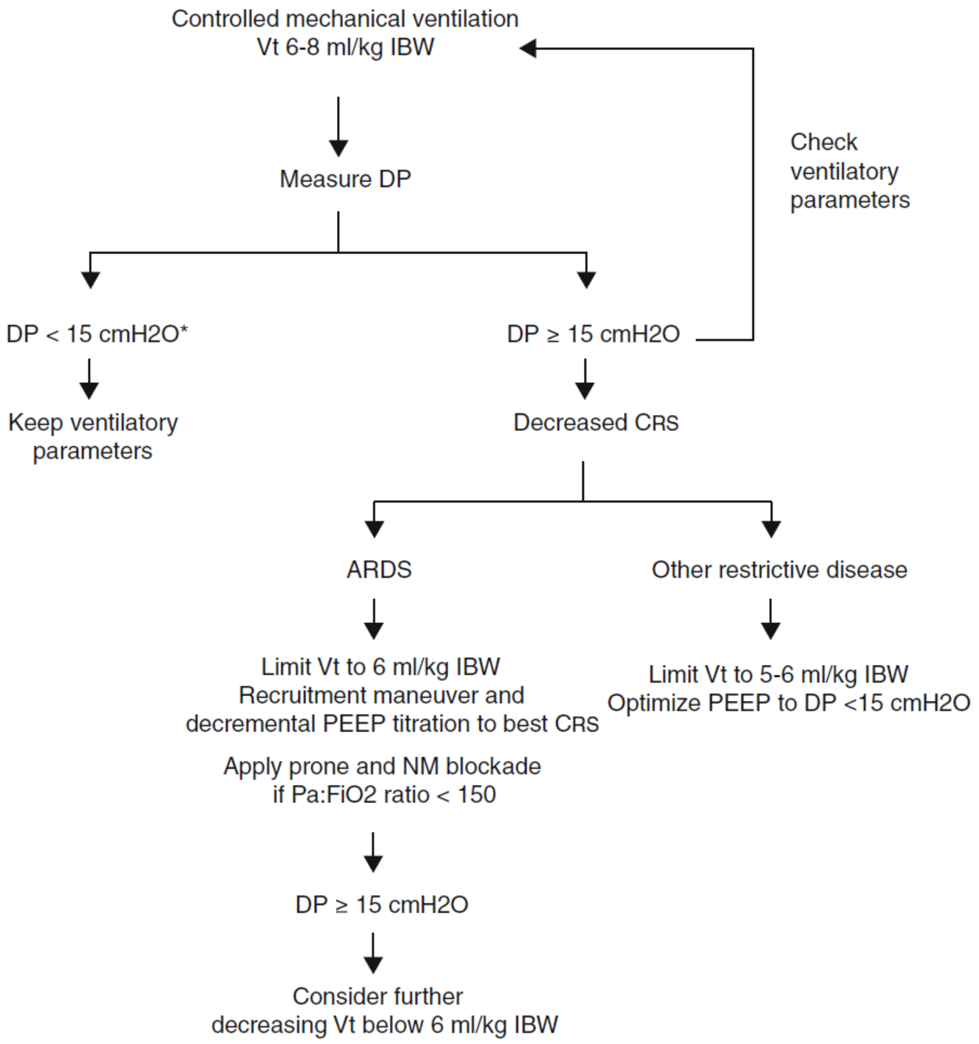
JAMA. 2016;315(8):788-800.

Several Methods can Reduce Driving Pressure

- Reduction of tidal volume
- Optimization of PEEP
- Recruitment maneuvers
- Neuromuscular blockade
- Prone positioning

Crit Care. 2015;19(1):342.
Curr Opin Crit Care. 2017;23(1):38-44.

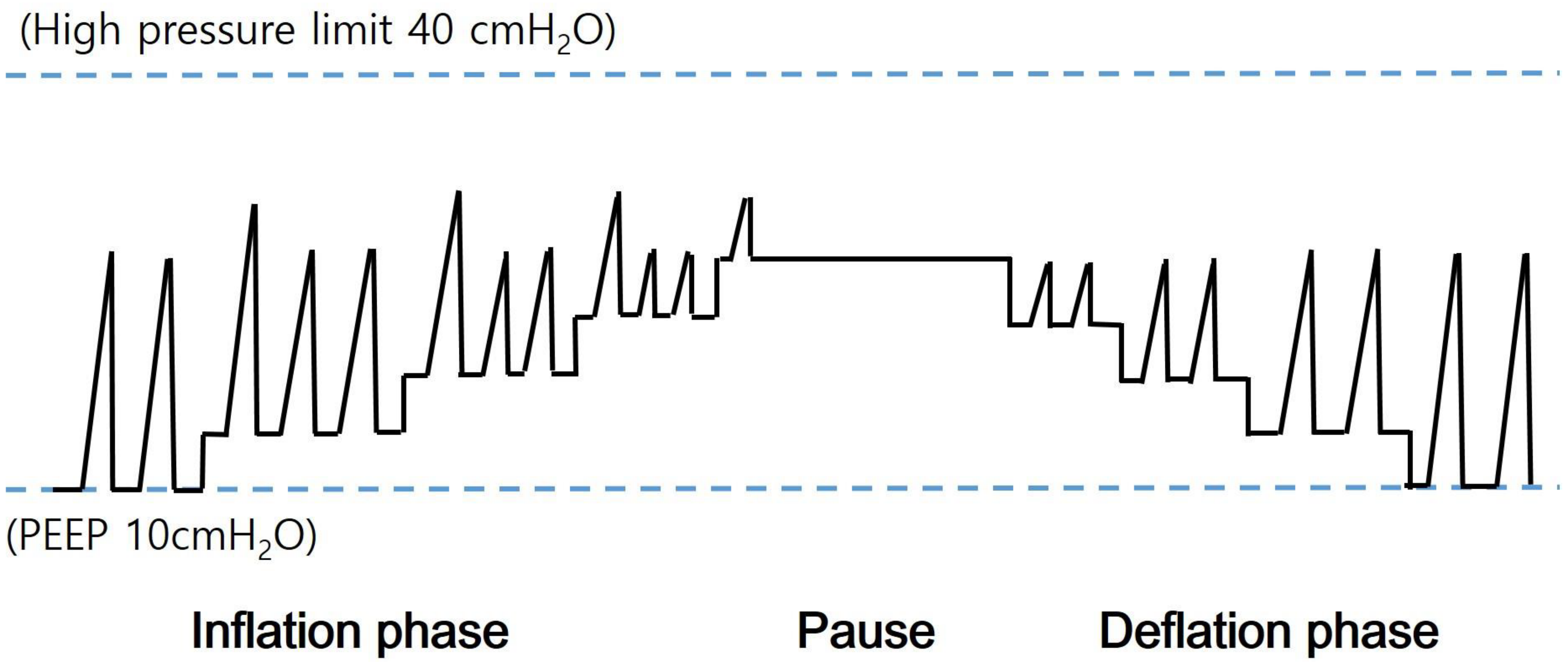
Adjusting ventilatory parameters according to driving pressure



Critical Care 2017;21:199

Recruit Maneuvers

Sustained increase in pressure with the goal of opening as many collapsed lung units as possible



Crit Care Med 2001;29(6):1255.

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Effect of Lung Recruitment and Titrated Positive End-Expiratory Pressure (PEEP) vs Low PEEP on Mortality in Patients With Acute Respiratory Distress Syndrome

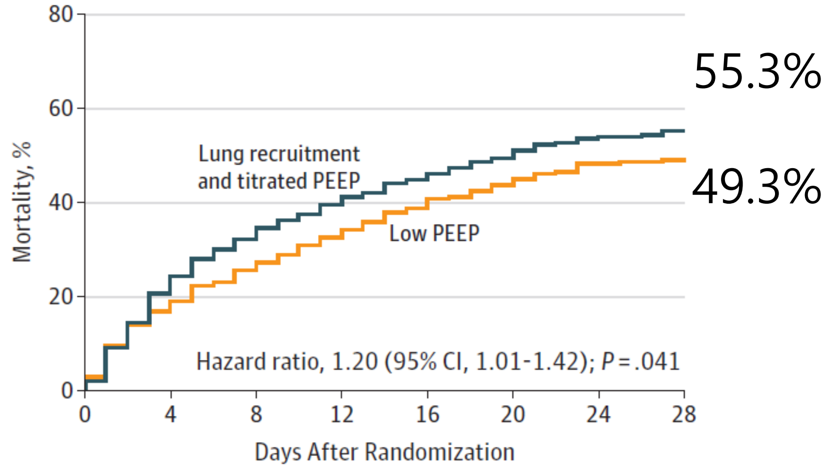
A Randomized Clinical Trial

Writing Group for the Alveolar Recruitment for Acute Respiratory Distress Syndrome Trial (ART) Investigators

Multicenter, randomized trial
conducted at 120 ICUs from 9 countries

RM and PEEP titration group (n = 501)
vs. low PEEP (n = 509)

Figure 2. 28-Day Mortality in the Lung Recruitment Maneuver With Titrated PEEP Group vs the Low-PEEP Group



No. at risk								
Lung recruitment and titrated PEEP	501	397	340	303	276	254	233	225
Low PEEP	509	423	378	343	312	286	264	260

JAMA. 2017;318(14):1335.

Maximal Recruitment Open Lung Ventilation in Acute Respiratory Distress Syndrome (PHARLAP)

A Phase II, Multicenter Randomized Controlled Clinical Trial

35 ICUs located in five countries

Outcomes	Intervention Group		Control Group		*P* Value
	N	*n* (%)*	*N*	*n* (%)*	
Primary outcome					
VFDs to Day 28, median (IQR), d	57	16 (0–21.0)	56	14.5 (0–21.5)	0.95
Secondary outcomes					
Death in ICU	57	14 (24.6)	56	15 (26.8)	0.79
Death in hospital	57	14 (24.6)	56	17 (30.4)	0.49
Mortality at Day 28	57	14 (24.6)	56	15 (26.8)	0.79
Mortality at Day 90	57	14 (24.6)	56	17 (30.4)	0.49
Mortality at 6 mo	57	14 (24.6)	56	17 (30.4)	0.49
Ventilation duration, median (IQR), h	57	212.0 (94.2–339.0)	56	214.4 (129.5–392.0)	0.41
ICU length of stay, median (IQR), d	57	11.1 (6.2–20.1)	56	13.8 (6.8–22.5)	0.69
Hospital length of stay, median (IQR), d	57	20.1 (8.1–37.2)	56	17.9 (9.0–39.0)	0.8
Safety outcomes, Days 1–28					
New cardiac arrhythmia	58	17 (29.3)	56	7 (12.5)	0.03
Bradycardia (<40 bpm)	58	4 (6.9)	56	3 (5.4)	0.99
Severe hypotension	58	20 (34.5)	56	12 (21.4)	0.12
New iNO cases	58	6 (10.3)	56	16 (28.6)	0.03
New prone positioning cases	58	4 (6.9)	56	7 (12.5)	0.02
New ECMO cases	58	1 (1.7)	56	7 (12.5)	0.03
New NMB	58	16 (27.6)	56	14 (25)	0.47
Refractory acidosis	58	9 (15.5)	56	4 (7.1)	0.16
Barotrauma	58	3 (5.2)	56	6 (10.7)	0.32
Pneumothorax requiring a chest drain	58	3 (5.2)	56	3 (5.4)	0.99
Exploratory outcomes					
Pneumothorax requiring drainage ≤7 d	58	3 (5.2)	56	2 (3.6)	0.99
Barotrauma ≤7 d	58	3 (5.2)	56	3 (5.4)	0.99

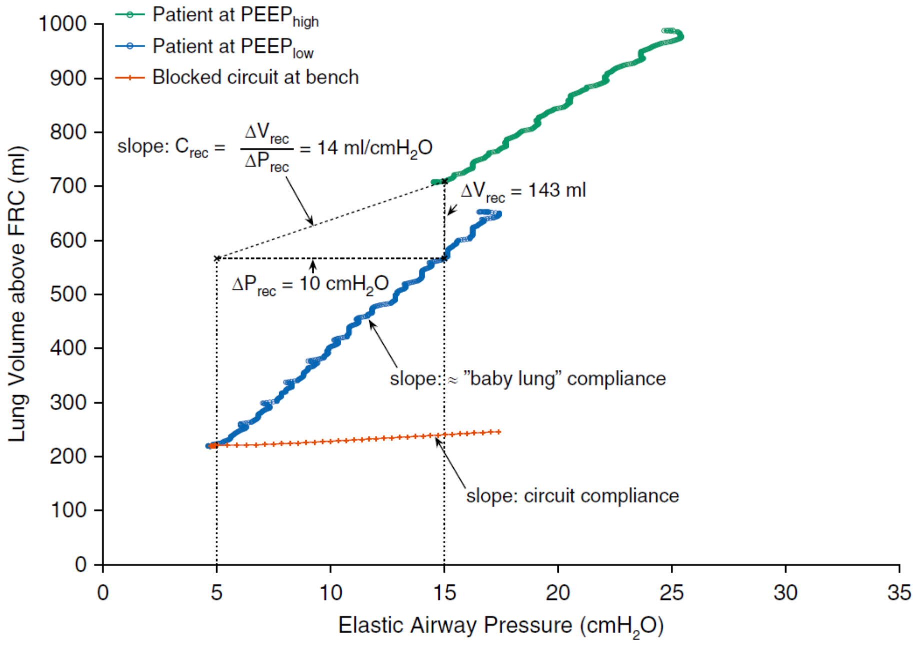
Am J Respir Crit Care Med. 2019;200(11):1363.

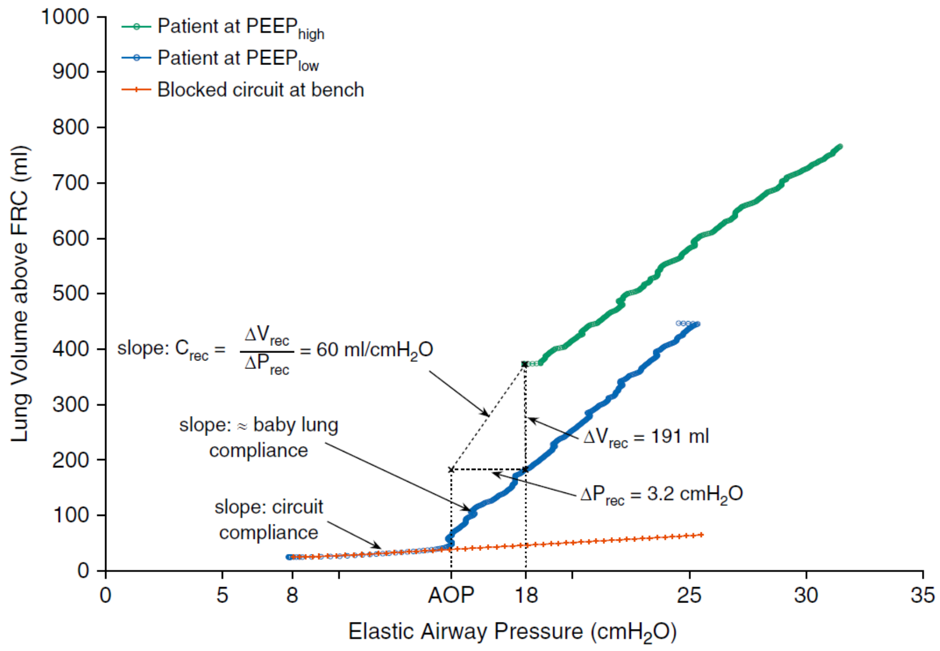
Recruitment to Inflation (R/I) Ratio

- Balance between recruitment and overinflation
- Associated with better oxygenation
- Assess lung recruitability
  - Recruiters vs. nonrecruiters

Am J Respir Crit Care Med. 2020 ;201(2):178-187.

Potential for Lung Recruitment Estimated by the Recruitment-to-Inflation Ratio in Acute Respiratory Distress Syndrome





The recruitment-to-inflation ratio correlated
with both oxygenation at low PEEP and the oxygenation response

Am J Respir Crit Care Med. 2020 ;201(2):178-187.

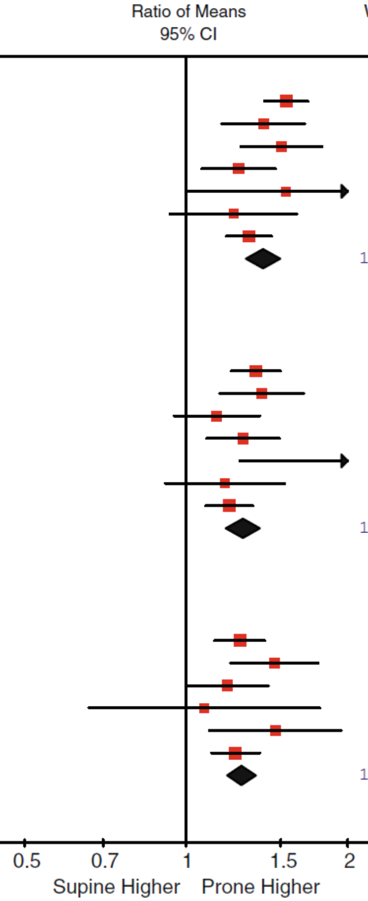
Prone Positioning

- PROSEVA trial and meta-analysis
  - Improved oxygenation and survival
  - Improved survival is not mediated through improved oxygenation
  - Due to a more even distribution of volume and distention forces across the lung, **leading to a reduction of VILI**

J Clin Med. 2022;11(2):319.

Prone ventilation reduces mortality in patients with acute respiratory failure and severe hypoxemia: systematic review and meta-analysis

Study or sub-category	Prone N	Supine N	Weight %	Ratio of Means 95% CI
Day 1				
Gattinoni 2001	147	148	25.70	1.53 [1.40, 1.69]
Watanabe 2002	8	8	12.50	1.39 [1.16, 1.66]
Curley 2005	48	51	12.82	1.50 [1.26, 1.79]
Mancebo 2006	73	59	14.71	1.25 [1.07, 1.47]
Chan 2007	11	11	2.89	1.53 [1.00, 2.34]
Fernandez 2008	21	15	6.41	1.22 [0.93, 1.61]
Taccone 2009	160	169	24.97	1.31 [1.19, 1.44]
Subtotal (95% CI)	468	461	100.00	1.39 [1.29, 1.50]
Test for Overall Effect: p=<0.00001				
Heterogeneity: $I^2 = 35\%$				
Day 2				
Gattinoni 2001	121	148	24.21	1.35 [1.21, 1.50]
Watanabe 2002	8	8	12.90	1.38 [1.16, 1.65]
Curley 2005	45	49	12.47	1.14 [0.95, 1.37]
Mancebo 2006	71	59	15.60	1.27 [1.09, 1.49]
Chan 2007	8	7	2.16	2.09 [1.26, 3.46]
Fernandez 2008	21	18	7.40	1.18 [0.91, 1.53]
Taccone 2009	159	167	25.26	1.20 [1.09, 1.33]
Subtotal (95% CI)	433	456	100.00	1.27 [1.18, 1.37]
Test for Overall Effect: p=<0.00001				
Heterogeneity: $I^2 = 30\%$				
Day 3				
Gattinoni 2001	95	139	29.04	1.26 [1.13, 1.40]
Watanabe 2002	8	8	14.59	1.46 [1.21, 1.76]
Curley 2005	41	47	16.16	1.19 [1.00, 1.42]
Chan 2007	8	7	2.74	1.08 [0.66, 1.77]
Fernandez 2008	20	17	7.58	1.47 [1.10, 1.94]
Taccone 2009	153	161	29.90	1.23 [1.11, 1.37]
Subtotal (95% CI)	325	379	100.00	1.27 [1.19, 1.35]
Test for Overall Effect: p=<0.00001				
Heterogeneity: $I^2 = 0\%$				



Intensive Care Med 2010;36:585.

Prone Positioning in Severe ARDS

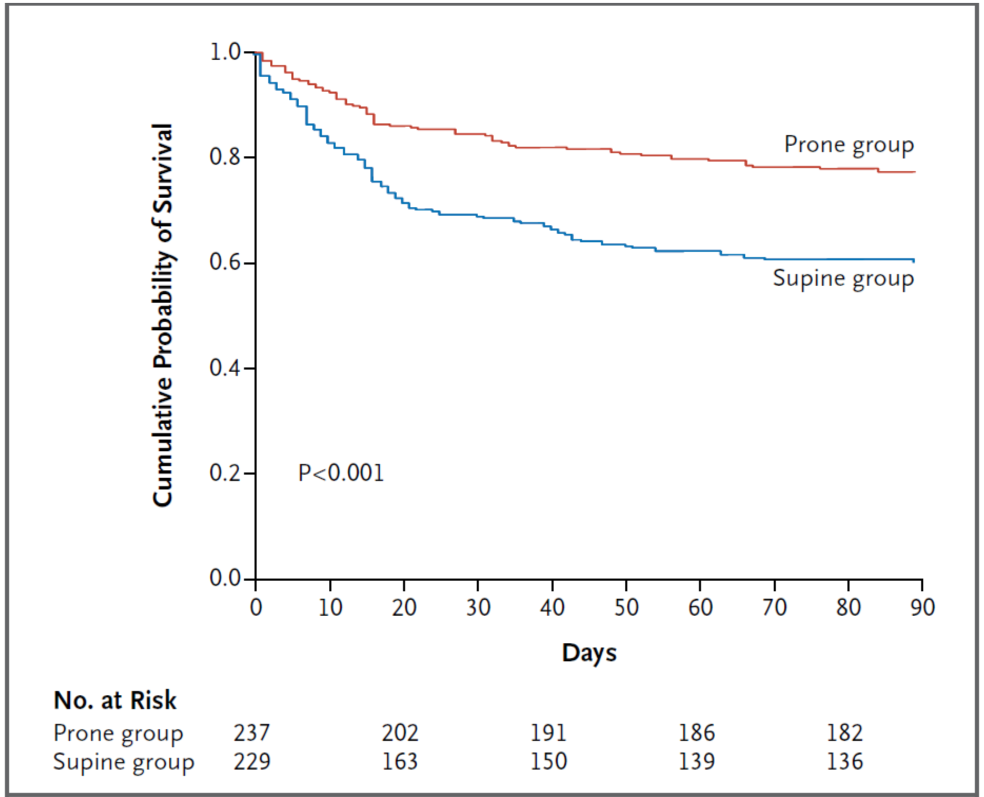


Figure 2. Kaplan–Meier Plot of the Probability of Survival from Randomization to Day 90.

The PROSEVA Study Group

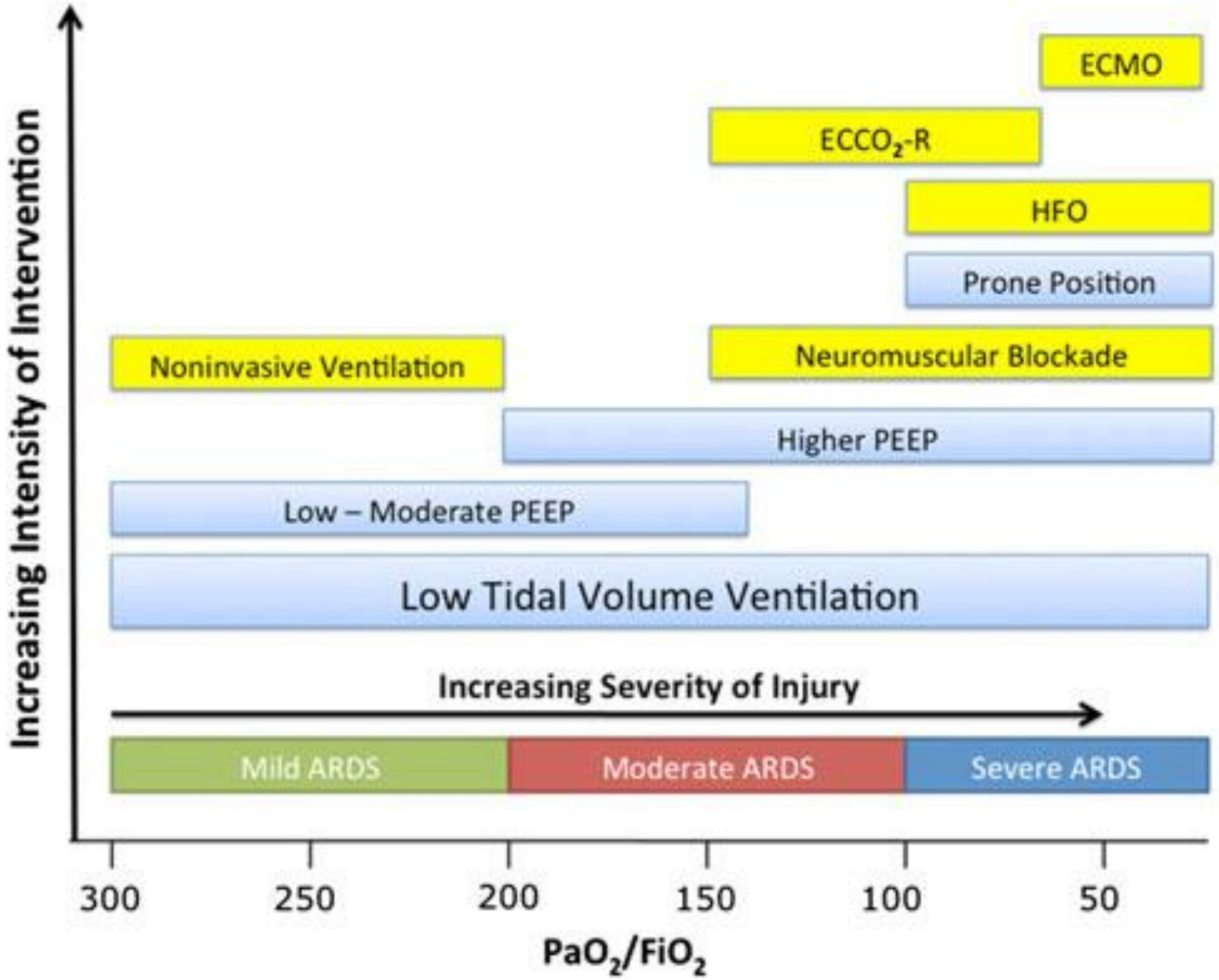
- Multi-center, prospective RCT
- 446 patients
  - 237 prone, 229 supine
- Severe ARDS
  - P/F ratio <150
  - $FiO_2 \geq 0.6$
  - PEEP ≥5 cmH_20
- Early application of prolonged prone session
  - At least 16 consecutive hours/day

N Engl J Med 2013;368:2159-68.

Society	Recommendation	Strength of Recommendation	Evidence
ATS/ESICM/SCCM	Mechanical ventilation with low tidal volumes and inspiratory pressures	Strong	Moderate
	Daily prone positioning >12 h	Strong	Moderate-high
	Avoid HFOV in patients with moderate or severe ARDS	Strong	Moderate-high
	Mechanical ventilation with higher levels of PEEP for moderate or severe ARDS	Conditional	Moderate
	Recruitment maneuvers should be used	Conditional	Low-moderate
	Additional research needed to recommend use of ECMO in patients with ARDS	Not applicable	Not applicable
FICM/ICS	Mechanical ventilation with low tidal volumes (<6 mL/kg ideal body weight) and plateau pressure (<30 cm H_2O)	Strong	Moderate
	Daily prone positioning ≥12 h in patients with moderate/severe ARDS	Strong	Moderate
	Avoid HFOV	Strong	Moderate
	Conservative fluid management	Weakly in favor	Low
	Mechanical ventilation with higher levels of PEEP in patients with moderate/severe ARDS	Weakly in favor	Low
	Neuromuscular blocking agents in patients with moderate/severe ARDS	Weakly in favor	Moderate
	Use of ECMO in patients with severe ARDS	Weakly in favor	Very low

Abbreviations: ATS: American Thoracic Society; ESICM: European Society of Intensive Care Medicine; SCCM: Society of Critical Care Medicine Clinical Practice Guideline; FICM: Faculty of Intensive Care Medicine; ICS: Intensive Care Society.

J Clin Med. 2022;11(2):319.



Intensive Care Med. 2012;38:1573.

Fundamental Elements of Initial ICU Care for Patients with ARDS

- Lung protective ventilation strategy: goal tidal volume ≤6 mL/kg, plateau pressure ≤30 cm H_2O, PEEP relative to FiO_2 set according to ARDS Network grids or local practice,[91] generally PEEP ≥5 cm H_2O
- Assiduous search for and treatment of underlying cause of ARDS
- Sedation and analgesia only as needed to promote comfort, ventilator synchrony
- Fluid conservative strategy including aggressive diuresis if needed to reach net negative fluid status, once shock has resolved (off vasopressors)
- Stress ulcer prophylaxis, deep venous thrombosis prophylaxis with subcutaneous heparin or low-molecular weight heparin, unless otherwise contraindicated
- Daily spontaneous breathing trials to assess for ventilator liberation beginning when the patient can tolerate FiO_2 ≤0·5 and PEEP ≤8 cm H_2O
- For patients with moderate to severe ARDS (PaO_2/FiO_2 ratio <150 mm Hg), consider:
    - Neuromuscular blockade, with goal duration <48 h
    - Prone positioning for at least 17 h per day

Lancet 2021;398:622

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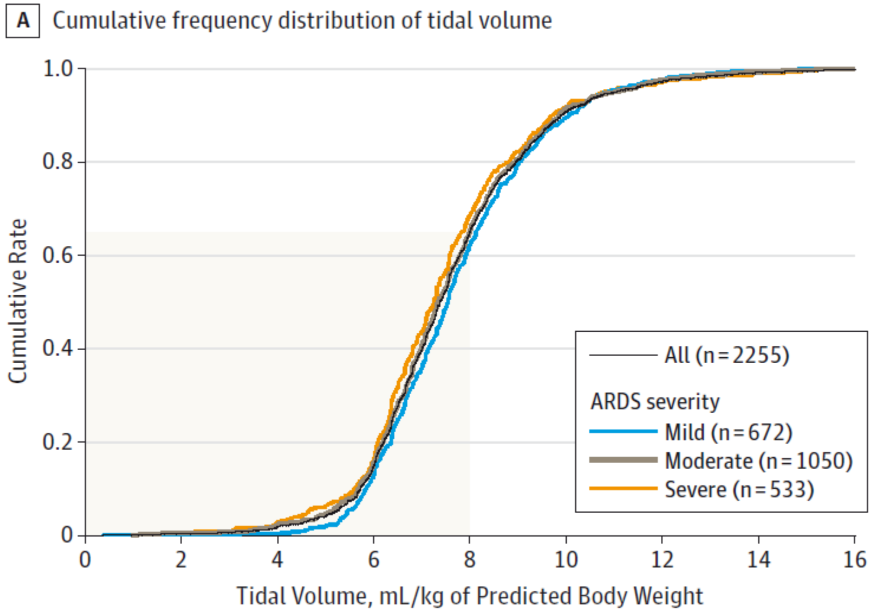
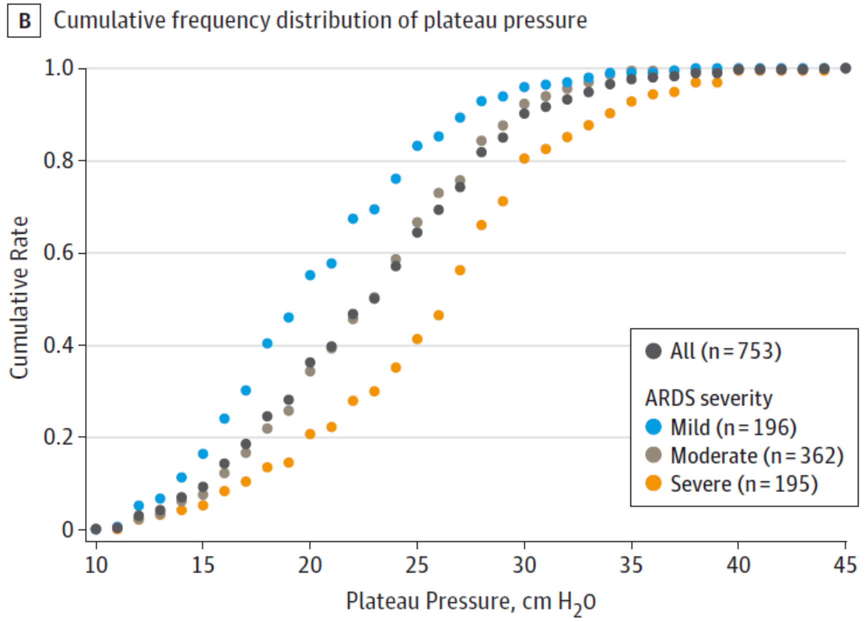
Epidemiology, Patterns of Care, and Mortality for Patients With Acute Respiratory Distress Syndrome in Intensive Care Units in 50 Countries





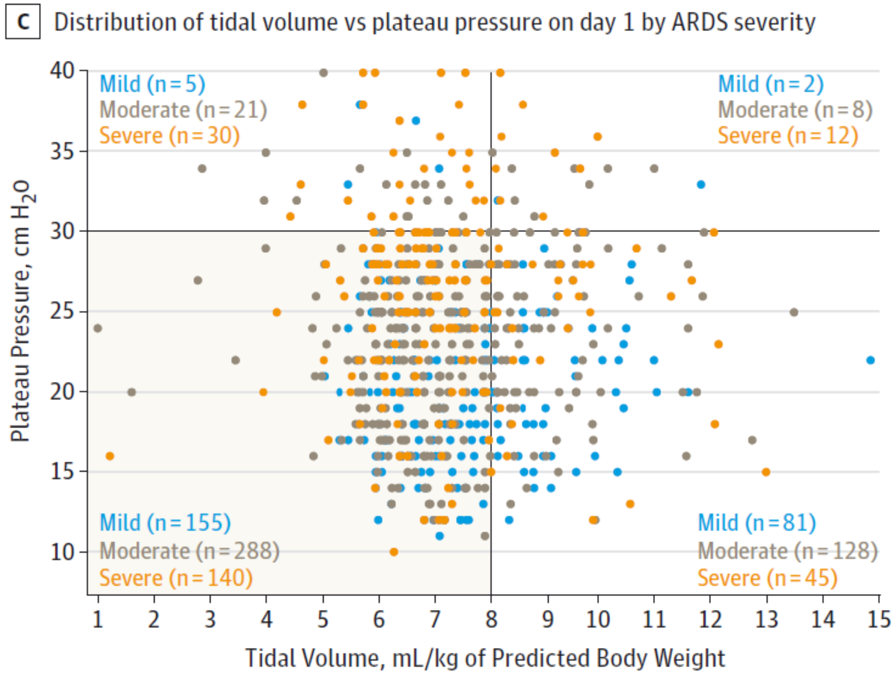
35.1% received a **TV >8 mL/kg PBW**

Plateau pressure was measured in **40.1%.**

JAMA. 2016;315(8):788.

JAMA | 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

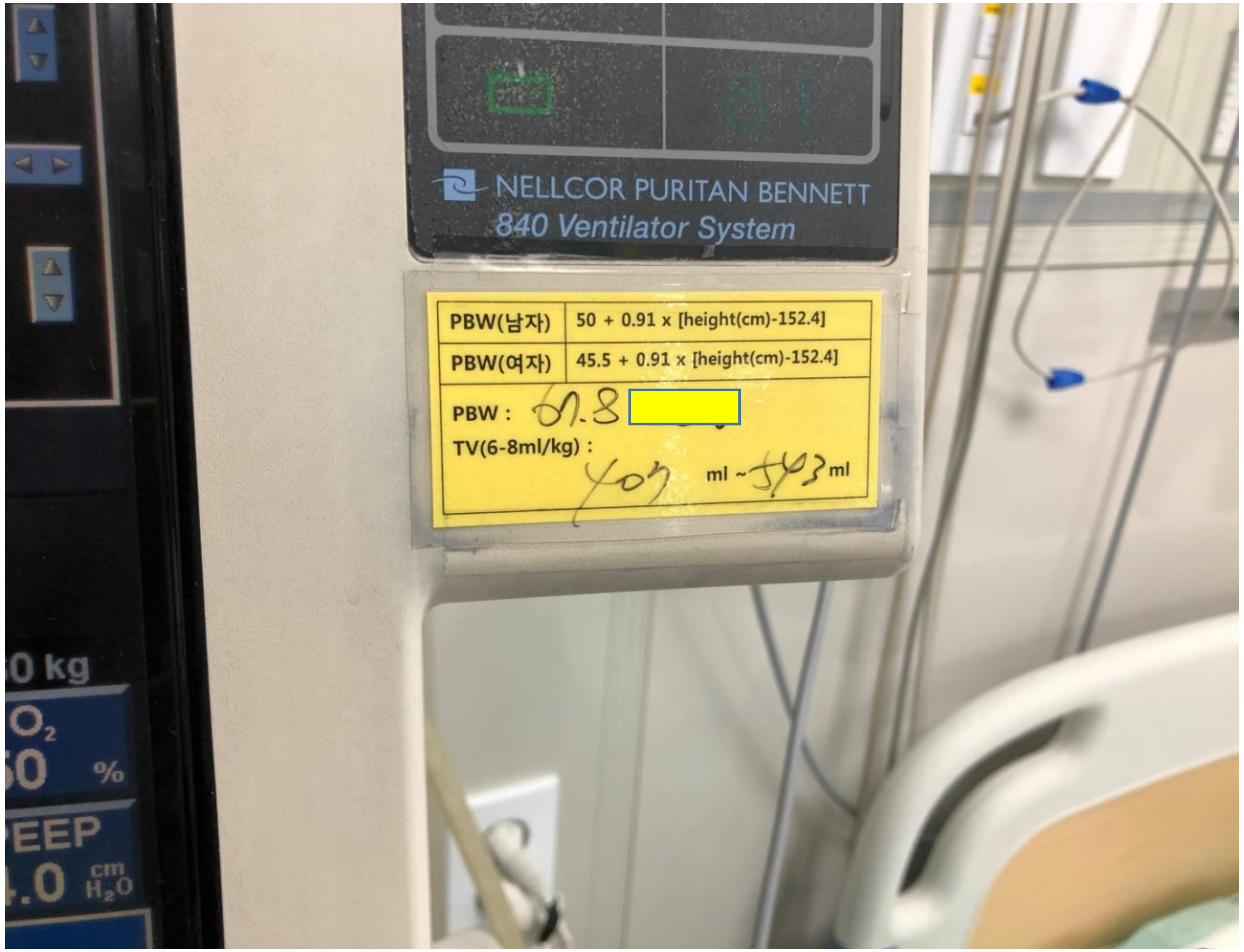


2/3 within the limits for *protective ventilation*

Prone positioning

16.3% of patients with severe ARDS.

JAMA. 2016;315(8):788.


NELLCOR PURITAN BENNETT
840 Ventilator System
PBW(남자) 50 + 0.91 x [height(cm)-152.4]
PBW(여자) 45.5 + 0.91 x [height(cm)-152.4]
PBW : 67.8
TV(6-8ml/kg) :
407 ml ~ 543 ml