# *Setting PEEP and Tidal Volume in ARDS*

New York State Thoracic Society
Annual Assembly

Westchester Medical Center
Valhalla, New York
March 24, 2018

Roy Brower
Johns Hopkins University

# Disclosures

- No conflicts of interest
- No off-label

# Case Presentation

- 27 year old M with alcoholic hepatitis and pneumonia
- Height 193 cm (6'4"). Predicted Body Wt = 87 kg
- 6 ml/kg = 520 mL PEEP = 10.

  Pplat = 34 cm $H_2O$

  Driving Pressure (Pplat – PEEP, $\Delta P$) = 24

# Case Presentation

- 27 year old M with alcoholic hepatitis and pneumonia
- Height 193 cm (6’4”). Predicted Body Wt = 87 kg
- 6 ml/kg = 520 mL. PEEP = 10. Pplat = 34. $\Delta P = 24$
- Chest volumes not large

# Case Presentation

- 27 year old M with alcoholic hepatitis and pneumonia
- Height 193 cm (6'4"). Predicted Body Wt = 87 kg
- 6 ml/kg = 520 mL. PEEP = 10
  - Pplat = 34. Driving Pressure ($\Delta P$) = 24
- Chest volumes not large
- Tidal volume decreased to 5, 4 mL/kg PBW
  - Pplat = 28, Driving Pressure ($\Delta P$) = 18

# ACUTE RESPIRATORY DISTRESS IN ADULTS

DAVID G. ASHBAUGH
M.D. Ohio State
ASSISTANT PROFESSOR OF SURGERY

D. BOYD BIGELOW
M.D. Colorado
ASSISTANT IN MEDICINE AND AMERICAN THORACIC SOCIETY-NATIONAL TUBERCULOSIS ASSOCIATION FELLOW IN PULMONARY DISEASE

THOMAS L. PETTY
M.D. Colorado
ASSISTANT PROFESSOR OF MEDICINE

BERNARD E. LEVINE
M.D. Michigan
AMERICAN THORACIC SOCIETY-NATIONAL TUBERCULOSIS ASSOCIATION FELLOW IN PULMONARY DISEASE*

Lancet 1967

# Continuous positive-pressure breathing (CPPB) in adult respiratory distress syndrome

*D. G. Ashbaugh, M.D.* (by invitation), T. L. Petty, M.D.** (by invitation), D. B. Bigelow, M.D.*** (by invitation), and T. M. Harris, M.D.**** (by invitation), Denver, Colo.*

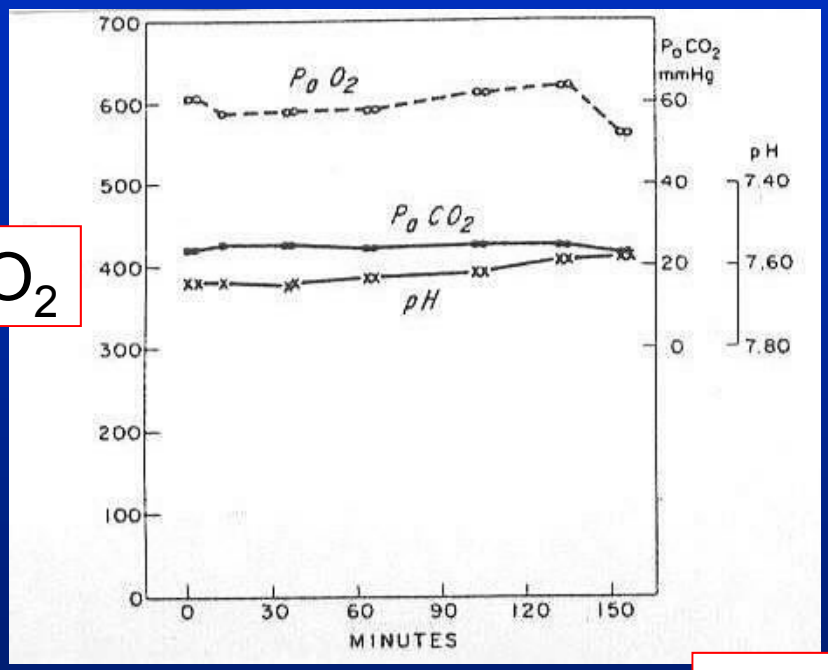
*Sponsored by W. R. Waddell, M.D., Denver, Colo.*

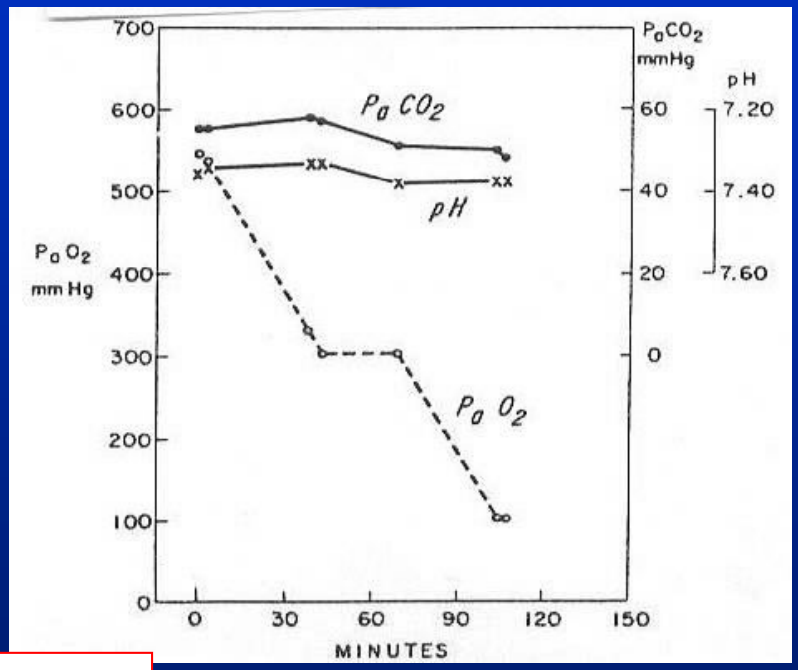
J Thor CV Surg 1969

"The lungs become very stiff and require 40 to 60 cm. of water to achieve adequate tidal volumes."

# Impaired Oxygenation During Anesthesia with Controlled Ventilation

$PaO_2$




Minutes

Bendixen et al. N Eng J Med 1963

MEDICAL PROGRESS

ACUTE RESPIRATORY FAILURE IN THE ADULT (Third of Three Parts)

H. PONTOPPIDAN, M.D., B. GEFFIN, M.D., AND E. LOWENSTEIN, M.D.

New Eng J Med 1972

"Extensive clinical experience … indicates that volumes of 7 ml per kilogram … [are] poorly tolerated…. Larger tidal volumes (10-15 ml per kilogram) are preferable, having been used in several thousand ventilated patients with no evidence of development of pulmonary damage.

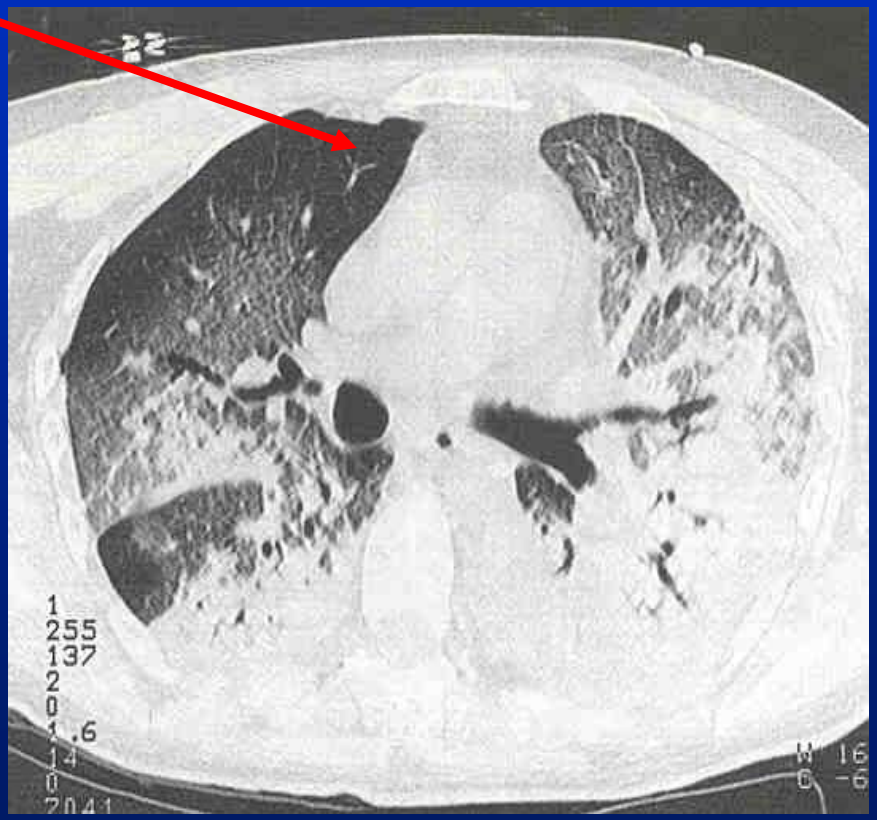
# Tidal Volumes 1965-1983

| Year | Authors | Journal | Tidal Volume (mL/kg) |
|---|---|---|---|
| 1965 | Sykes et al. (12) | *Br J Anaesth* | 10–15 |
| 1969 | McIntyre et al. (13) | *Can Anaesth Soc J* | 8–14 |
| 1970 | Kumar et al. (14) | *N Engl J Med* | 11–13 |
| 1972 | Pontoppidan et al. (15) | *N Engl J Med* | 10–15 |
| 1972 | Falke et al. (16) | *J Clin Invest* | 9–24 |
| 1972 | Lutch and Murray (17) | *Ann Intern Med* | 10–16 |
| 1973 | Kumar et al. (18) | *Crit Care Med* | 12–18 |
| 1974 | Steier et al. (19) | *J Thorac Cardiovasc Surg* | 14–21 |
| 1975 | Suter et al. (20) | *N Engl J Med* | 15 |
| 1979 | Hemmer and Suter (21) | *Anesthesiology* | 15 |
| 1981 | Jardin et al. (22) | *N Engl J Med* | 12–20 |
| 1983 | Mathru et al. (23) | *Crit Care Med* | 12–15 |

Brochard and Lemaire
Crit Care Med 1999

# Ventilator-Induced Lung Injury

High Volume
High Pressure
VILI



The New England
Journal of Medicine



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*

# $V_T$ Recommendation

$V_T$ Goal = 6 mL/kg Predicted Body Weight

PBW based on gender, height

# $V_T$ Recommendation

$V_T$ Goal = 6 mL/kg Predicted Body Weight

PBW based on gender, height

*Intended as a guide to lung size*

# $V_T$ Recommendation
## ARDS Network

$V_T$ Goal = 6 mL/kg Predicted Body Weight

PBW based on gender, height

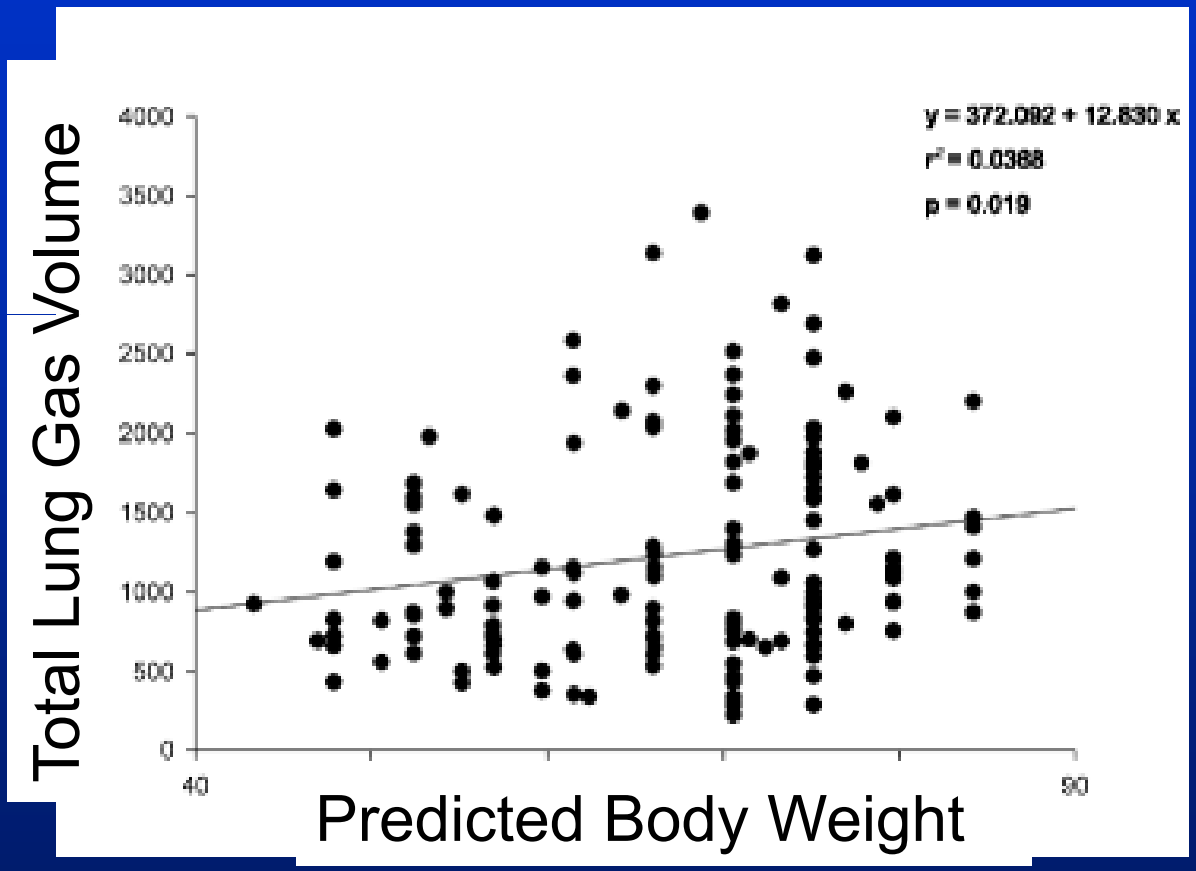
*Intended as a guide to lung size*

*Male, 180 cm*

*Predicted FRC = 3.8 L*

*Measured FRC SD = 0.99 L*

# Predicted Body Weight and Aerated Lung Volume in ARDS Patients



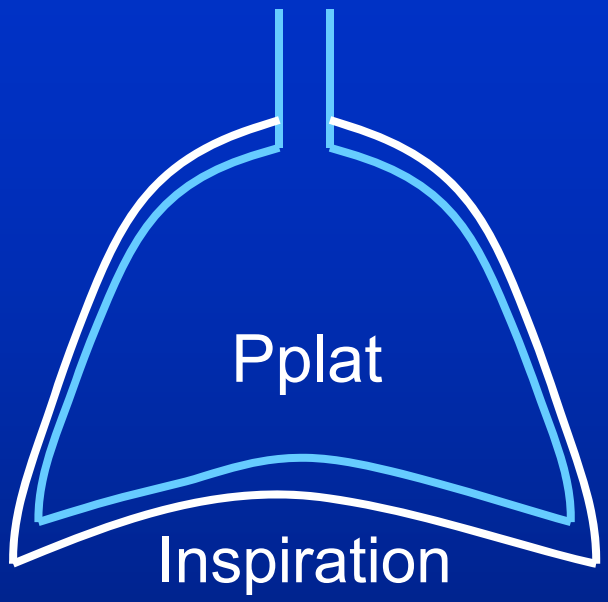

Chiumello et al. Crit Care 2016

# Clinical Recommendation

$V_T$ Goal = 6 mL/kg PBW

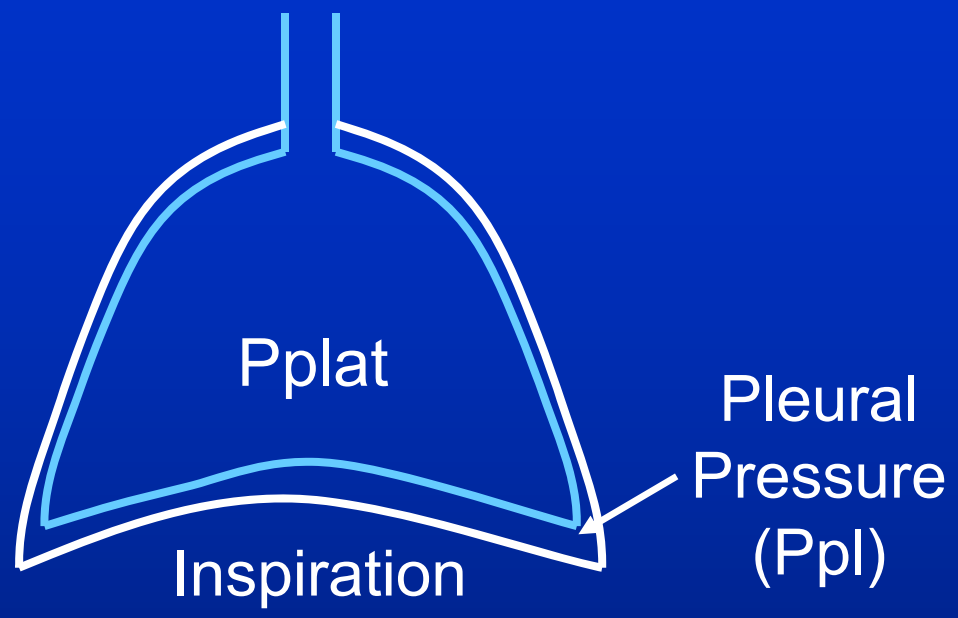
If Pplat > 30 cm $H_2O$, decrease $V_T$ to 5 or 4 mL/kg PBW.

# Pplat to Guide Tidal Volume?




Pplat = *Mean* distending pressure of *respiratory system* (lungs and chest wall)

# Pplat to Guide Tidal Volume?




Pplat = Distending pressure of the respiratory system

$P_{TP}$ = Pplat – Ppl = Distending pressure of the lung

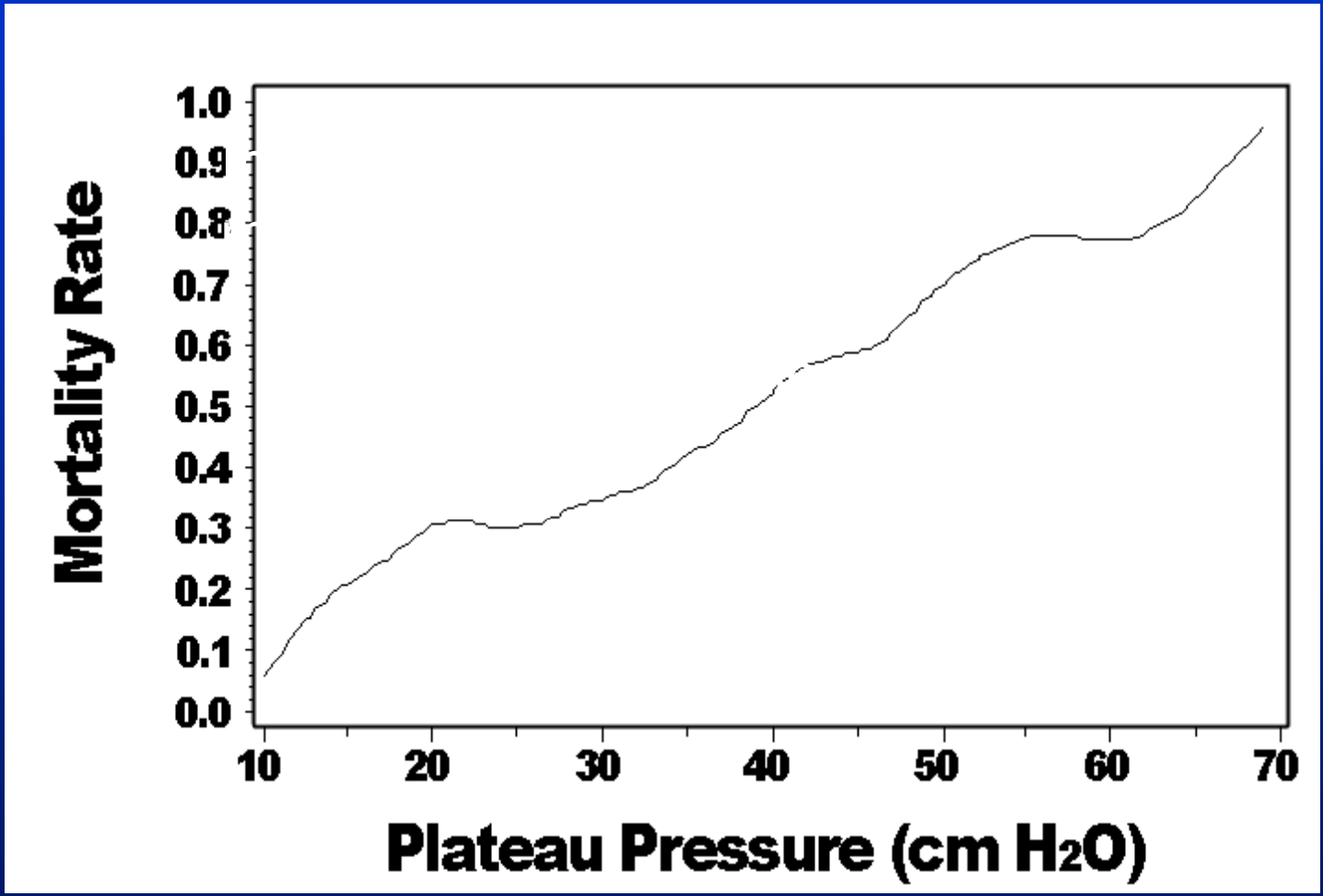
# Clinical Recommendation

$V_T$ Goal = 6 mL/kg PBW

If Pplat > 30 cm $H_2O$, decrease $V_T$ to 5 or 4 mL/kg PBW.

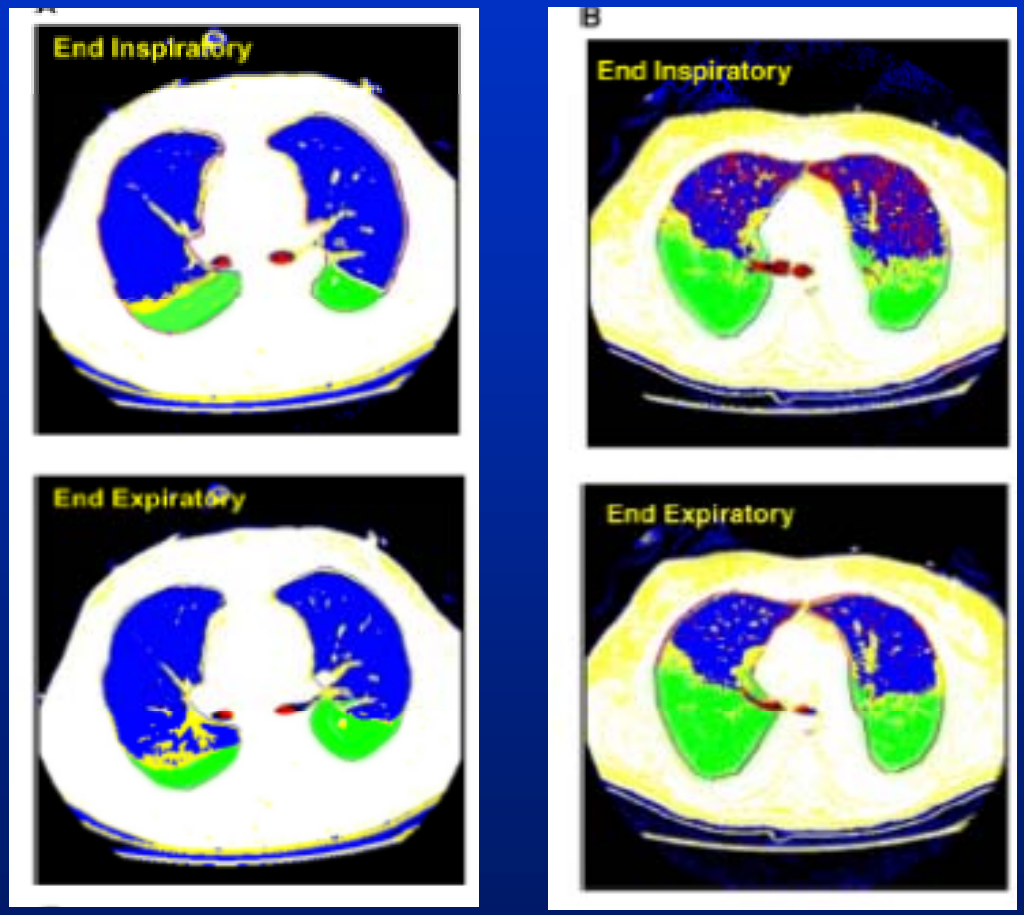
Are Pplats < 30 cm $H_2O$ safe?

# Safe Plateau Pressure?



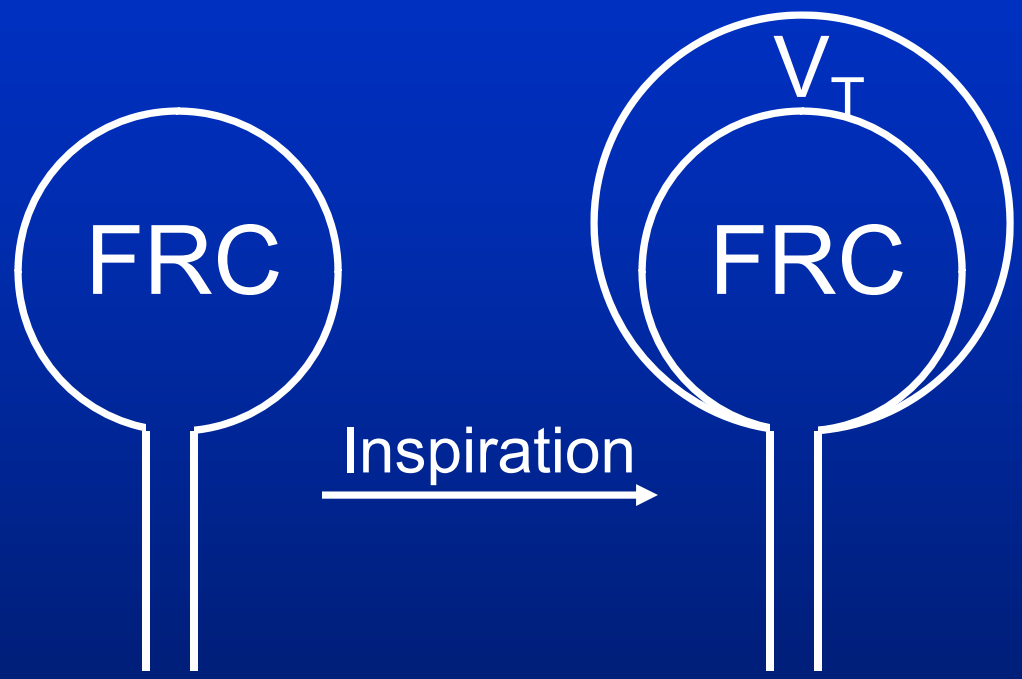

Hager et al, AJRCCM 2005

# Variable Consolidation, Edema, and Atelectasis




Terragni et al.
Am J Resp Crit Care Med 2007

# Strain




Strain = $V_T$/FRC

# Strain Approach

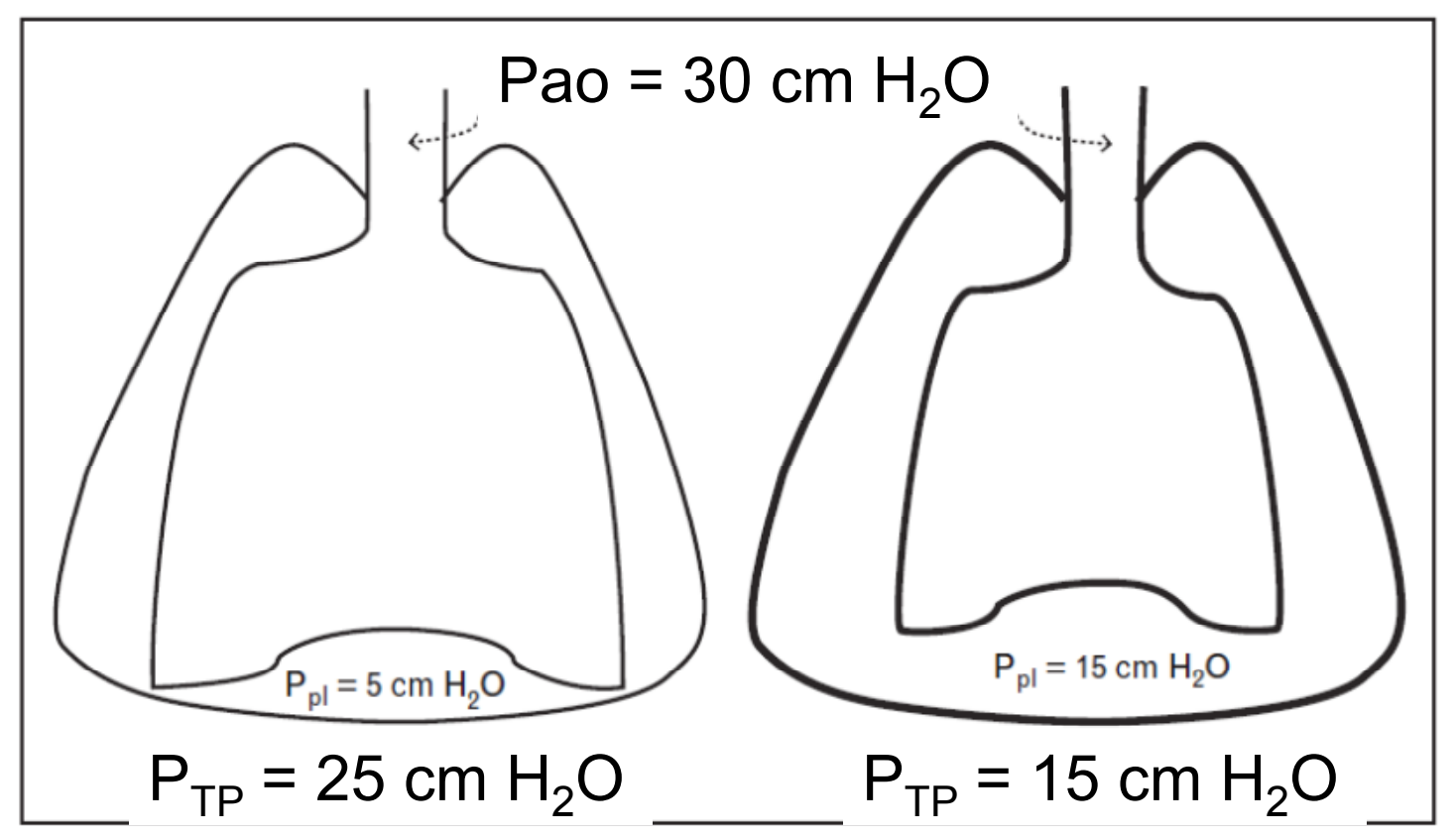
- Measure FRC
  - Computerized Tomography
  - Helium Dilution
  - Nitrogen Wash-in-Wash-out
- Set $V_T$ to keep strain below a safe level
  - What is a safe level?

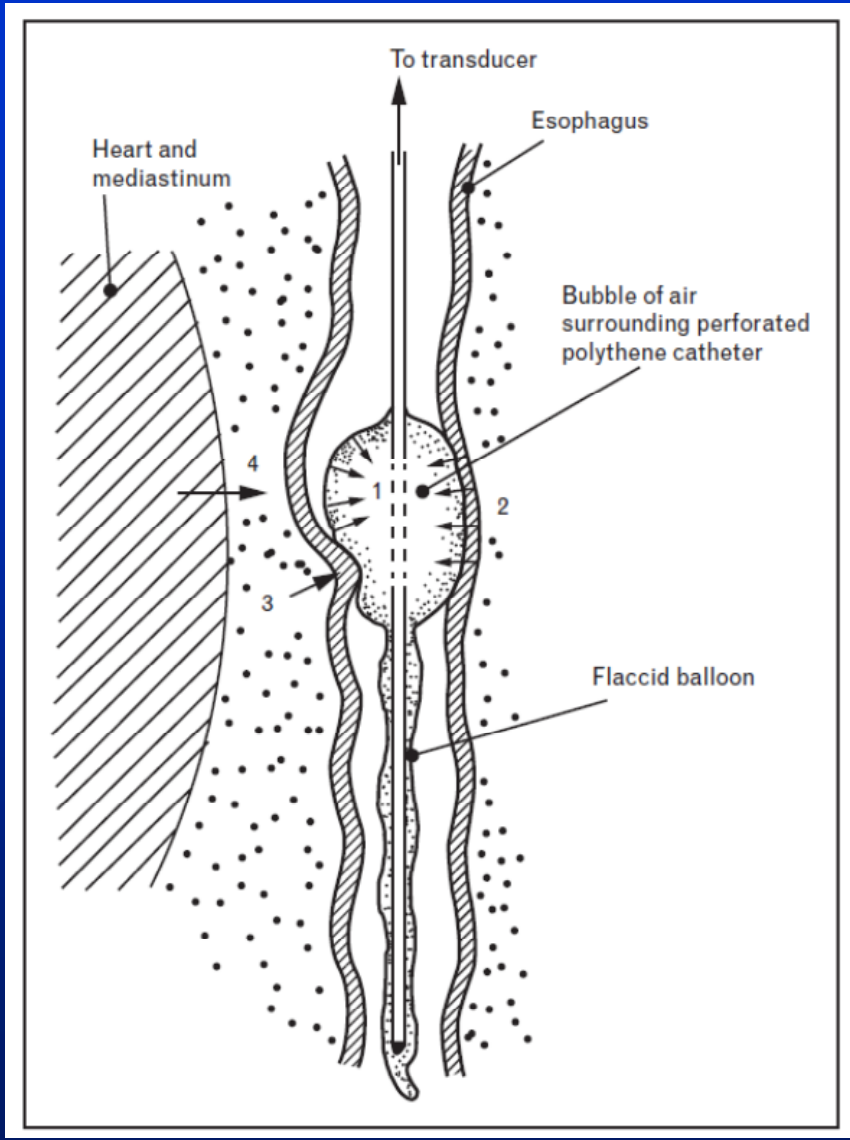
# Stress



Stress = Force/Area

# Airway, Pleural, and Transpulmonary Pressures

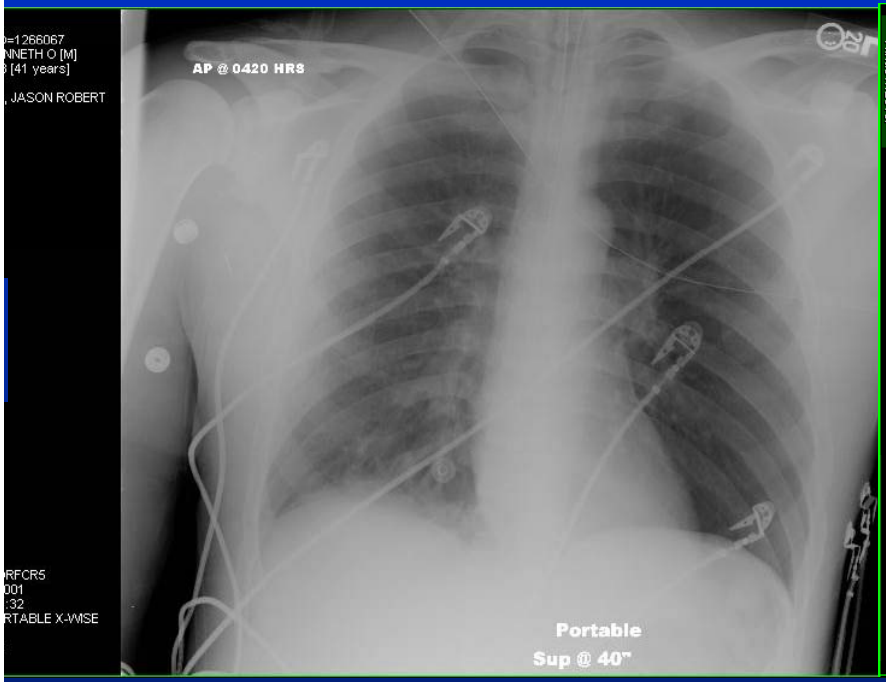




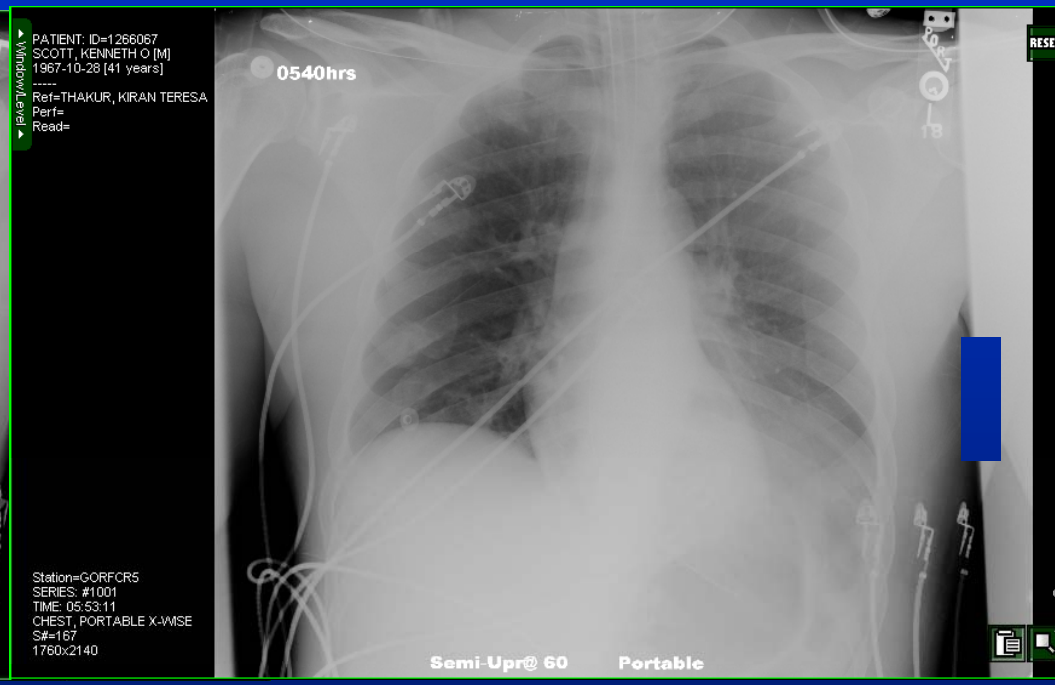

Gibson and Pride. Br J Dis Chest 1976

Potential sources of error in estimating pleural pressure by esophageal manometry

# Pleural Pressures Vary by Region




January 4




January 5

# Problems with $P_{TP}$ Approach

- Requires esophageal catheter
- Pleural pressures not uniform in chest
  - Esophageal pressure not a good average
- $P_{TP}$ goal for setting Tidal Volume = ???

The NEW ENGLAND JOURNAL of MEDICINE

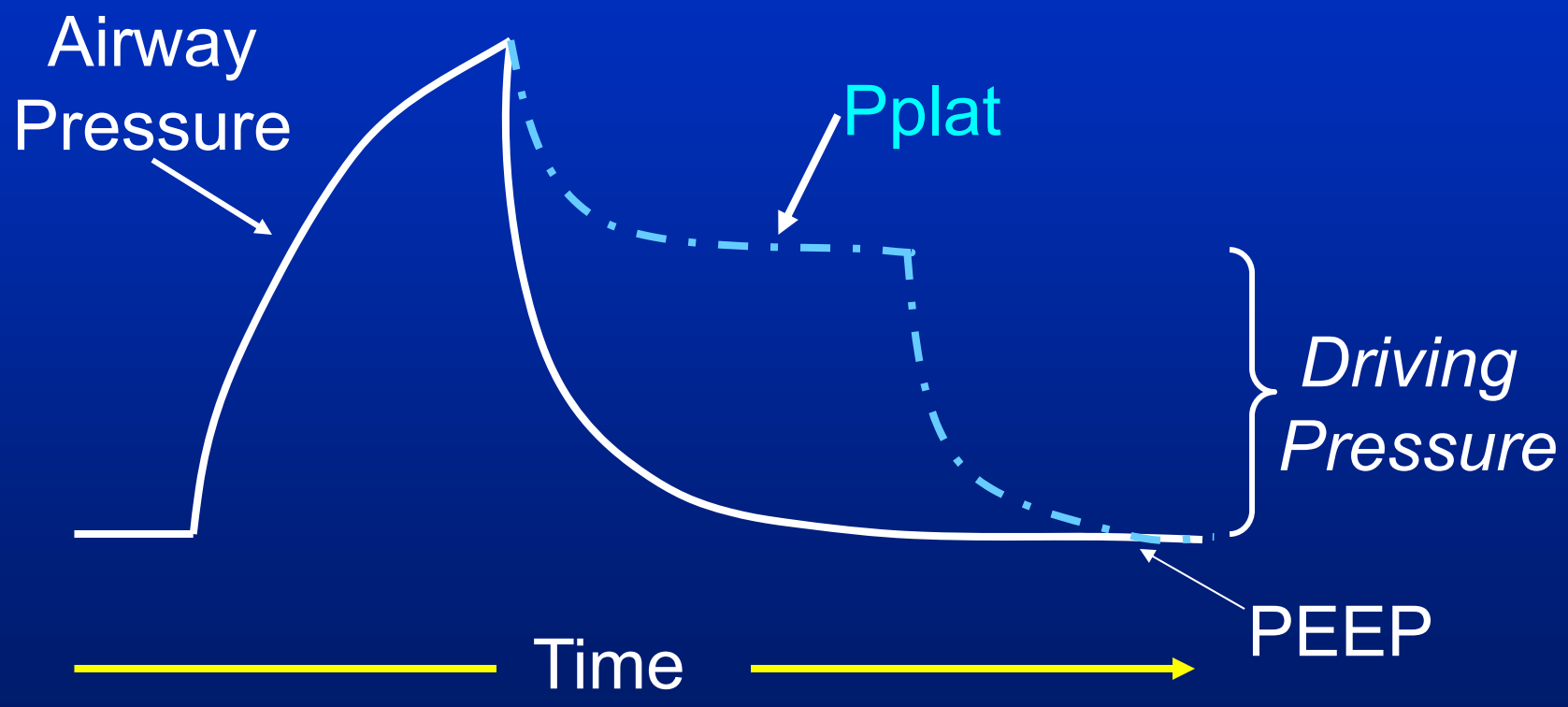
SPECIAL ARTICLE

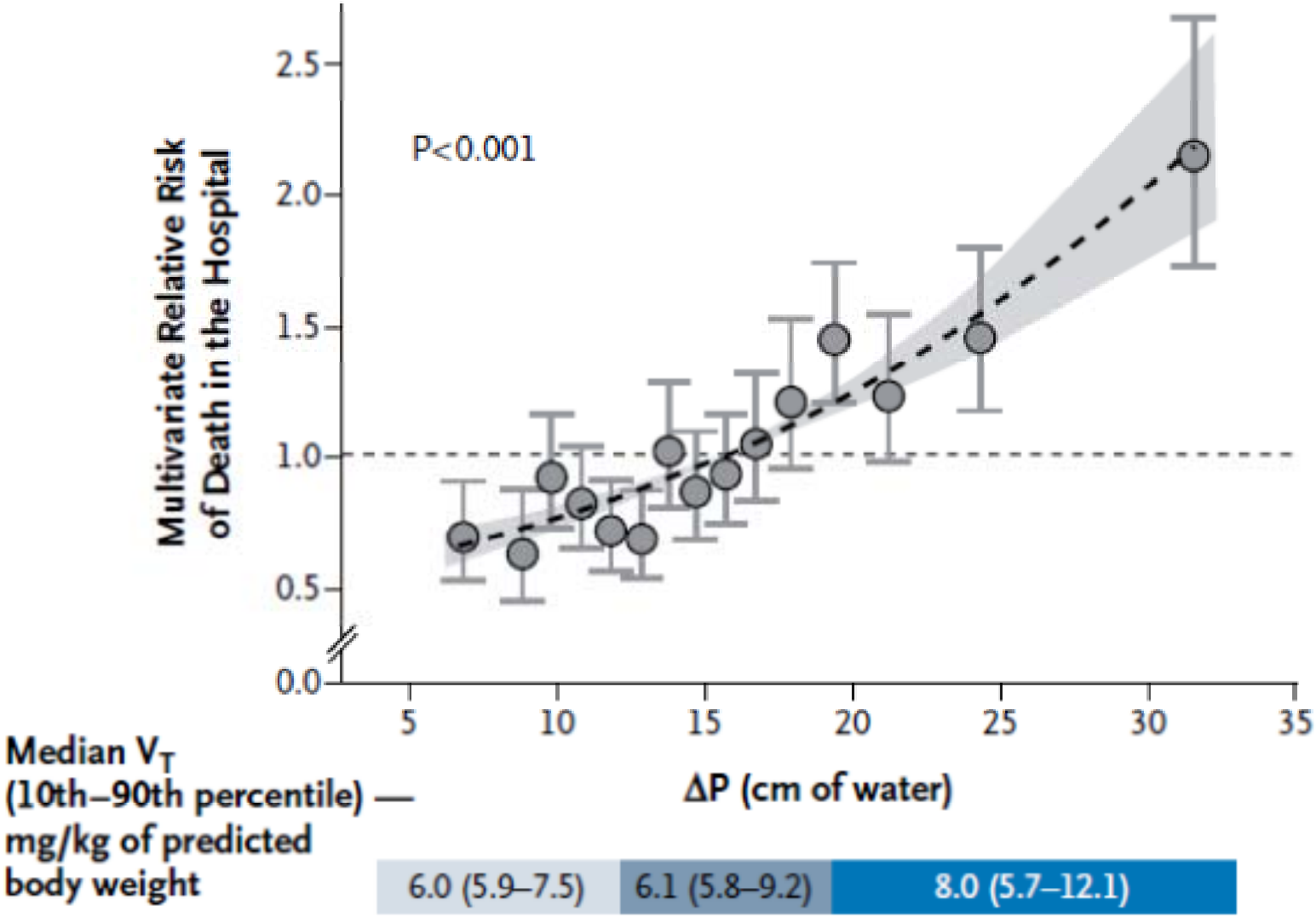
# Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.

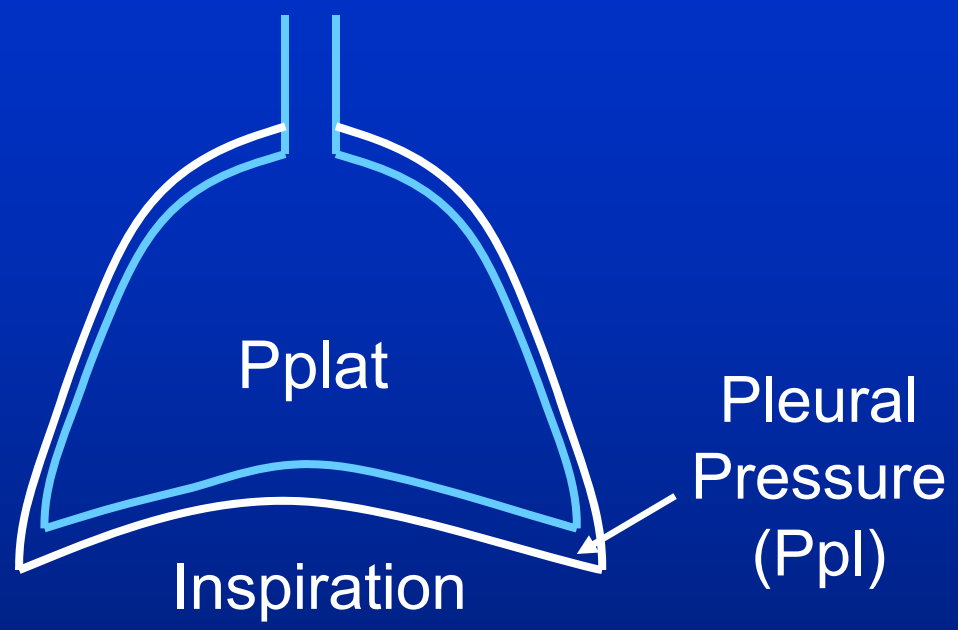
New Eng J Med 2015

# Driving Pressure




Multivariate Relative Risk of Death in the Hospital
2.5
2.0
1.5
1.0
0.5
0.0
P<0.001
5
10
15
20
25
30
35
ΔP (cm of water)
Median $V_T$ (10th–90th percentile) — mg/kg of predicted body weight
6.0 (5.9–7.5)
6.1 (5.8–9.2)
8.0 (5.7–12.1)

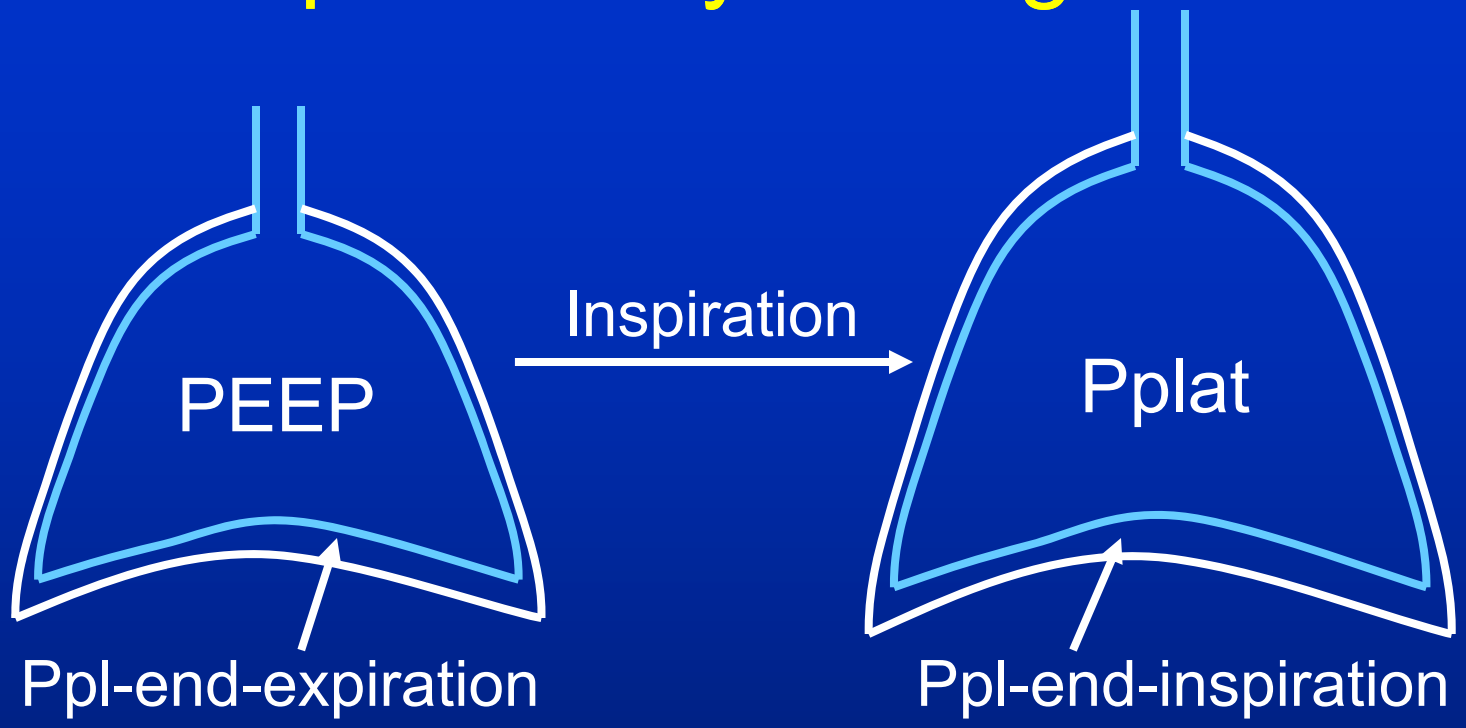
# Problems with Driving Pressure Approach




Pplat = Distending pressure of the respir system

$P_{TP}$ = Pplat – Ppl = Distending pressure of the lung

# Transpulmonary Driving Pressure




Transpulmonary Driving Pressure ($\Delta P_{TP}$)

$P_{TP}ei - P_{TP}ee$

$\Delta P_{TP} = V_T/C_L$

# Problems with $\Delta P_{TP}$ Approach

- Requires esophageal catheter
  - Many assumptions
- Safe upper limit?
  - Normal: $C_L = 200$, $V_T = 400$, then

    $\Delta P_{TP} = 400/200 = 2$ cm $H_2O$
  - ARDS: $C_L = 20 – 50$, $V_T = 400$

    $\Delta P_{TP} = 8 – 20$ cm $H_2O$

# How to Set $V_T$ in ARDS

- Method must be acceptable to most clinicians
- Initial $V_T$ = 6 mL/kg PBW (easiest)
- Reduce $V_T$ in decrements of ~0.5 ml/kg PBW over several hours until signs of intolerance.

# PBW vs Strain vs Stress vs Driving Pressure vs Transpulmonary Driving Pressure?

Decrease $V_T$ until *signs of intolerance*:

- Tachycardia
- Hypertension or hypotension
- Agitation
- Tachypnea, dyssynchrony
- Acidosis
- Hypoxemia despite high $FiO_2$

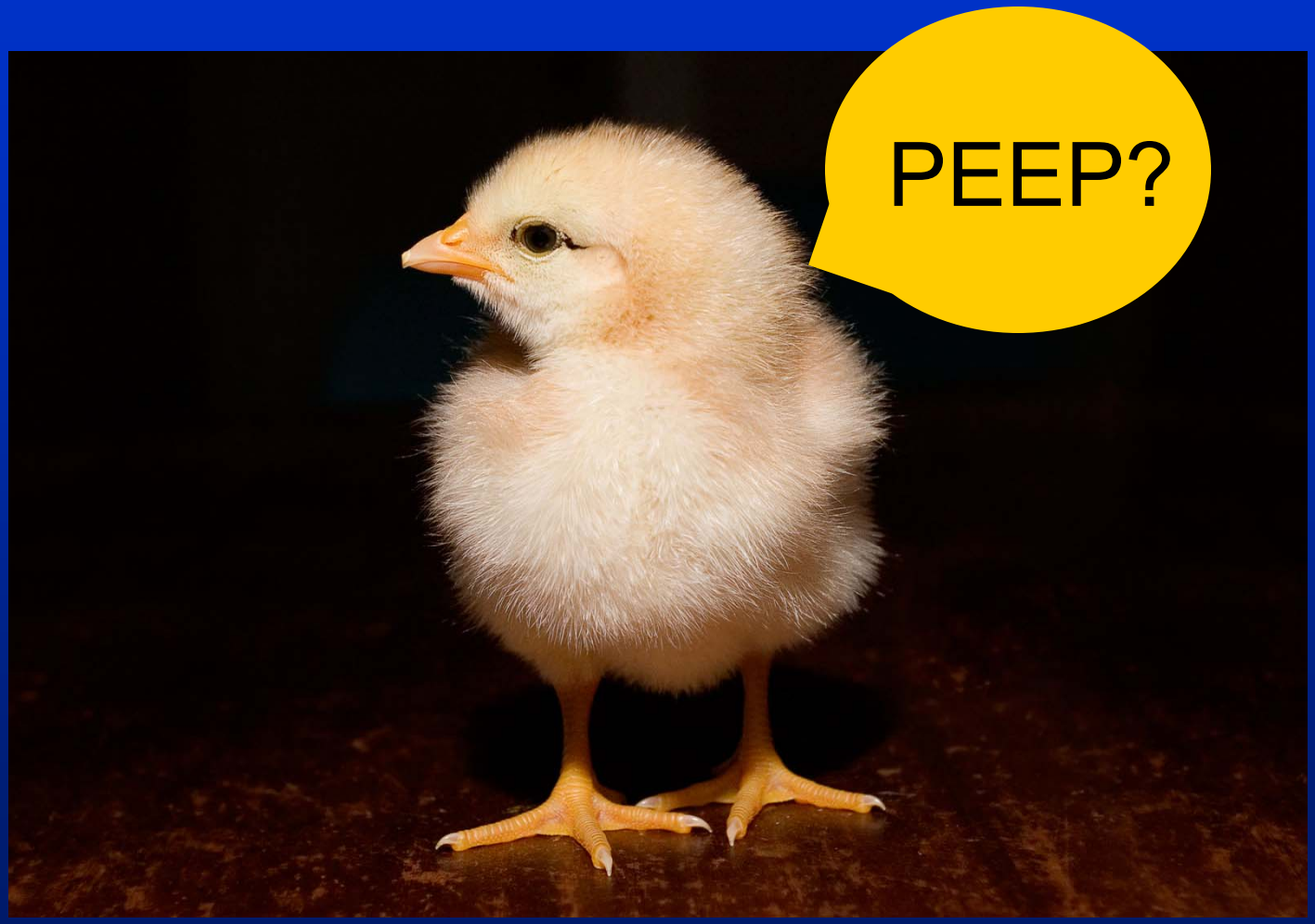
# Case Presentation

- 27 year old M with alcoholic hepatitis and pneumonia
- Height 193 cm (6'4"). Predicted Body Wt = 87 kg
- 6 ml/kg = 520 mL. PEEP = 10
  - Pplat = 34. $\Delta P$ = 24
- Chest volumes not large
- Tidal volume decreased to 5, 4 mL/kg PBW
  - Pplat = 28, $\Delta P$ = 18
- $PaCO_2$ = 55, pH = 7.28

# Case Presentation

- 27 year old M with alcoholic hepatitis and pneumonia
- Height 193 cm (6'4"). Predicted Body Wt = 87 kg
- 6 ml/kg = 520 mL. PEEP = 10
  - Pplat = 34. $\Delta P$ = 24
- Chest volumes not large
- Tidal volume decreased to 5, 4 mL/kg PBW
  - Pplat = 28, $\Delta P$ = 18
- $PaCO_2$ = 55, pH = 7.28
- Tidal volume decreased to 2.8 mL/kg PBW. RR 40.
- Pplat = 24, $\Delta P$ = 14

# Living on the Edge of the Evidence


PEEP?

# ACUTE RESPIRATORY DISTRESS IN ADULTS

DAVID G. ASHBAUGH
M.D. Ohio State
ASSISTANT PROFESSOR OF SURGERY

D. BOYD BIGELOW
M.D. Colorado
ASSISTANT IN MEDICINE AND AMERICAN THORACIC SOCIETY-NATIONAL TUBERCULOSIS ASSOCIATION FELLOW IN PULMONARY DISEASE

THOMAS L. PETTY
M.D. Colorado
ASSISTANT PROFESSOR OF MEDICINE

BERNARD E. LEVINE
M.D. Michigan
AMERICAN THORACIC SOCIETY-NATIONAL TUBERCULOSIS ASSOCIATION FELLOW IN PULMONARY DISEASE*

Lancet 1967; 2:319-323

# Setting PEEP

Traditional Approach

Adjust PEEP to allow acceptable arterial oxygenation on $FiO_2 \leq .70$

PEEP = 5 -12 cm $H_2O$

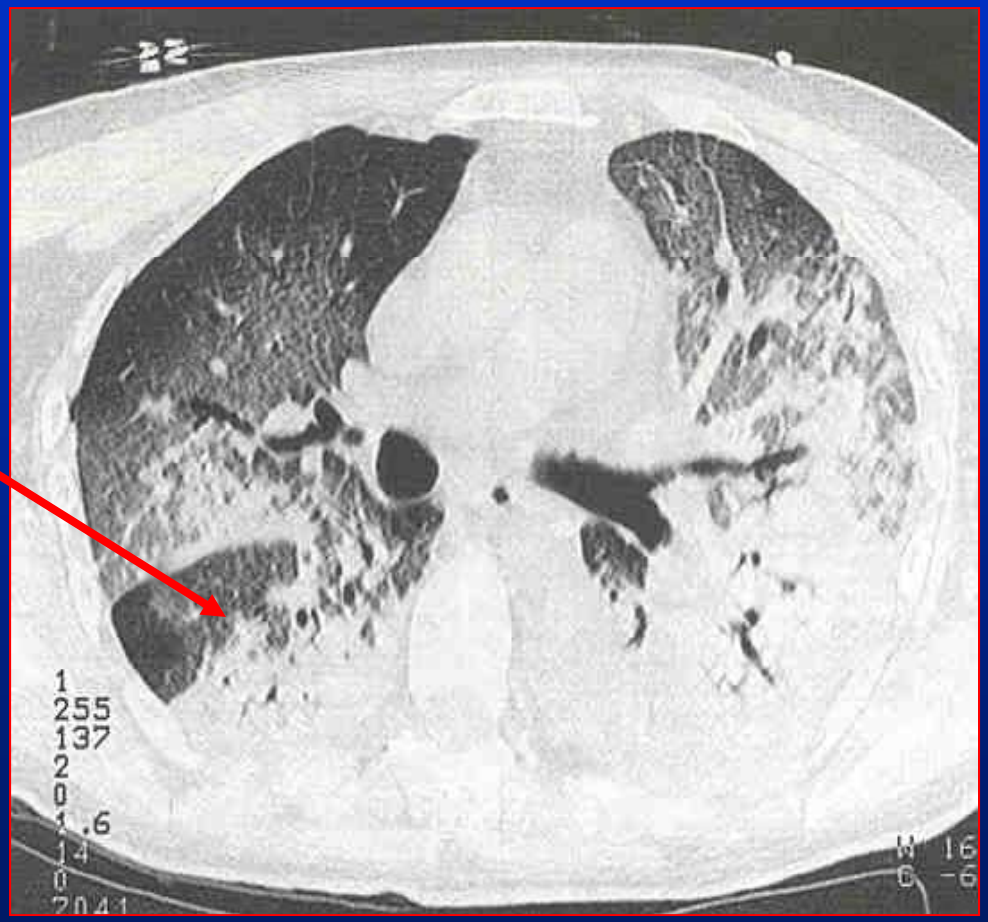
# How to Set PEEP

Table of fixed combinations of PEEP and $FiO_2$

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | **.3** | **.4** | **.4** | **.5** | **.5** | **.6** | **.7** | **.7** | **.7** | **.8** | **.9** | **.9** | **.9** | **1.0** |
| **PEEP** | **5** | **5** | **8** | **8** | **10** | **10** | **10** | **12** | **14** | **14** | **14** | **16** | **18** | **18-24** |

# Ventilator-Induced Lung Injury

Low Volume
Low Pressure
VILI



# How to Set PEEP

Table of fixed combinations of PEEP and $FiO_2$

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | **.3** | **.4** | **.4** | **.5** | **.5** | **.6** | **.7** | **.7** | **.7** | **.8** | **.9** | **.9** | **.9** | **1.0** |
| **PEEP** | **5** | **5** | **8** | **8** | **10** | **10** | **10** | **12** | **14** | **14** | **14** | **16** | **18** | **18-24** |

**<u>Higher PEEP/Lower $FiO_2$</u>**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | **.3** | **.3** | **.4** | **.4** | **.5** | **.5** | **.5-.8** | **.8** | **.9** | **1.0** |
| **PEEP** | **12** | **14** | **14** | **16** | **16** | **18** | **20** | **22** | **22** | **22-24** |

# 4 Higher PEEP Trials

| | % Mortality | |
|---|---|---|
| | Higher PEEP | Lower PEEP |
| ARDSNet (549) | 27.5 | 24.9 |
| Canadian (983) | 36.4 | 40.4 |
| French (767) | 35.4 | 39.4 |
| ART (1010) | 55.3* | 49.3 |
| Combined (3309) | 40.4 | 40.2 |

ARDSnet NEJM 2004 Meade JAMA 2008
Mercat JAMA 2008 Cavalcanti JAMA 2017

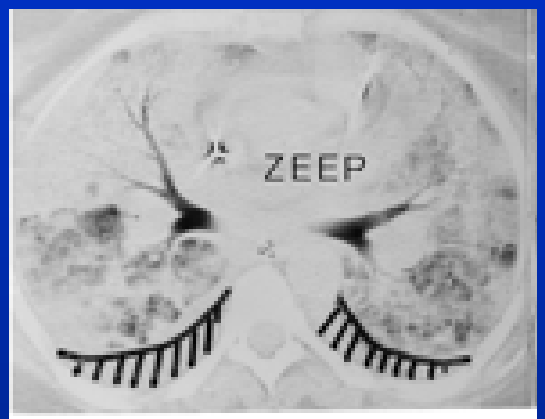
# Why Mortality Not Lower with Higher PEEP?

Effects of Higher PEEP in each patient

- Reduce VILI from Low volume/Low pressure
- Increase VILI from Overdistention

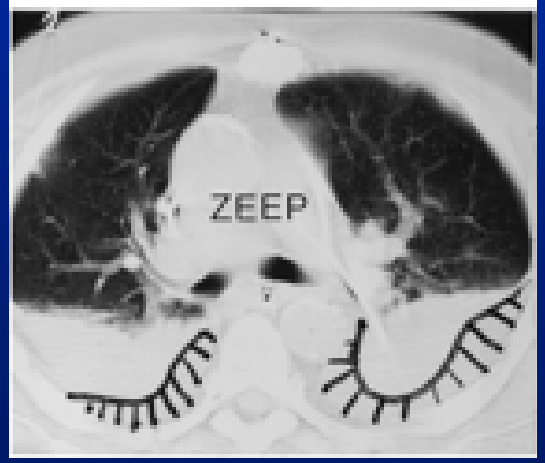
# Effects of PEEP are Variable Among Patients

Diffuse




Recruitment

Overdistention




Recruitment

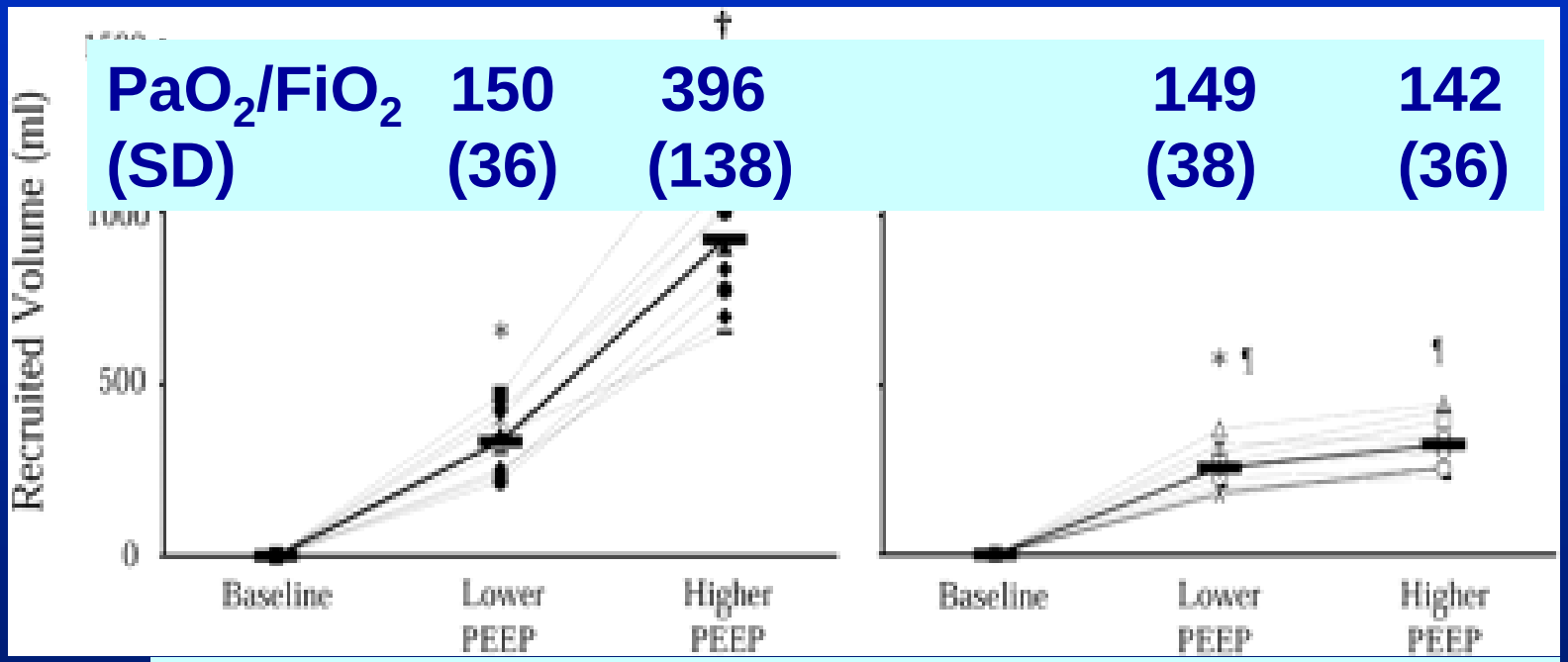
Overdistention

Lobar

- Who are the PEEP responders?
- How much PEEP in responders?
- When to decrease PEEP in responders?
- How much PEEP in nonresponders?

# Effects of PEEP

| | Responders | | Nonresponders | |
|---|---|---|---|---|
| $PaO_2/FiO_2$ (SD) | 150 (36) | 396 (138) | 149 (38) | 142 (36) |
| PEEP | 9 | 16 | 9 | 15 |




Grasso et al. Am J Resp Crit Care Med 2005; 171: 1002-1008

# Lower PEEP ⟶ Higher PEEP Tables

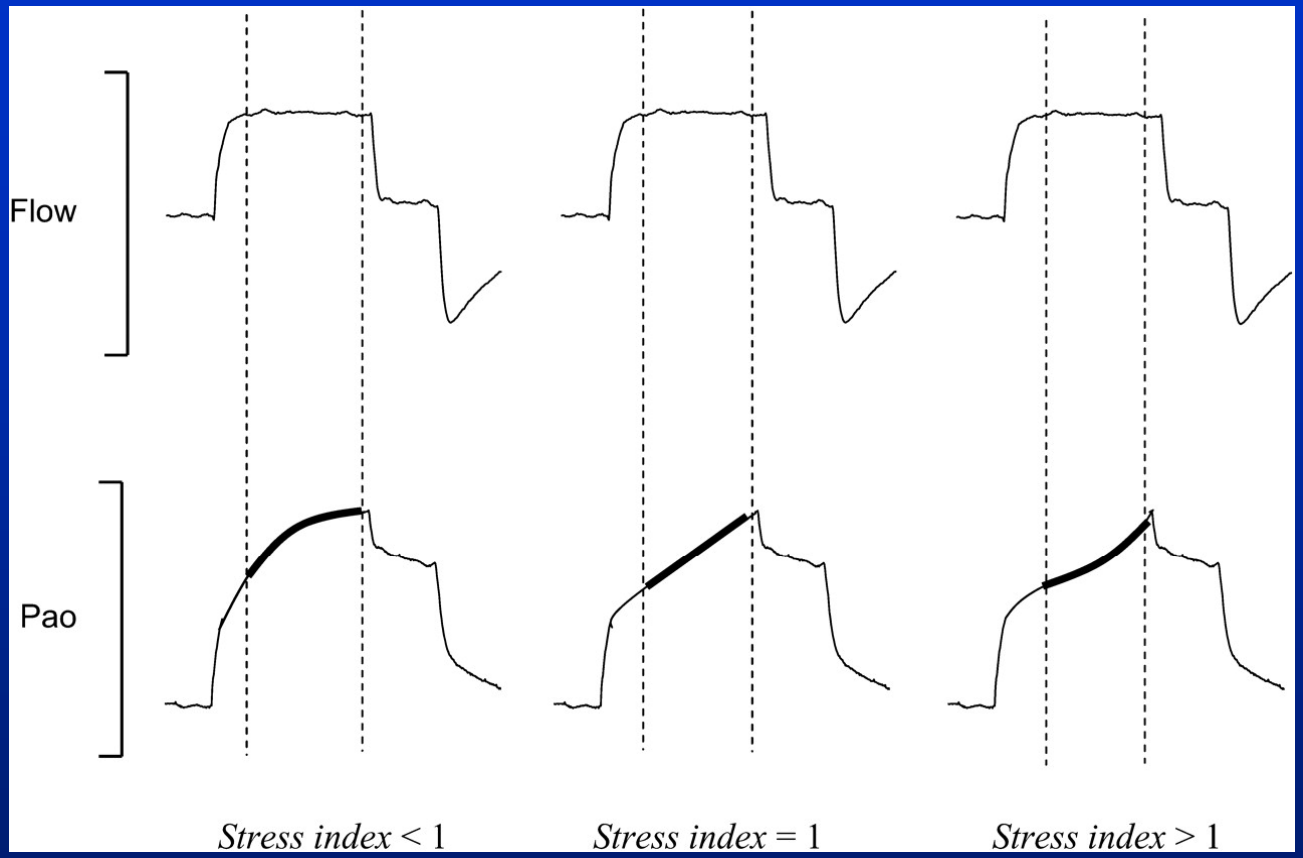
- Easy to identify PEEP responders
- No special equipment
- Optimal PEEP?
- Some patients may need lower PEEP than they receive on the lower PEEP table

# EXPRESS PEEP

- Raise PEEP until inspiratory Pplat approaches 30 cm $H_2O$
  - Greater Ventilator-free days
  - Mortality NS but favorable trend

Mercat et al
JAMA 2008

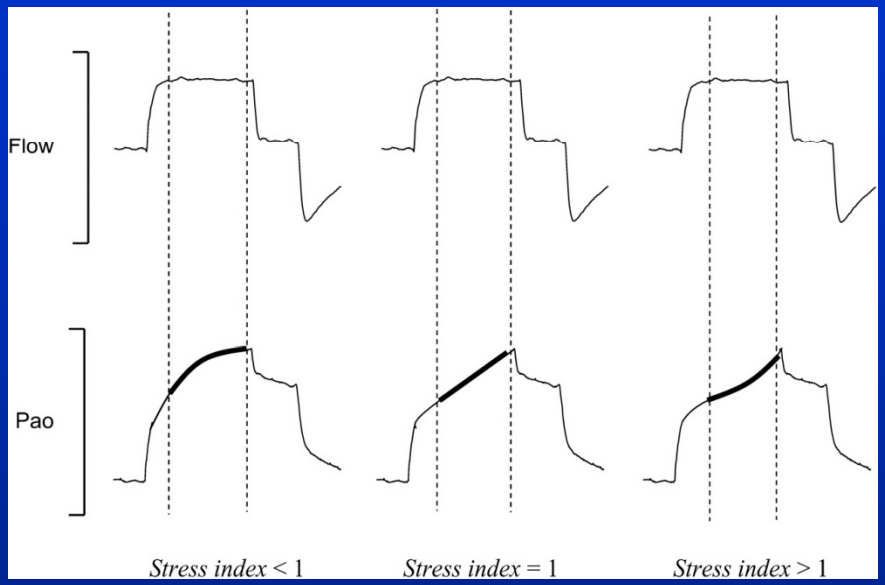
# Stress Index




$$\text{Pao} = a \cdot \text{inspiratory time}^{b} + c$$

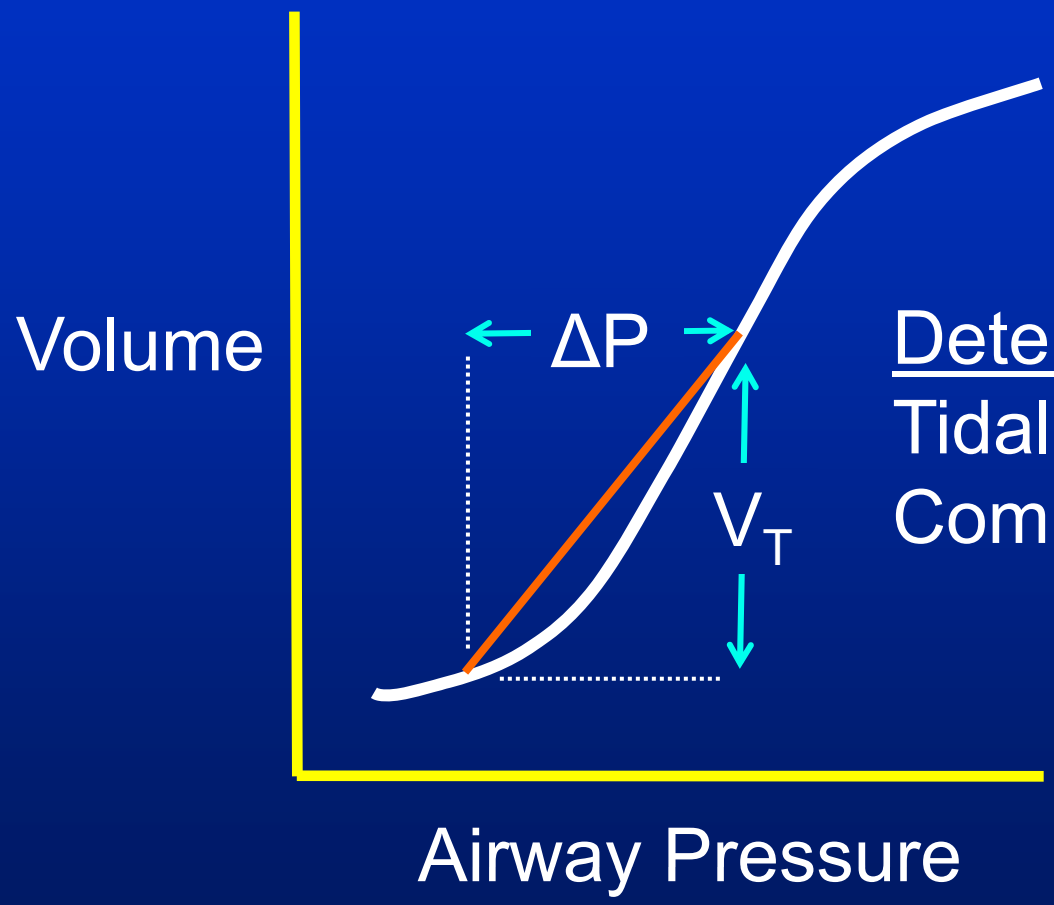
Grasso S et al. Am J Resp Crit Care Med 2007;176:761-767

# Stress Index




- Special monitoring equipment needed
- Must be relaxed during inspiration

# Driving Pressure (ΔP)




<u>Determinants of ΔP</u>

Tidal Volume ($V_T$)

$Compliance_{RS}$

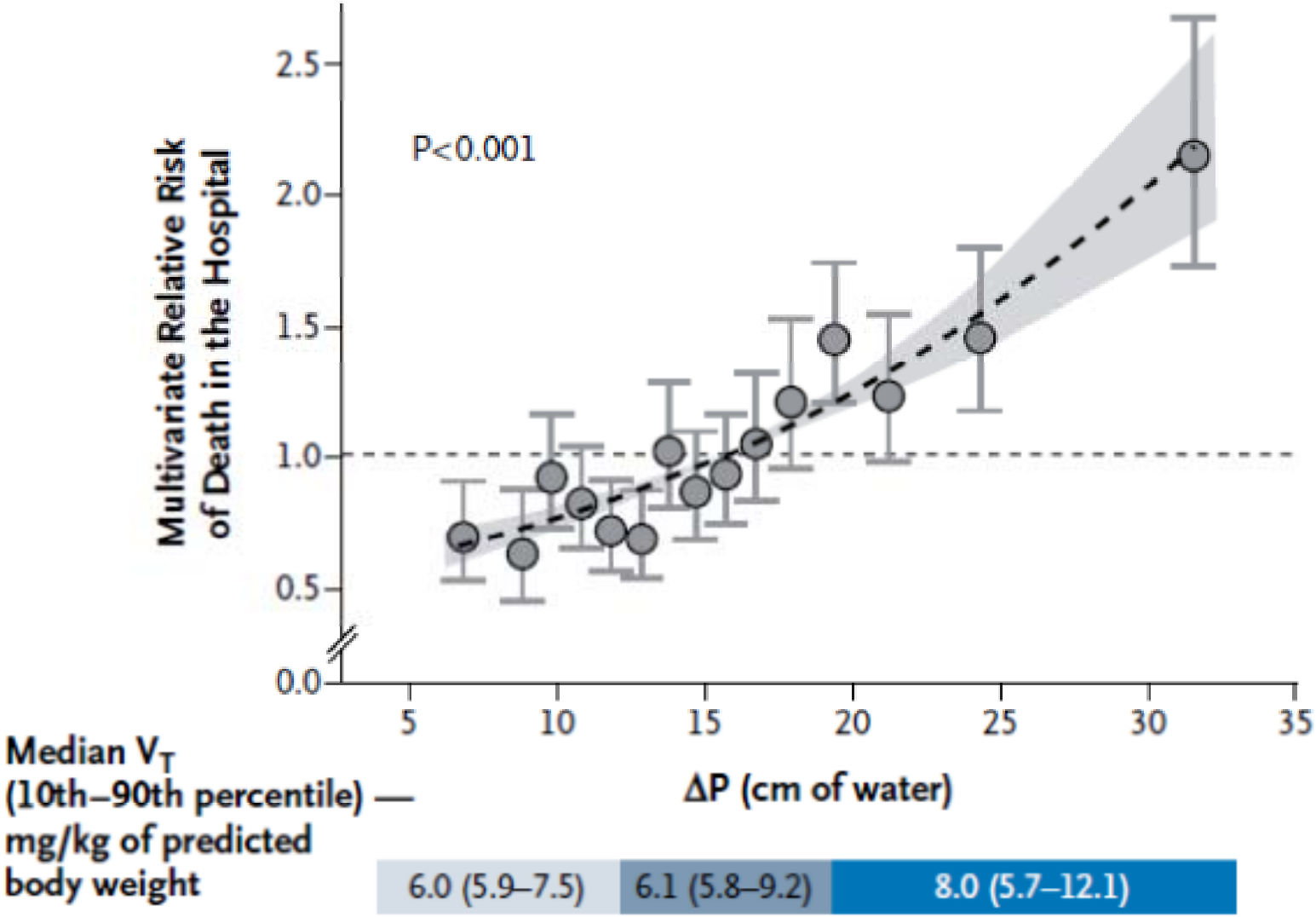
The NEW ENGLAND JOURNAL of MEDICINE

SPECIAL ARTICLE

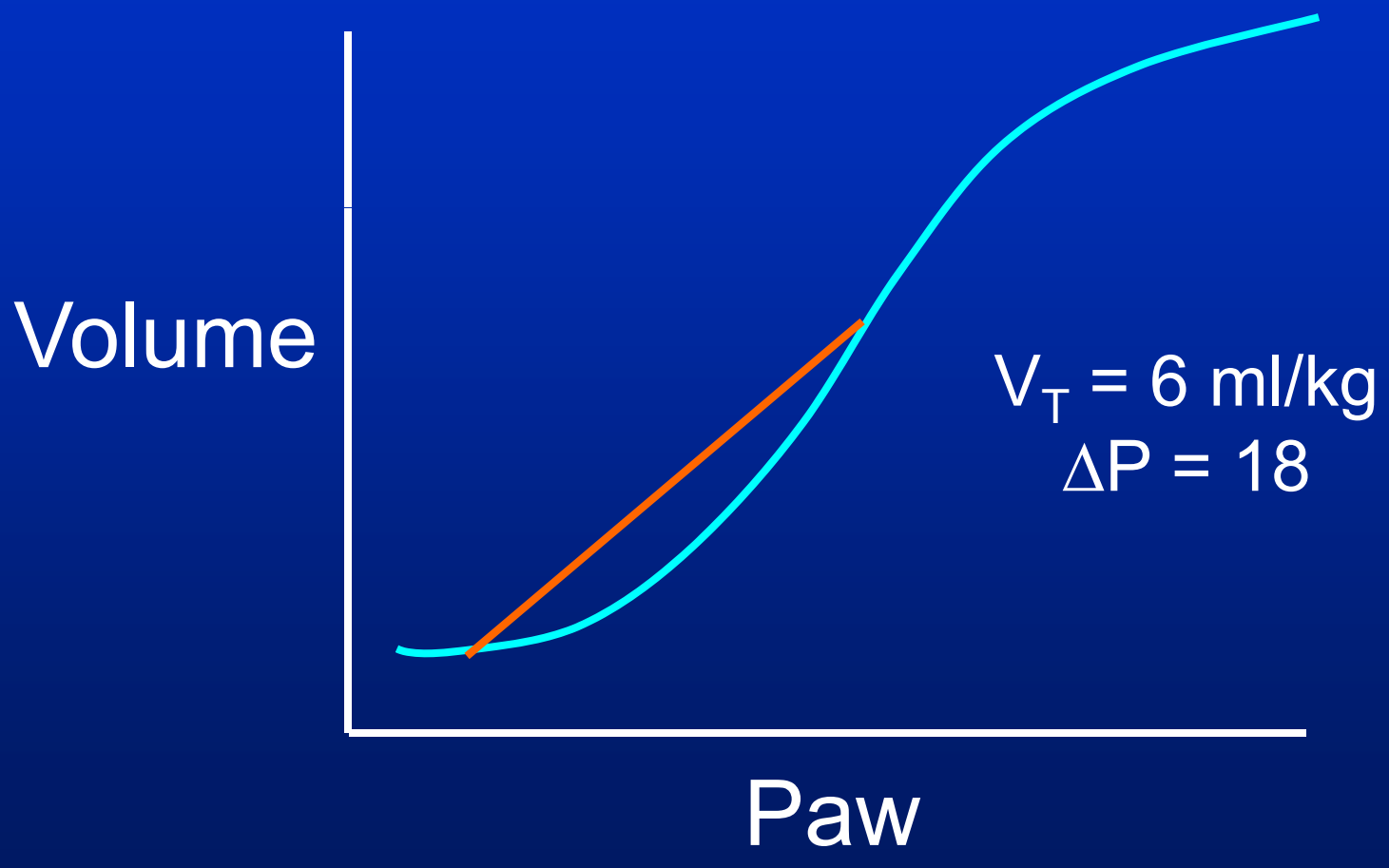
# Driving Pressure and Survival in the Acute Respiratory Distress Syndrome

Marcelo B.P. Amato, M.D., Maureen O. Meade, M.D., Arthur S. Slutsky, M.D., Laurent Brochard, M.D., Eduardo L.V. Costa, M.D., David A. Schoenfeld, Ph.D., Thomas E. Stewart, M.D., Matthias Briel, M.D., Daniel Talmor, M.D., M.P.H., Alain Mercat, M.D., Jean-Christophe M. Richard, M.D., Carlos R.R. Carvalho, M.D., and Roy G. Brower, M.D.

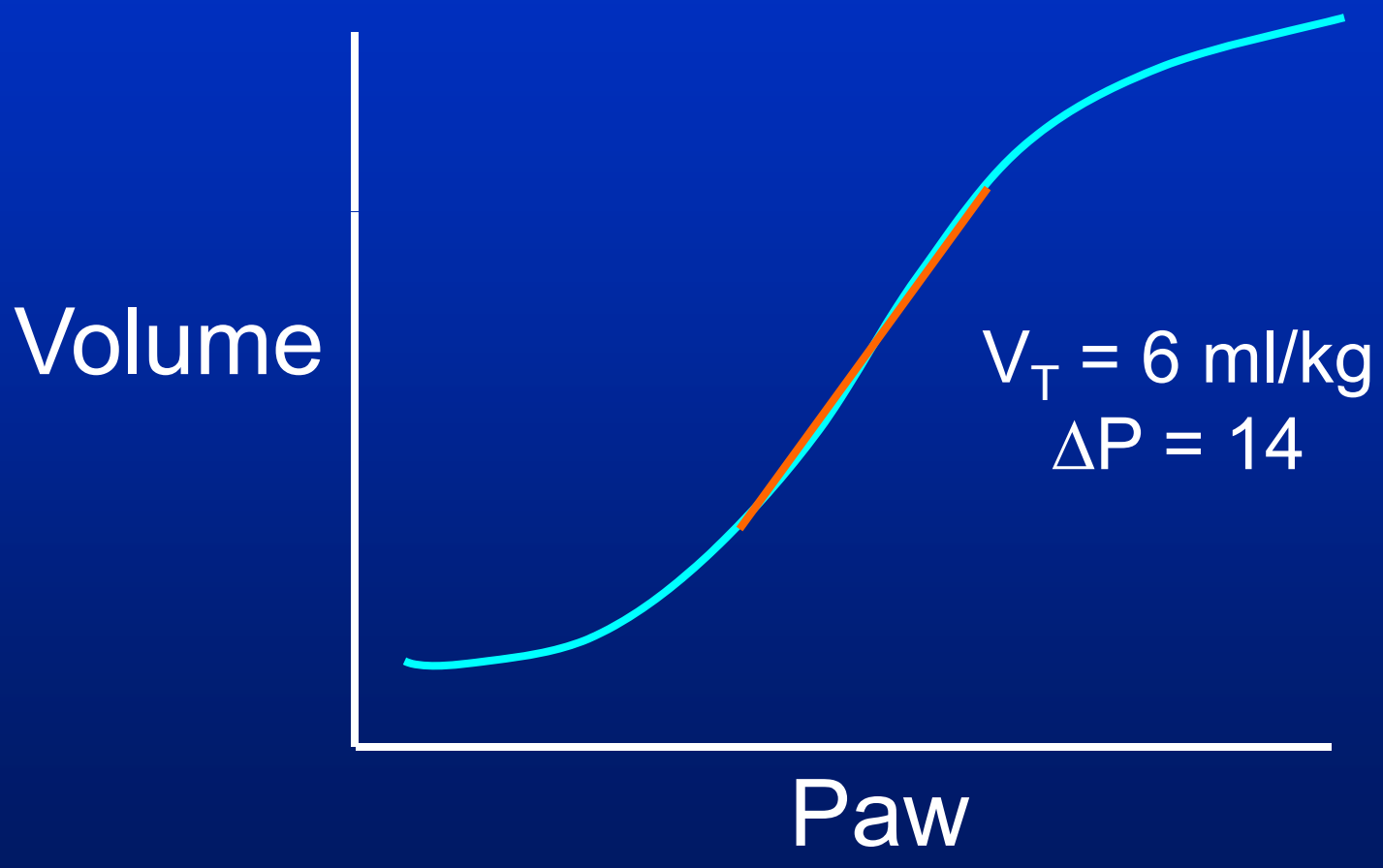
New Eng J Med 2015


Multivariate Relative Risk of Death in the Hospital
2.5
2.0
1.5
1.0
0.5
0.0
P<0.001
5
10
15
20
25
30
35
ΔP (cm of water)
Median $V_T$ (10th–90th percentile) — mg/kg of predicted body weight
6.0 (5.9–7.5)
6.1 (5.8–9.2)
8.0 (5.7–12.1)

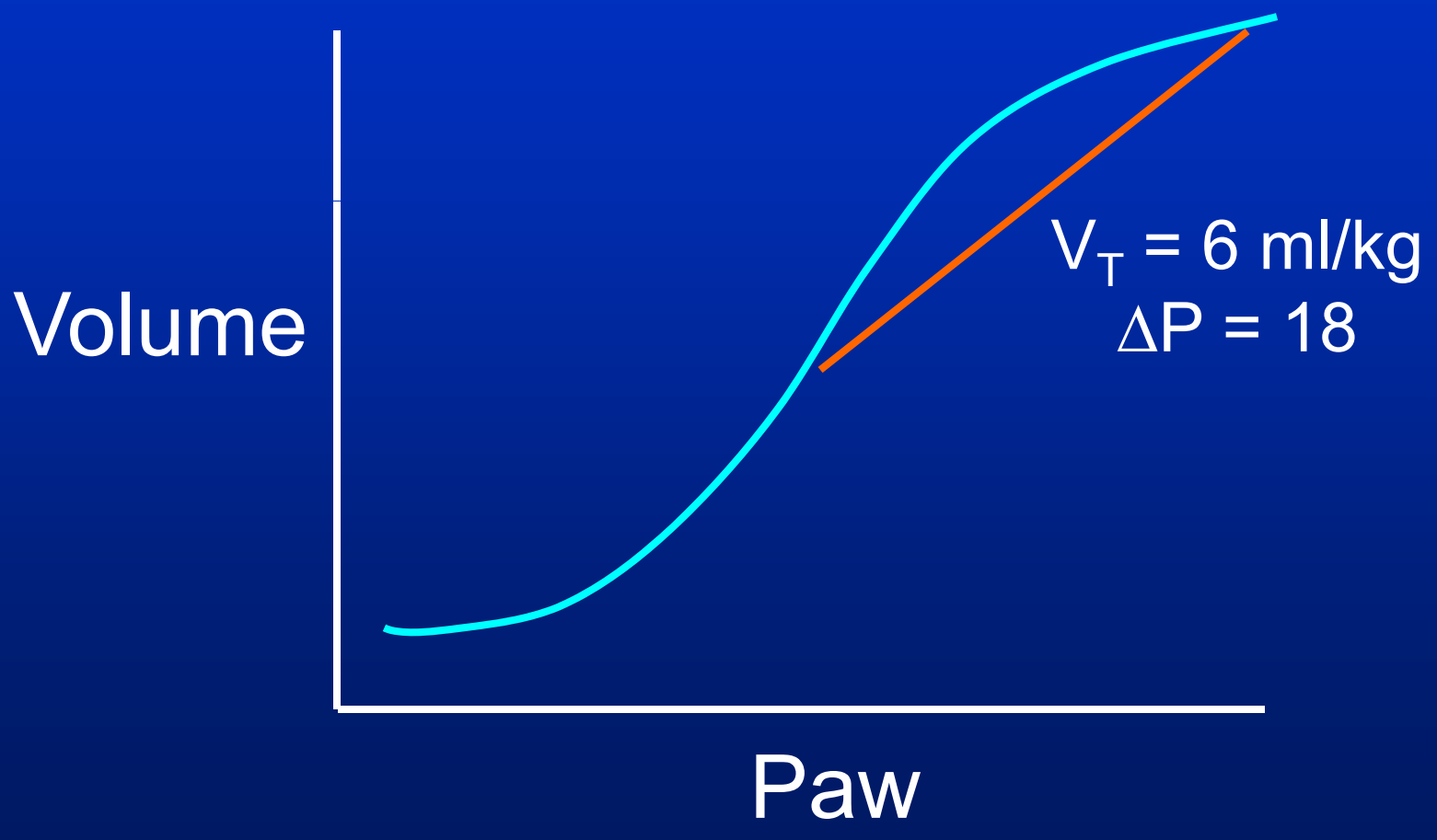
# ΔP-Guided PEEP



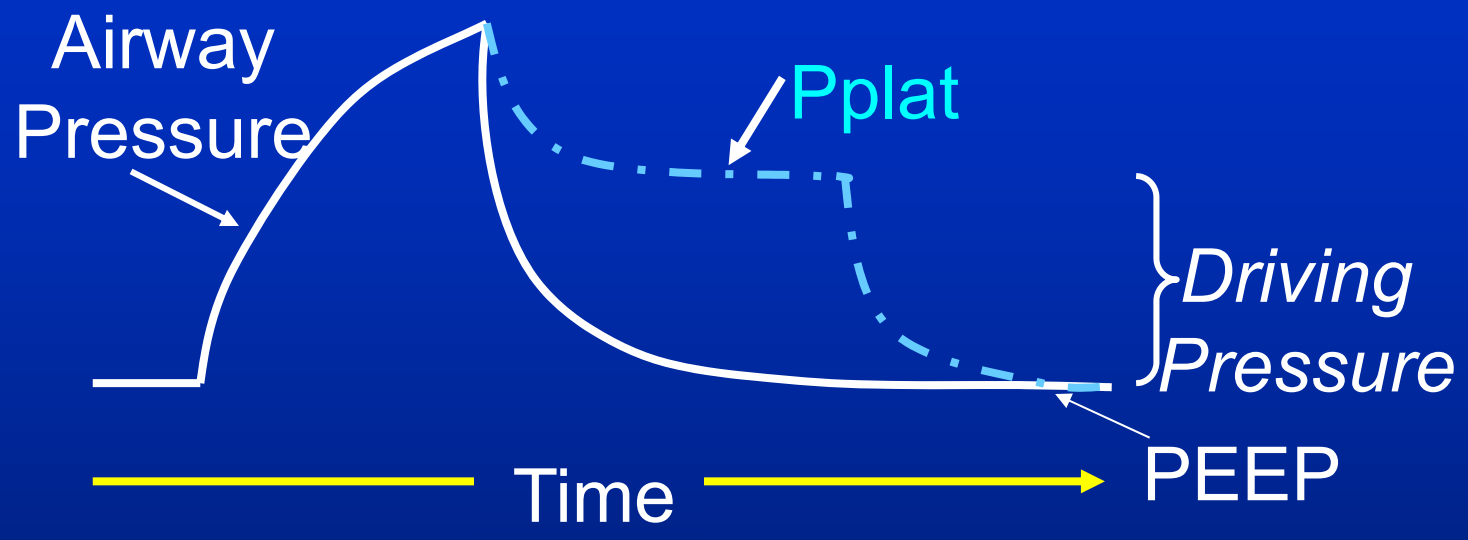
# ΔP-Guided PEEP



# ΔP-Guided PEEP



# Driving Pressure




- Special monitoring equipment not needed
- Inspiratory efforts OK
- Patient must be relaxed during exhalation

# Higher PEEP to More Recruitable Lung and Lower PEEP to Less Recruitable Lung

- Table of fixed combinations of PEEP and $FiO_2$ YES
- Raise PEEP until Pplat approaches 30 cm $H_2O$ No
- Raise PEEP until transpulmonary pressure > 0 No
- Adjust PEEP to Stress Index = 1.0 No
- Adjust PEEP to minimize Driving Pressure ?

Chiumello D
Crit Care Med 2014

# How to Set PEEP

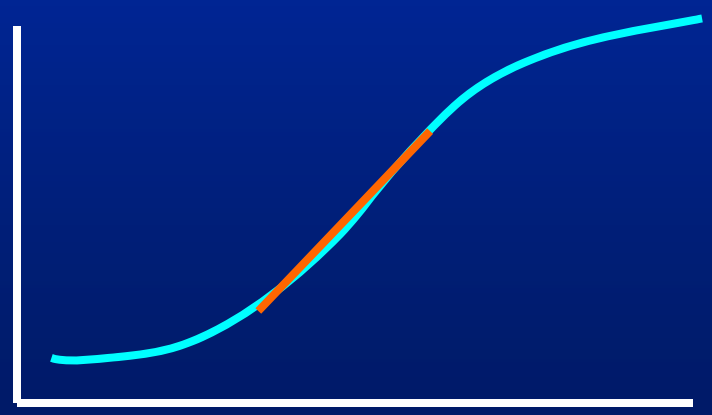
Table of fixed combinations of PEEP and $FiO_2$

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | **.3** | **.4** | **.4** | **.5** | **.5** | **.6** | **.7** | **.7** | **.7** | **.8** | **.9** | **.9** | **.9** | **1.0** |
| **PEEP** | **5** | **5** | **8** | **8** | **10** | **10** | **10** | **12** | **14** | **14** | **14** | **16** | **18** | **18-24** |

# How to Set PEEP

Table of fixed combinations of PEEP and $FiO_2$

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$FiO_2$** | **.3** | **.4** | **.4** | **.5** | **.5** | **.6** | **.7** | **.7** | **.7** | **.8** | **.9** | **.9** | **.9** | **1.0** |
| **PEEP** | **5** | **5** | **8** | **8** | **10** | **10** | **10** | **12** | **14** | **14** | **14** | **16** | **18** | **18-24** |



# Thank You

# Thank You

# Trials of Lung-protective Mechanical Ventilation

Clinical Trials (3562 Patients)

1. Amato NEJM 1998 – Lower $V_T$ + Higher PEEP
2. Stewart NEJM 1998 – Lower $V_T$
3. Brochard AJRCCM 1998 – Lower $V_T$
4. Brower CCM 1999 – Lower $V_T$
5. ARDS Network NEJM 2000 - Lower $V_T$
6. ARDS Network NEJM 2004 – Higher PEEP
7. Mercat JAMA 2008 – Higher PEEP
8. Meade JAMA 2008 – Higher PEEP
9. Talmor NEJM 2008 – Pes guided higher PEEP

# Model Variables

<u>Patient variables</u>

Days on mech vent

Age

APACHE III (1.31)

# Organ failures

Arterial pH (0.64)

$PaCO_2$

$PaO_2/FIO_2$

Tidal-compliance

<u>Mech Vent Variables</u>

Tidal volume

Plateau pressure

PEEP

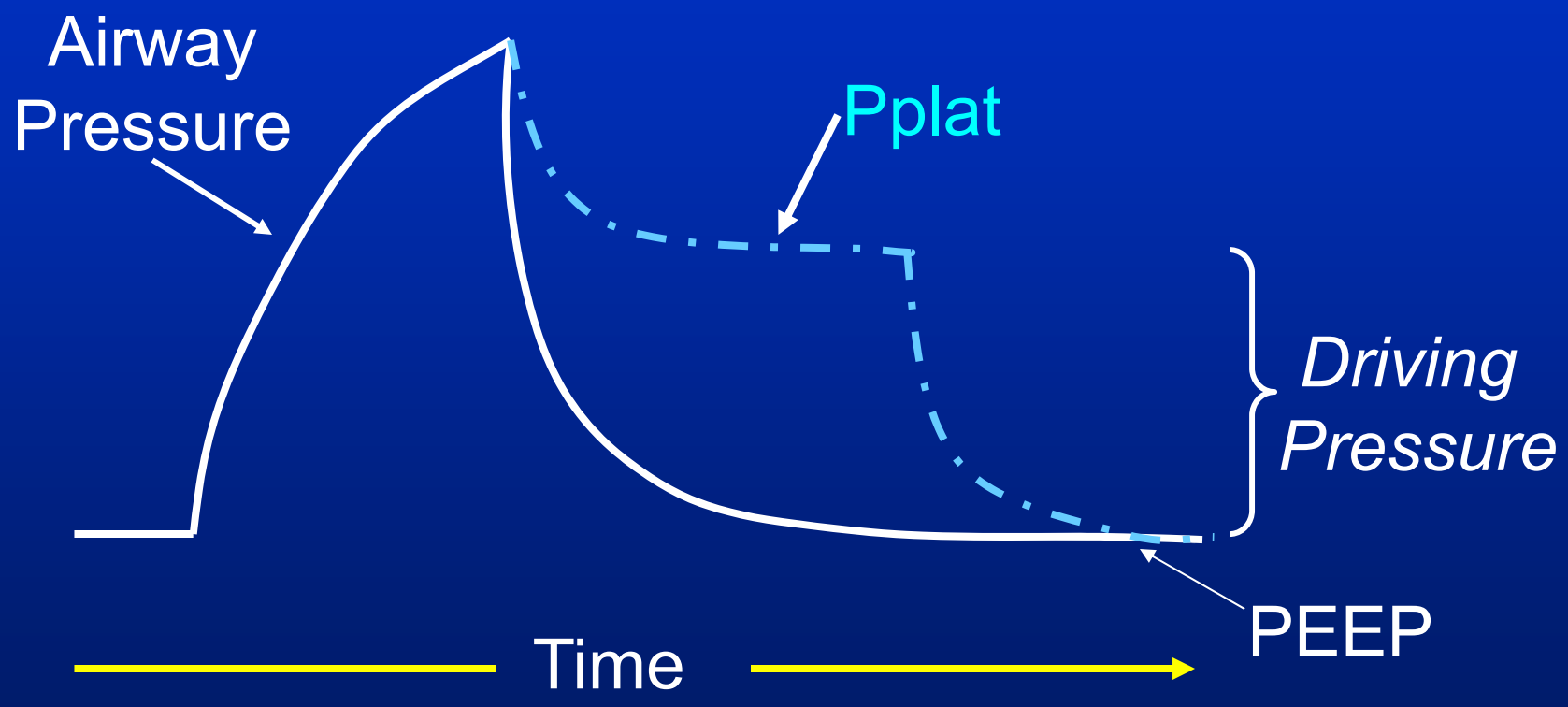
$FiO_2$ (1.32)

Respiratory rate

Mean airway pressure

$\Delta P$ (Pplat – PEEP) (1.47)

# Driving Pressure

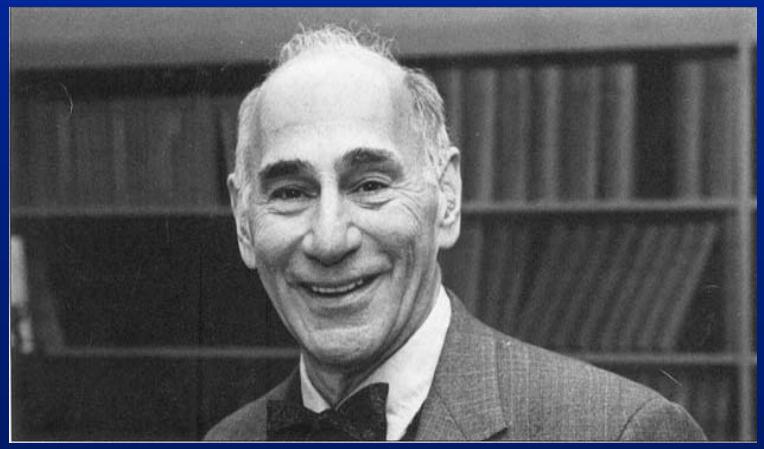


Reprinted from JOURNAL OF APPLIED PHYSIOLOGY
Vol. 21, No. 5, September, 1966
*Printed in U.S.A.*

# Effect of ventilation on surface forces in excised dogs' lungs[1,2]

to Roy —
Important, if true?!
Sol

EDMUND E. FARIDY,[3] SOLBERT PERMUTT,
AND RICHARD L. RILEY
*Department of Environmental Medicine, Johns Hopkins University, Baltimore, Maryland*

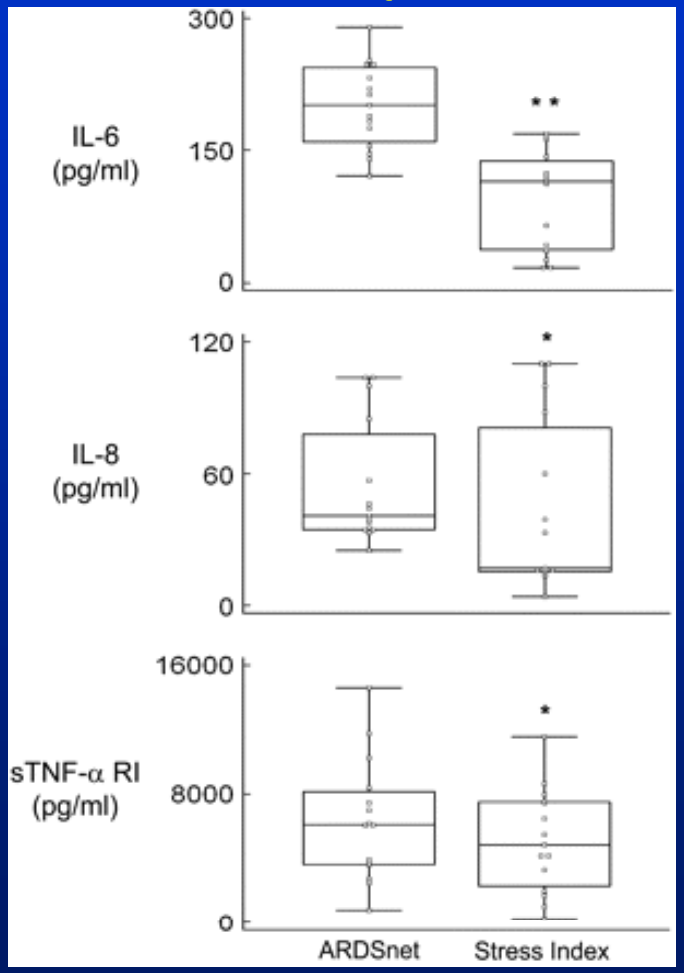


Sol Permutt

# Mechanical Ventilation and ARDS

- Critical for survival
  - ensure gas exchange
  - buy time …
- Can cause lung injury
  - may prevent recovery

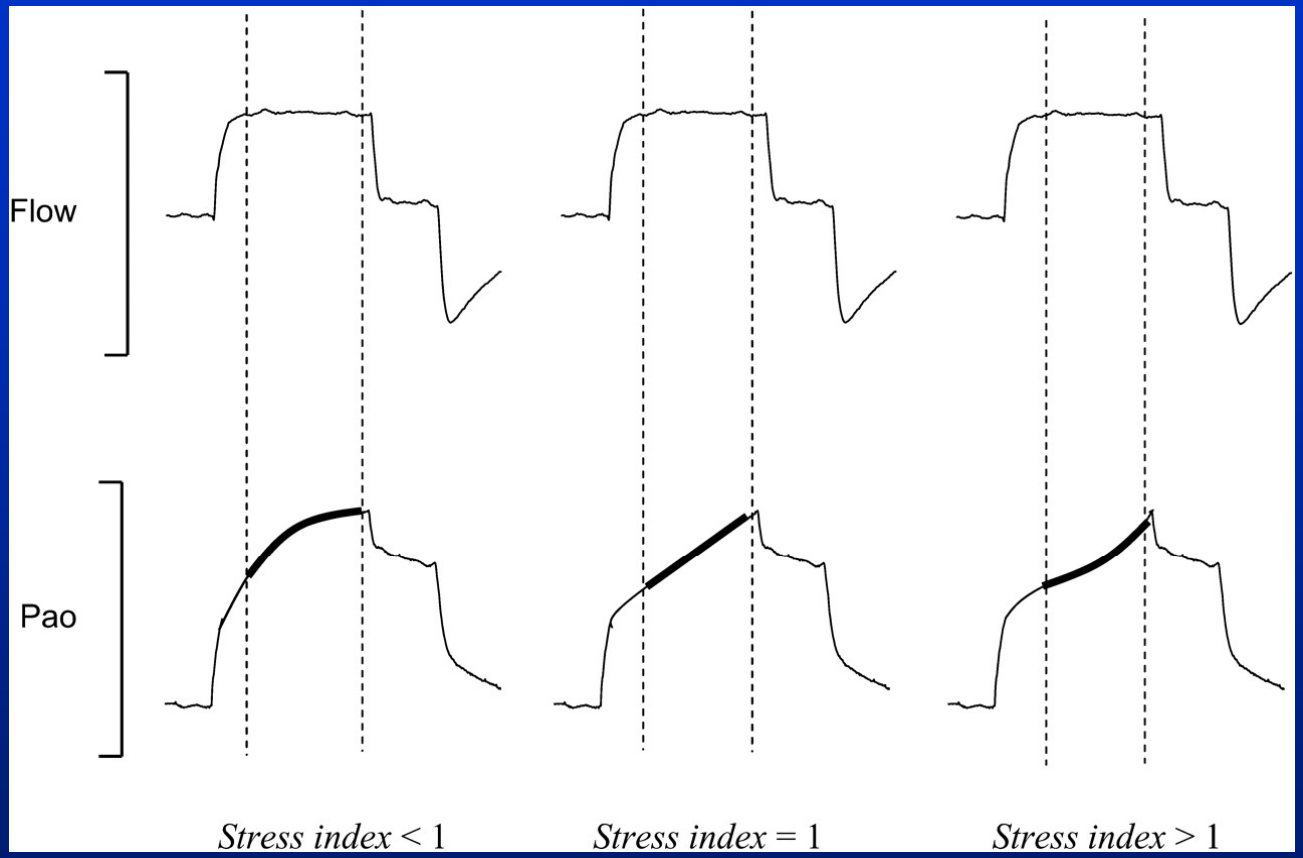
# Effects of Lower-lower PEEP on Inflammatory Mediators




Grasso S et al.

Am J Resp Crit Care Med 2007; 176:761-767

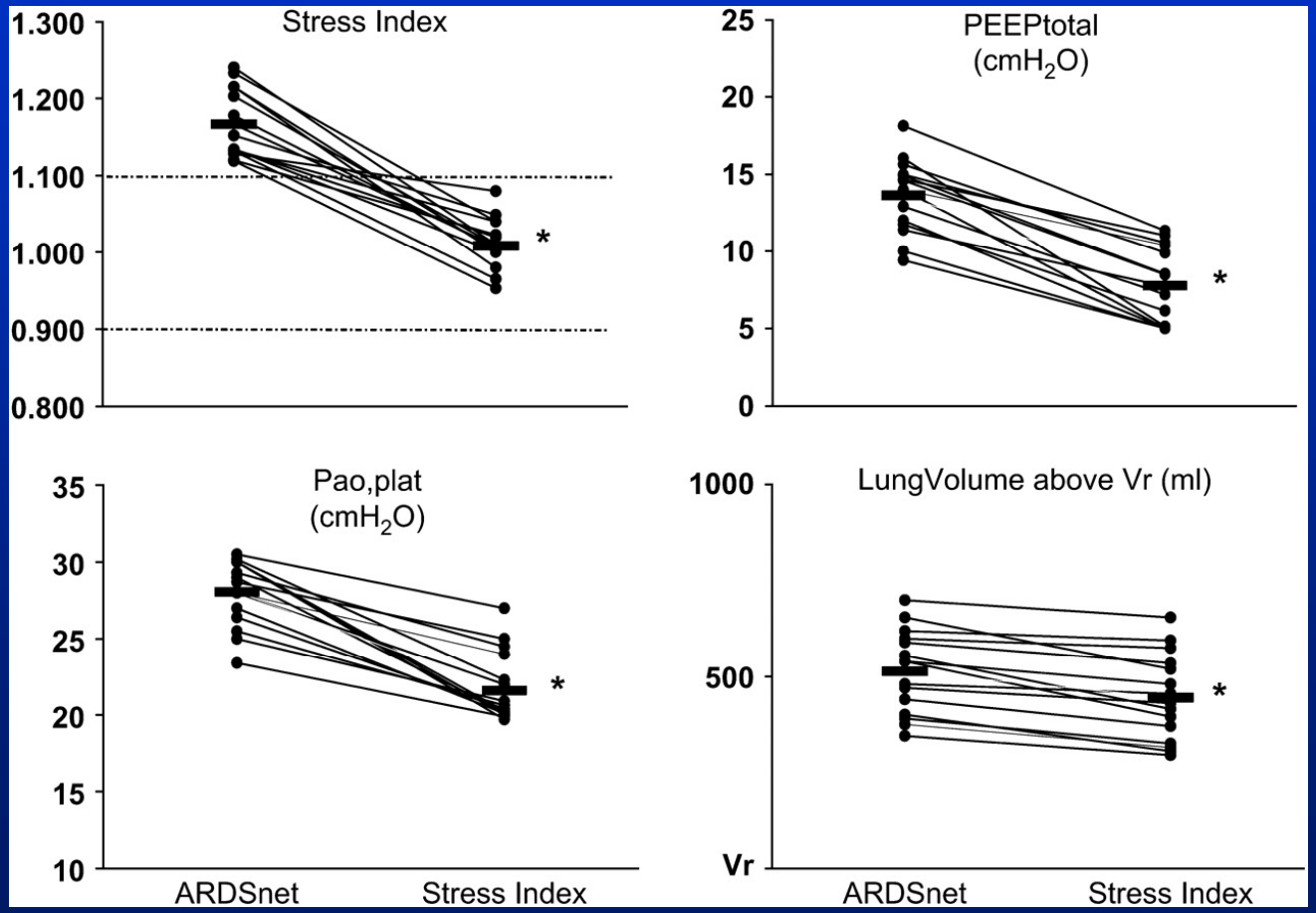
# Stress Index




$$\text{Pao} = a \cdot \text{inspiratory time}^{b} + c$$

Grasso S et al. Am J Resp Crit Care Med 2007;176:761-767

# Stress Index in “Lobar” ARDS PEEP, Pplat, and Lung Volume



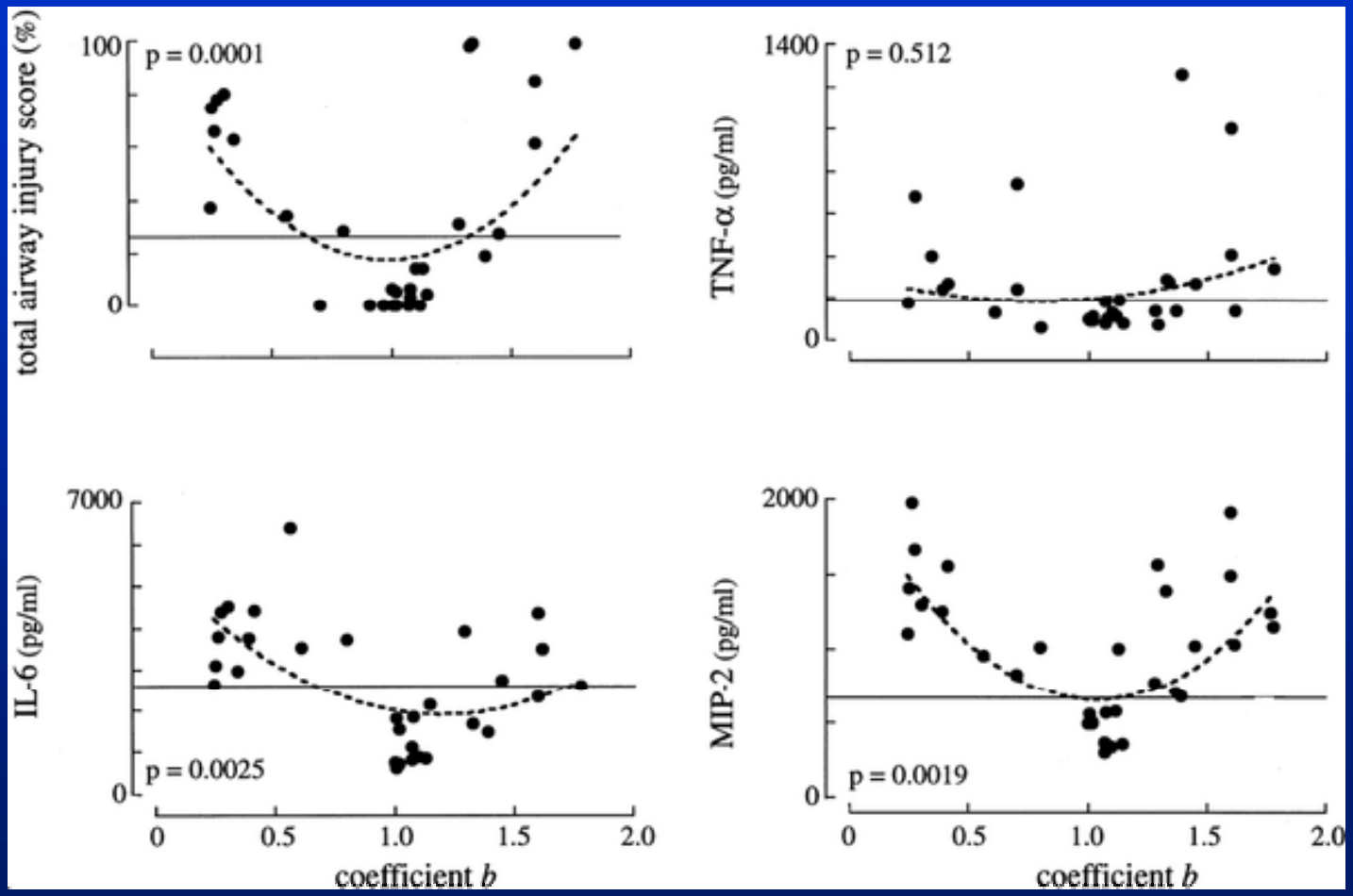

Grasso S et al. Am J Resp Crit Care Med 2007;176:761-767

# Effects of Lowering PEEP on Gas Exchange in Lobar ARDS

| | ARDSNet Table | Stress Index |
|---|---|---|
| $PaO_2/FiO_2$ | 122 ± 44 | 110 ± 32 (NS) |
| $PaCO_2$ (mm Hg) | 46 ± 6 | 42 ± 6 (<0.01) |

Grasso S et al. Am J Resp Crit Care Med 2007;176:761-767

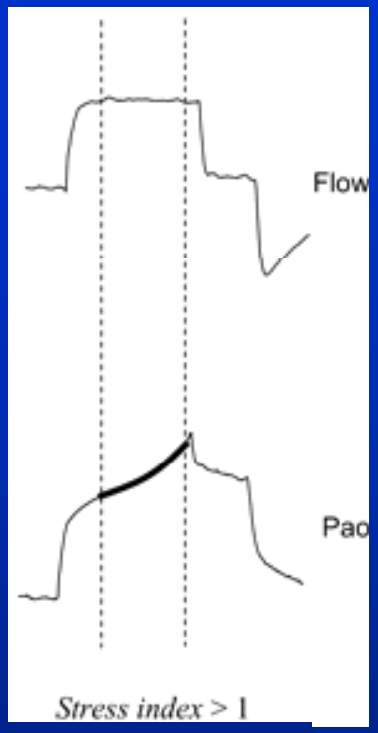
# Stress Index Predicts Lung Injury



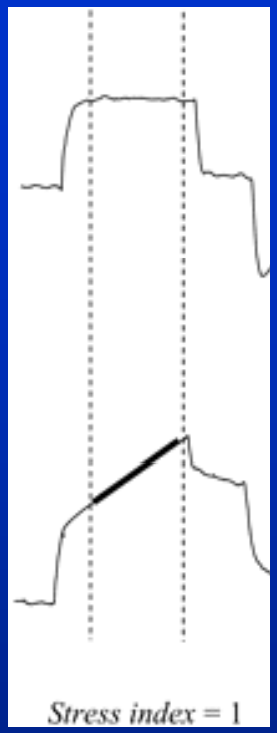

Ranieri et al. Anesthesiology. 2000 Nov;93(5):1320-8.

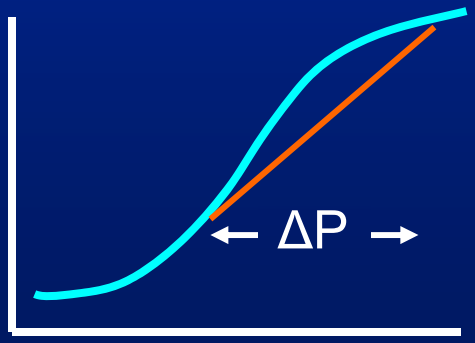
Air Flow

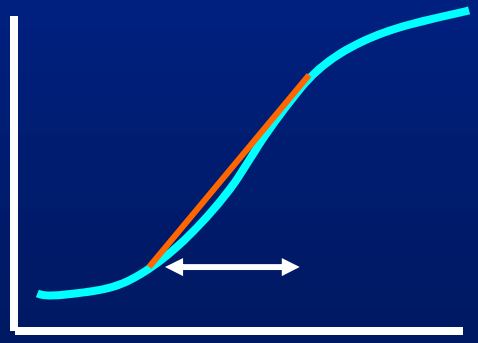
Airway Pressure




Decrease PEEP

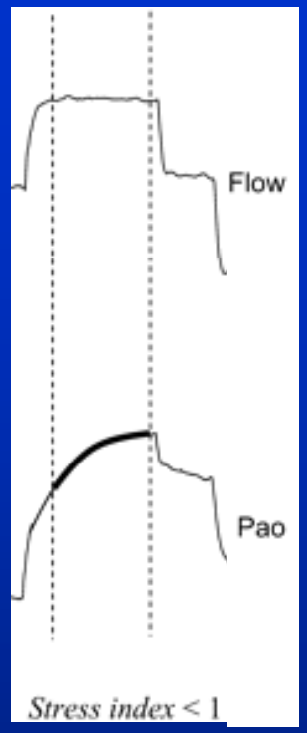


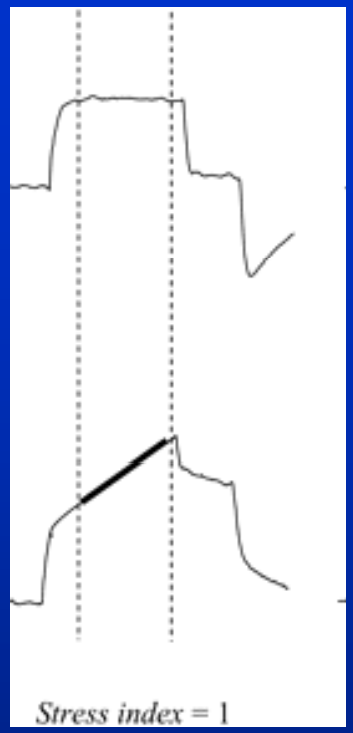



Air Flow

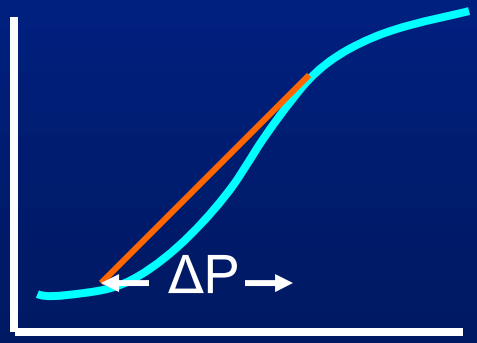
Airway Pressure

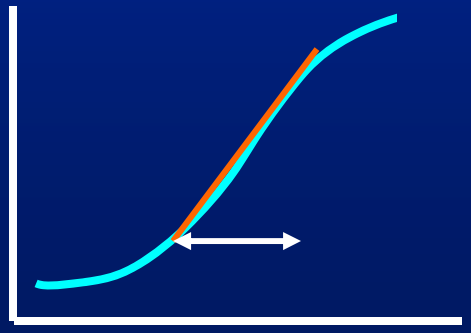



Raise PEEP




Grasso S et al. Am J Resp Crit Care Med 2007;176:761-767



# Driving Pressures in Higher PEEP Trials

| | Pplat | PEEP | ΔP | Δ-ΔP |
|---|---|---|---|---|
| ARDSnet | | | | |
| Lower | 24.0 | 8.9 | 15.1 | |
| Higher | 27.0 | 14.7 | 12.3 | -2.8 |
| Canadian | | | | |
| Lower | 24.9 | 10.1 | 14.8 | |
| Higher | 30.2 | 15.6 | 14.6 | -0.2 |
| French | | | | |
| Lower | 21.1 | 8.4 | 12.7 | |
| Higher | 27.5 | 14.6 | 12.9 | +0.2 |

# Model Variables

<u>Patient variables</u>

Days on mech vent

Age

APACHE III

# Organ failures

Arterial pH

$PaCO_2$

$PaO_2/FIO_2$

Tidal-compliance

<u>Mech Vent Variables</u>

Tidal volume

Plateau pressure

PEEP

$FiO_2$

Respiratory rate

Mean airway pressure

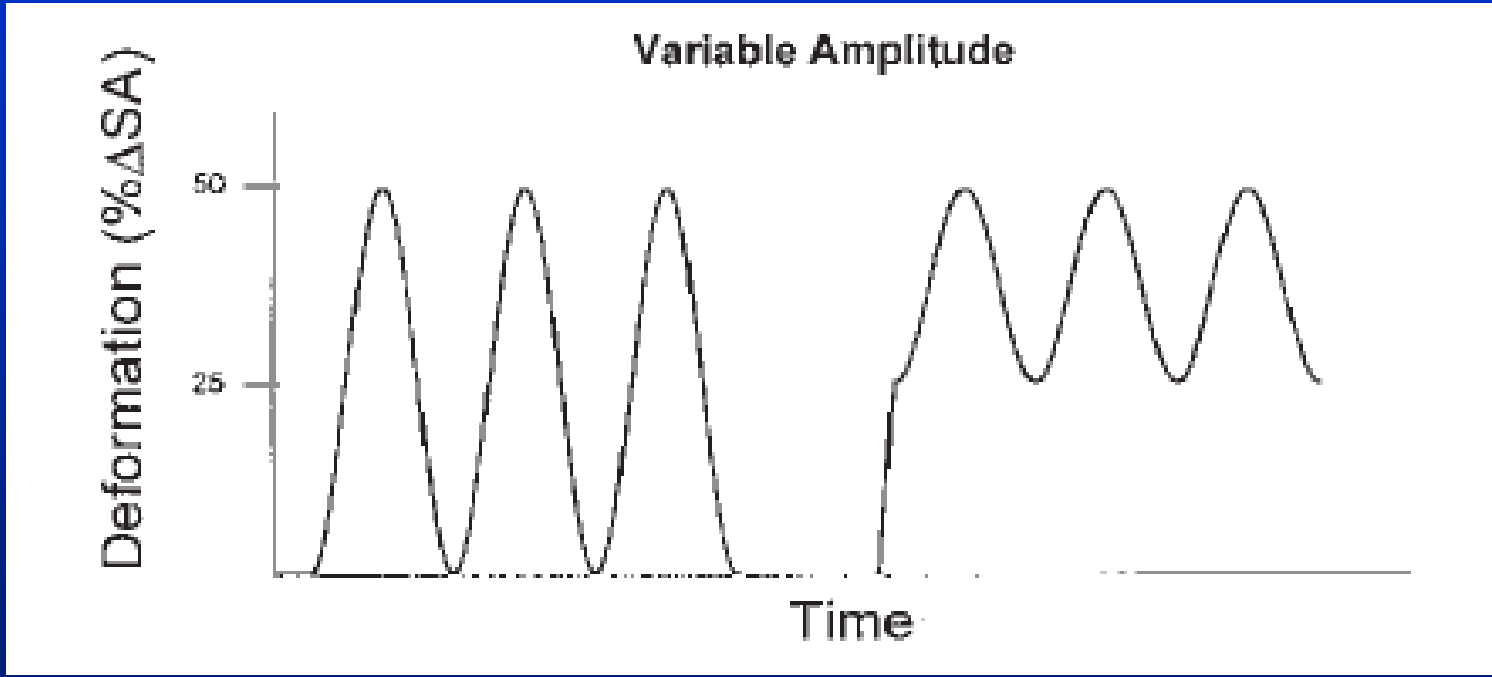
$\Delta P$ (Pplat – PEEP)

Driving Pressure (Pplat – PEEP) = $V_T/C_{RS}$

E.g., $V_T = 600$, $C_{RS} = 25$ ml/cm $H_2O$

Driving Pressure = 600/25 = 24 cm $H_2O$

# Alveolar Type II Epithelial Cells




Tschumperlin et al. Am J Respir Crit Care Med 2000

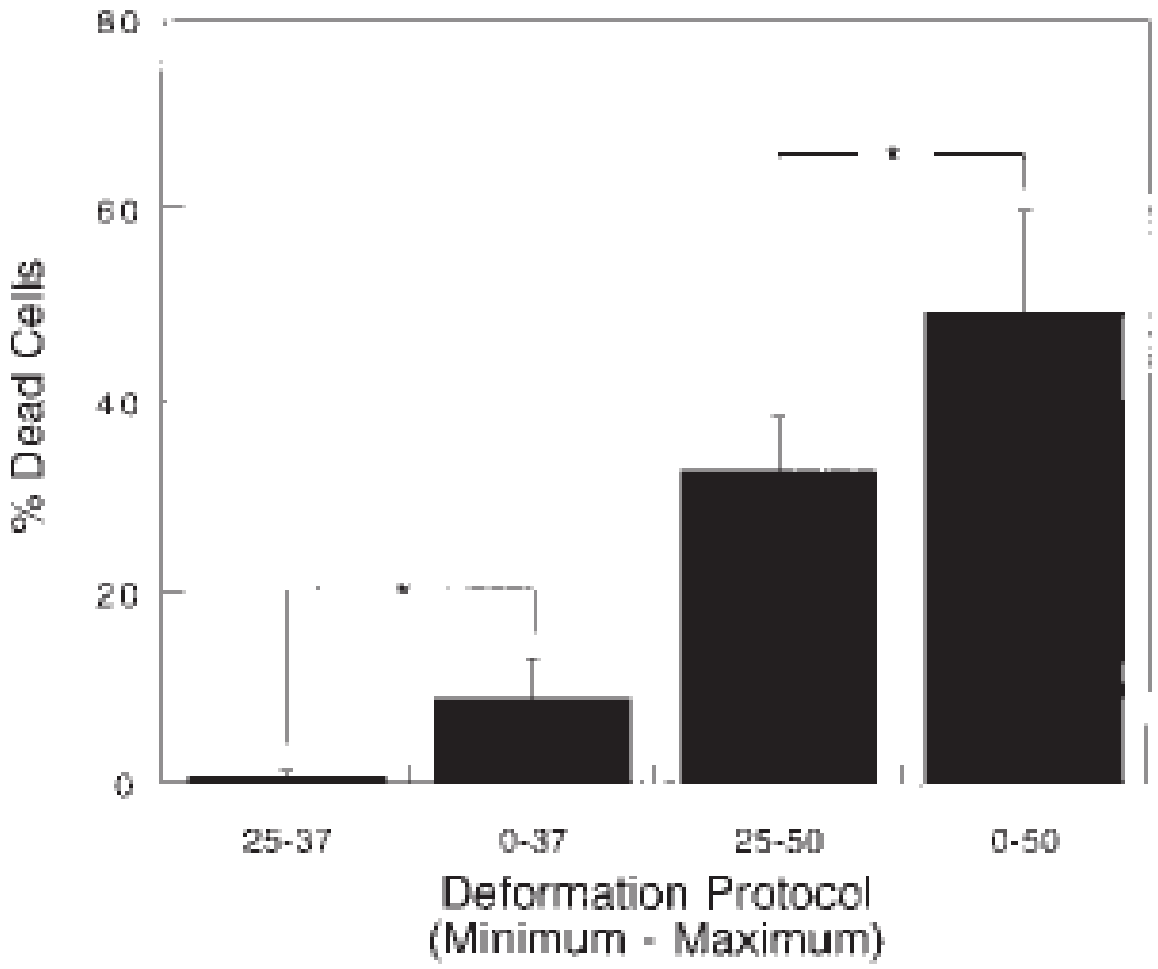
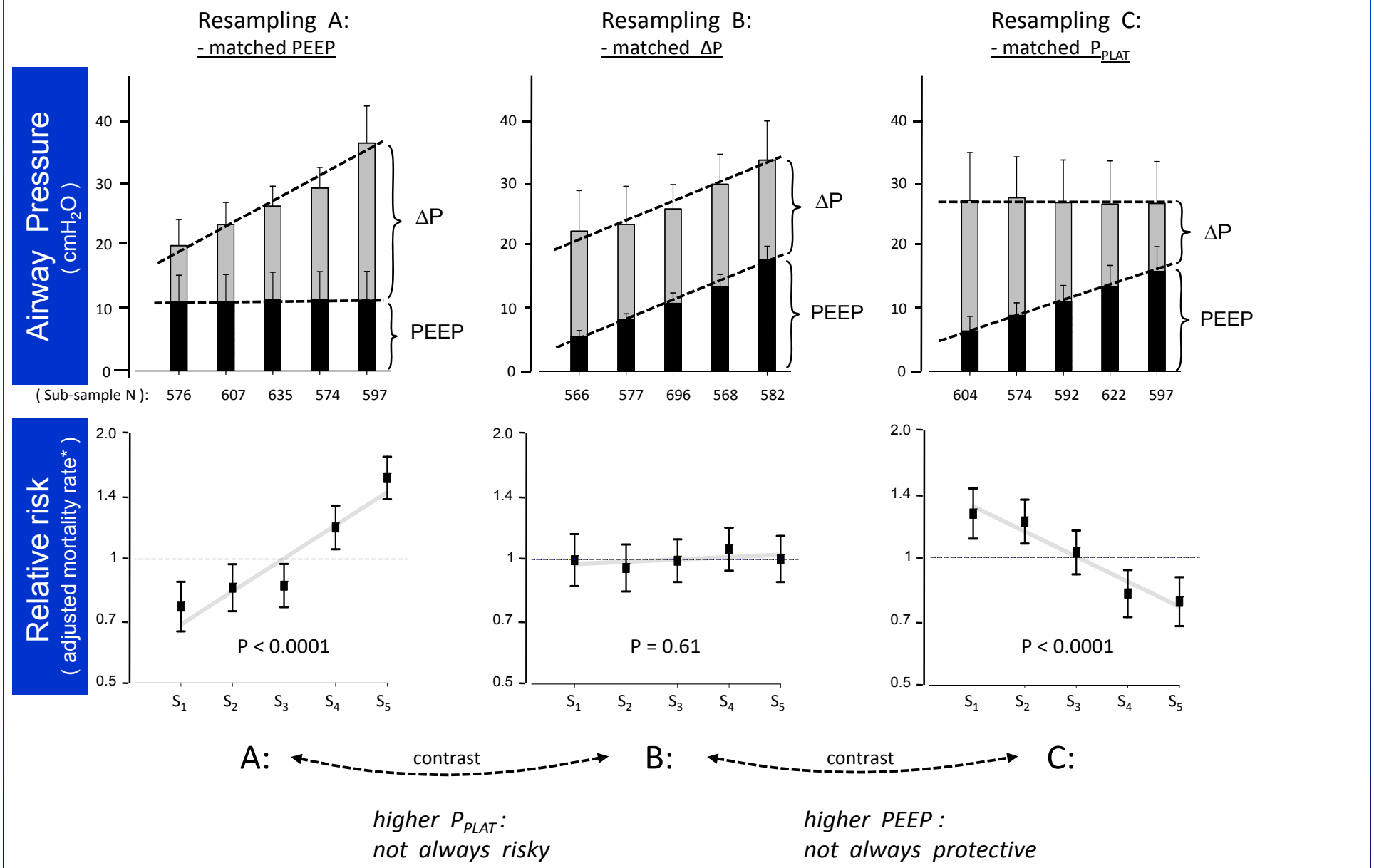
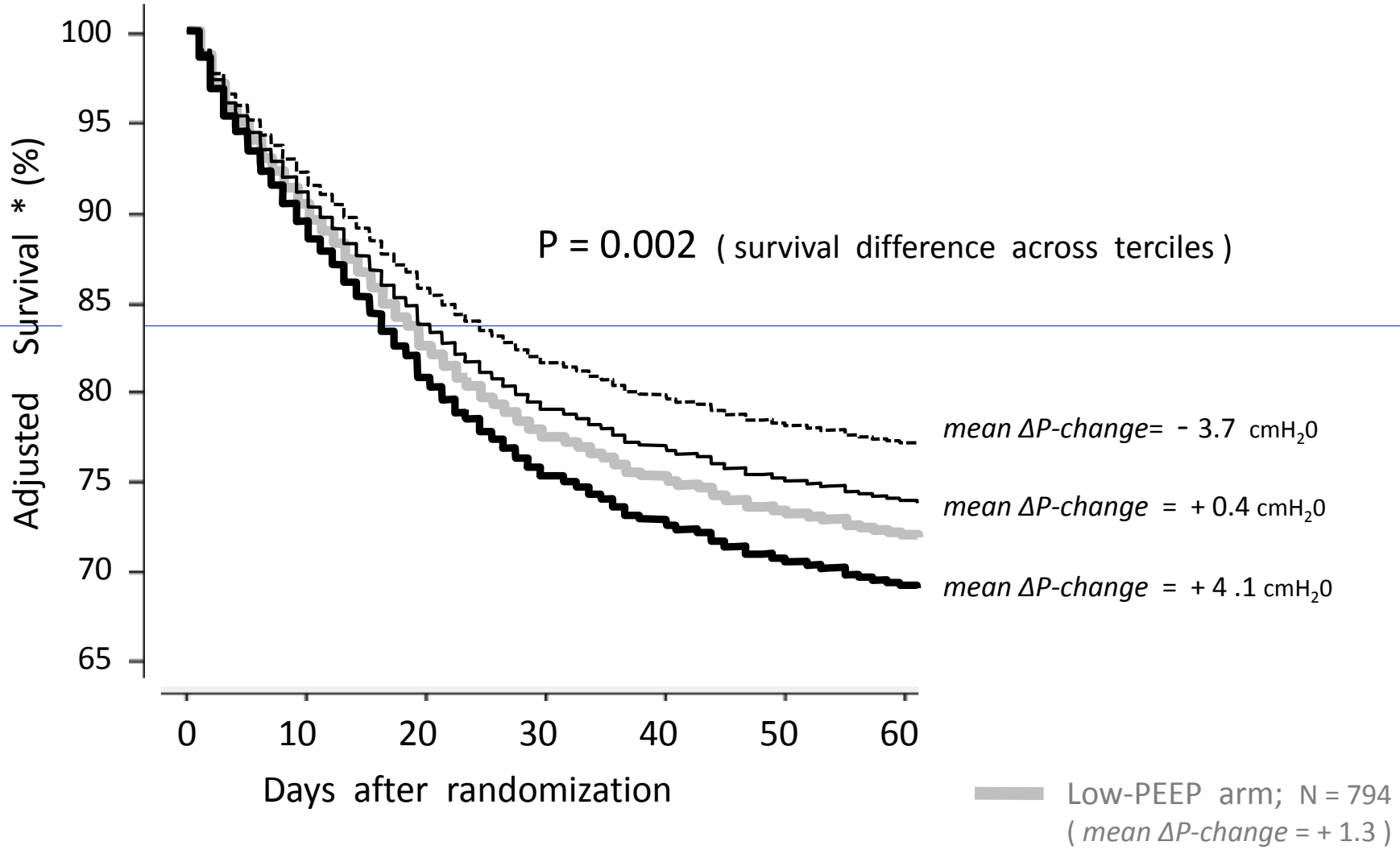

80
60
40
20
0
% Dead Cells
*
*
25-37
0-37
25-50
0-50
Deformation Protocol
(Minimum - Maximum)

Figure 1:




*: adjusted for age, APACHE/SAPS risk, arterial-pH, P/F ratio, and study-trial

Figure 4 : $\Delta P$-*changes* driven by randomization mediate survival in the higher-PEEP arms



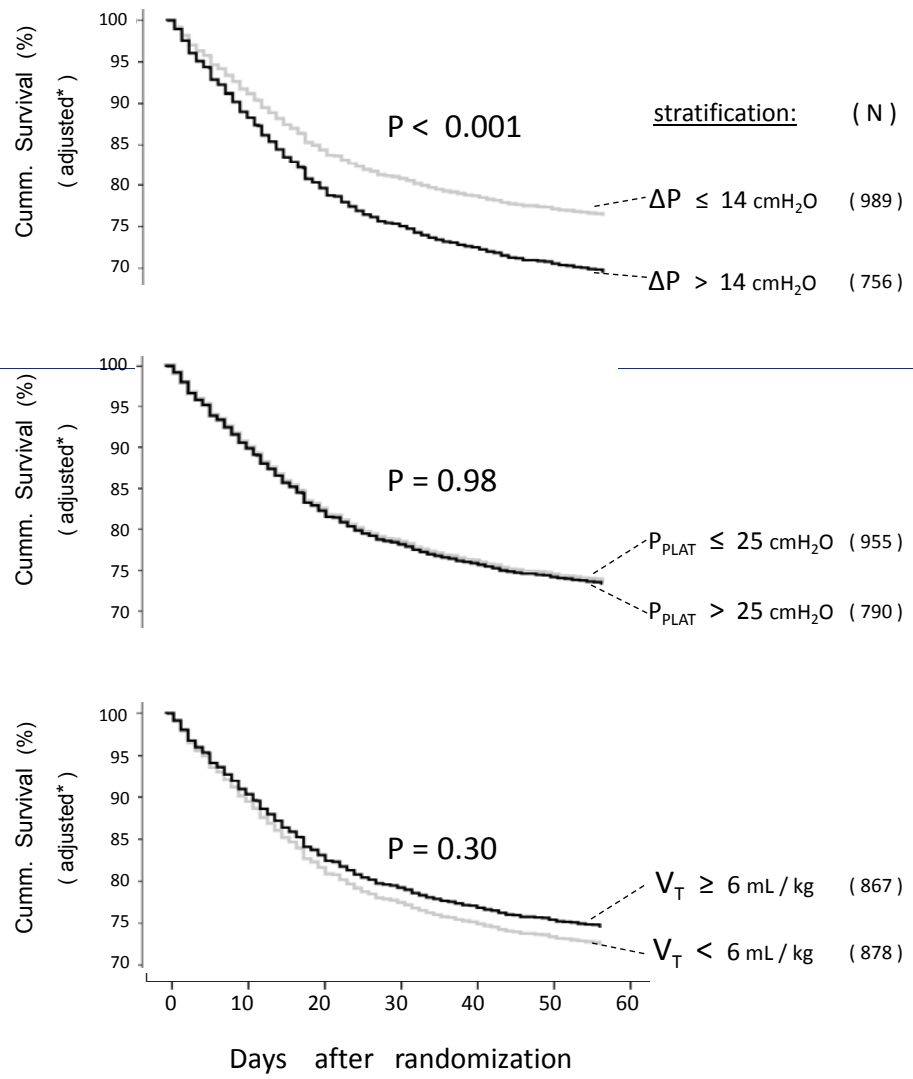

*: Adjusted for: age, APACHE/SAPS risk, arterial-pH, P/F ratio, study-trial, and ***Disease-ΔP***

Figure 2a :

Subsample of patients under "protective settings"

( N = 1745 )

All with Plateau-pressure ≤ 30 $cmH_2O$ & $V_T$ ≤ 7 mL / ibw




*: adjusted for age, APACHE/SAPS risk, arterial-pH, P/F ratio, and study-trial

they are compressed. Thus, we have

$$\epsilon = \frac{\Delta L}{L} = \frac{L' - L}{L} = \frac{L' - L}{L}$$

# Strain

Ratio of total deformation to the initial dimension of the material body in which the forces are being applied.

L

they are compressed. Thus, we have

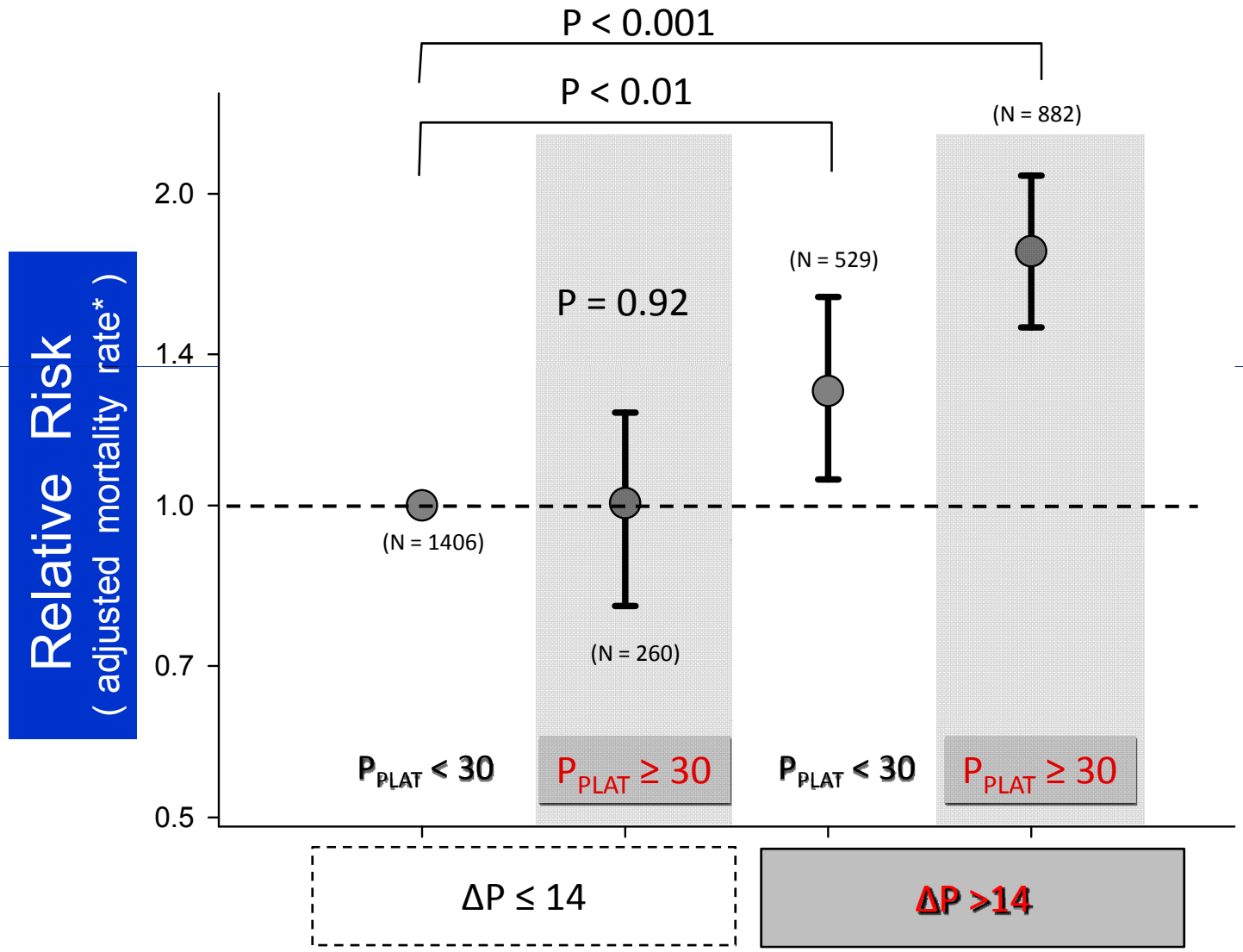
$$\varepsilon = \frac{\Delta L}{L} = \frac{L' - L}{L}$$

# Strain

Ratio of total deformation to the initial dimension of the material body in which the forces are being applied.


Strain = $\Delta L/L$

Figure 2b : Combined population of ARDS ( N = 3080 )

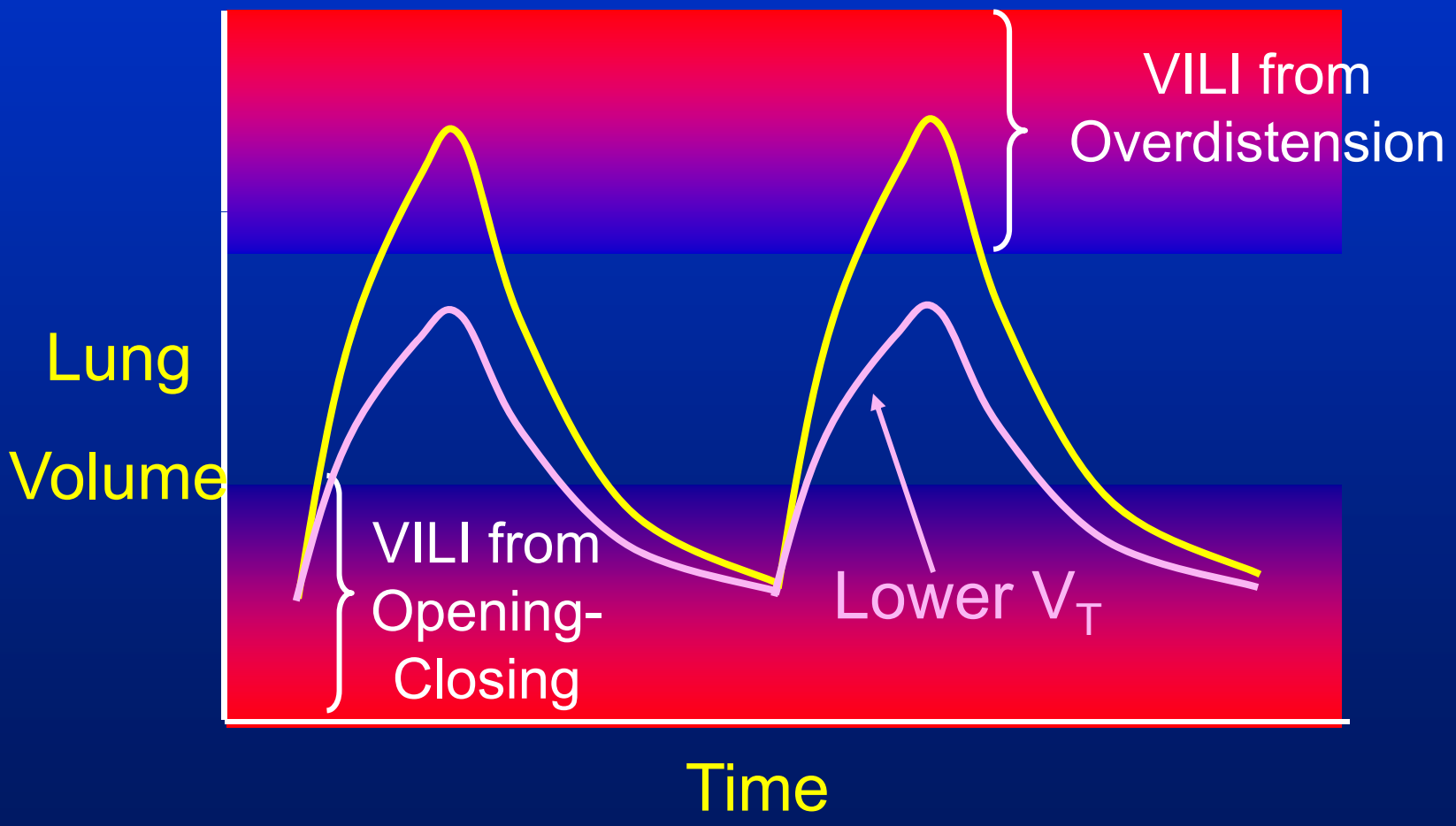



*: adjusted for age, APACHE/SAPS risk, arterial-pH, P/F ratio , and study-trial

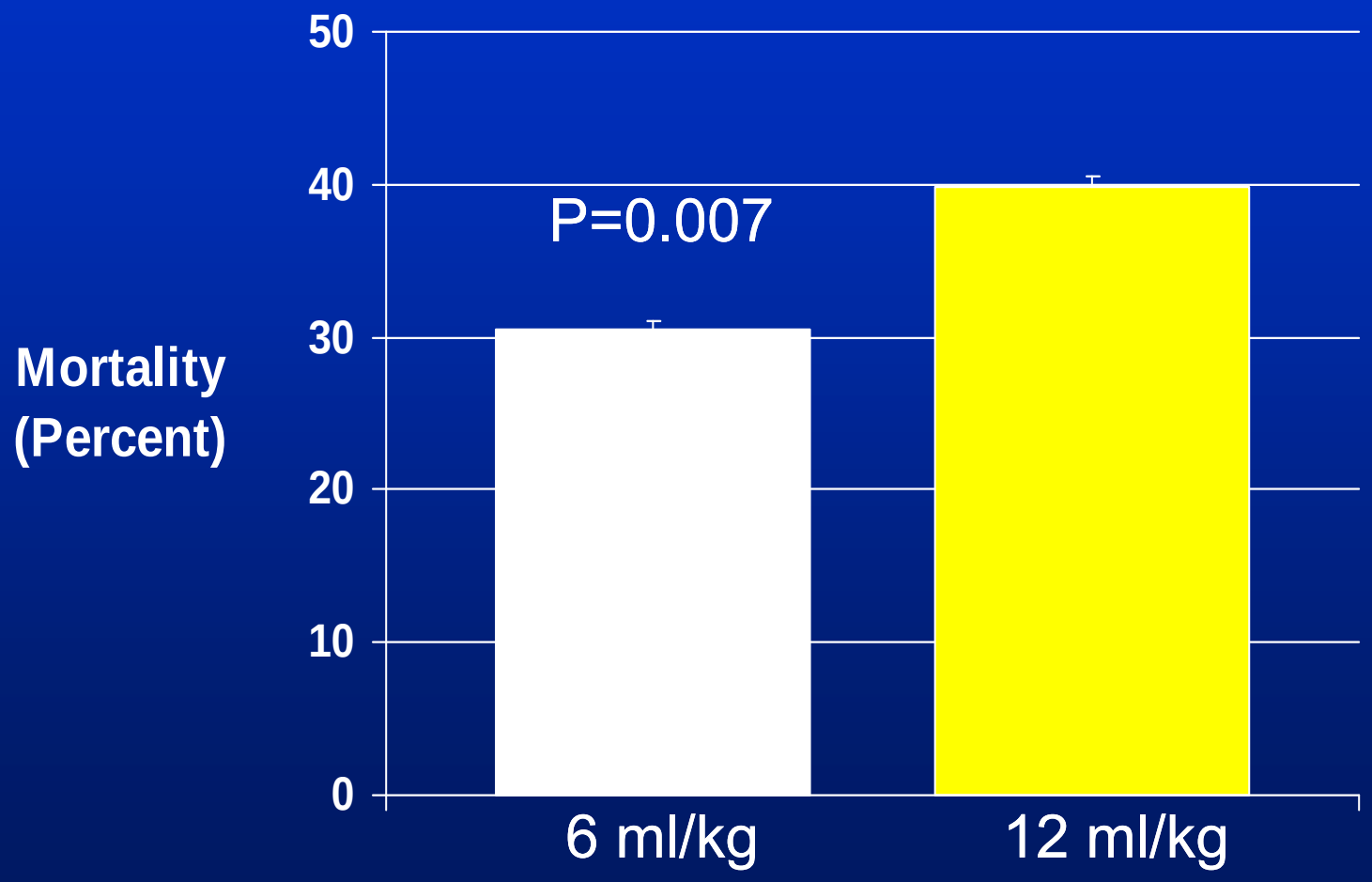
# Driving Pressures in Higher PEEP Trials

| | Pplat | PEEP | ΔP | Δ-ΔP |
|---|---|---|---|---|
| ARDSnet | | | | |
| Lower | 24.0 | 8.9 | 15.1 | |
| Higher | 27.0 | 14.7 | 12.3 | -2.8 |
| Canadian | | | | |
| Lower | 24.9 | 10.1 | 14.8 | |
| Higher | 30.2 | 15.6 | 14.6 | -0.2 |
| French | | | | |
| Lower | 21.1 | 8.4 | 12.7 | |
| Higher | 27.5 | 14.6 | 12.9 | +0.2 |
| ARDSnet Tidal Volume | | | | |
| Lower | 25 | 9.4 | 15.6 | -8.8 |
| Higher | 33 | 8.6 | 24.4 | |

# Lower $V_T$/Pressure Ventilation



# ARDS Network Tidal Volume Trial
# Mortality Before Hospital Discharge




ARDSnet. NEJM 2000

# ARDS Network Tidal Volume Trial

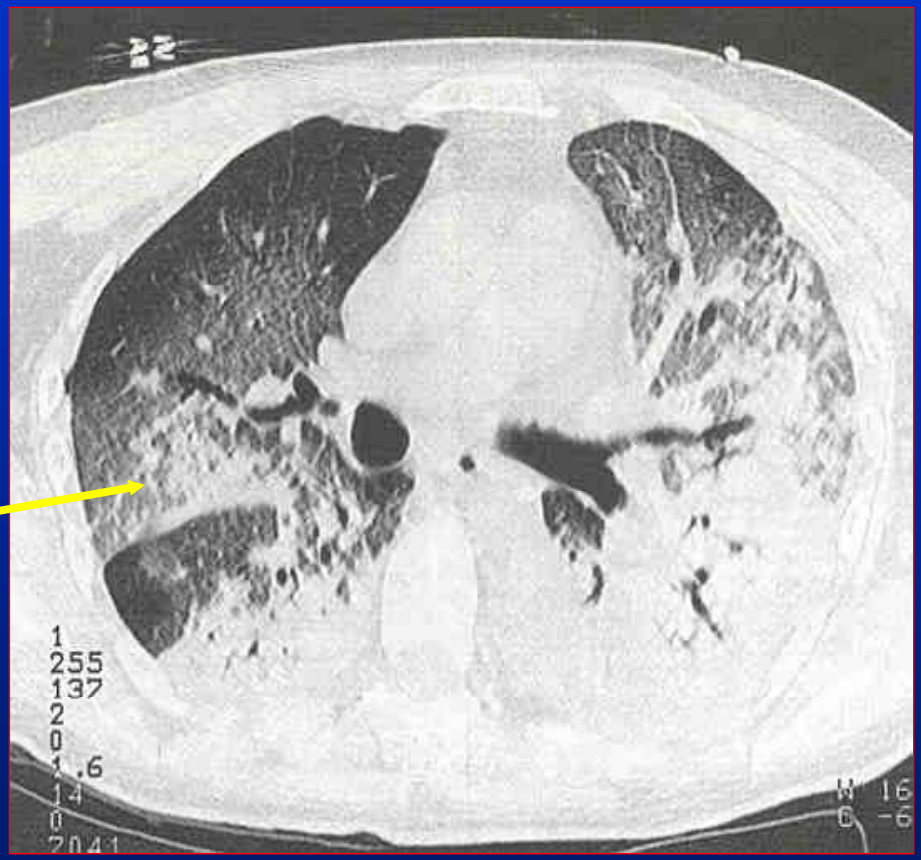
Tidal Volume goal = 6 ml/kg PBW

Plateau Pressure limit = 30 cm $H_2O$

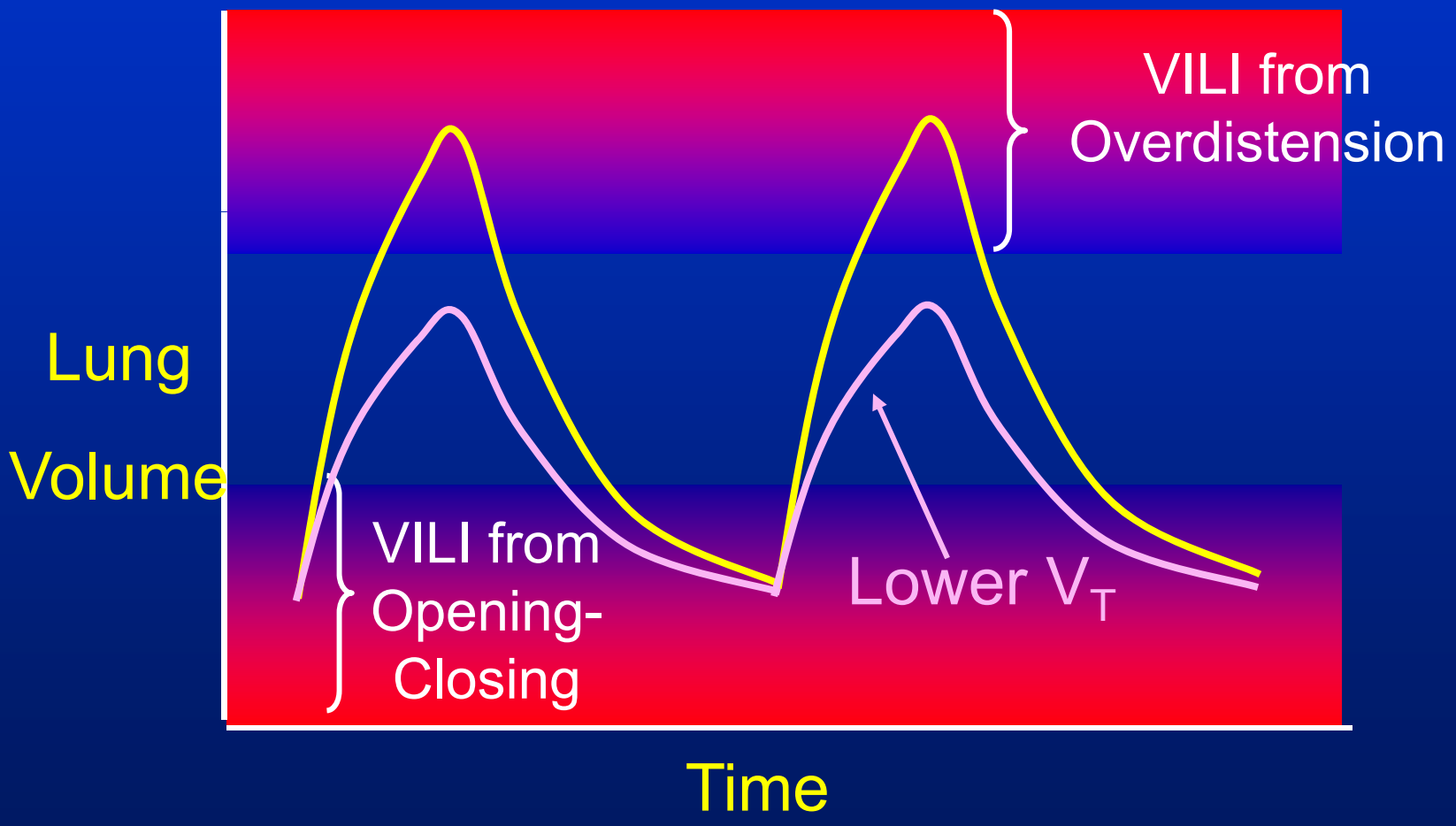
# Mechanical Ventilation
## Traditional Approach

PEEP 0-12 cm $H_2O$

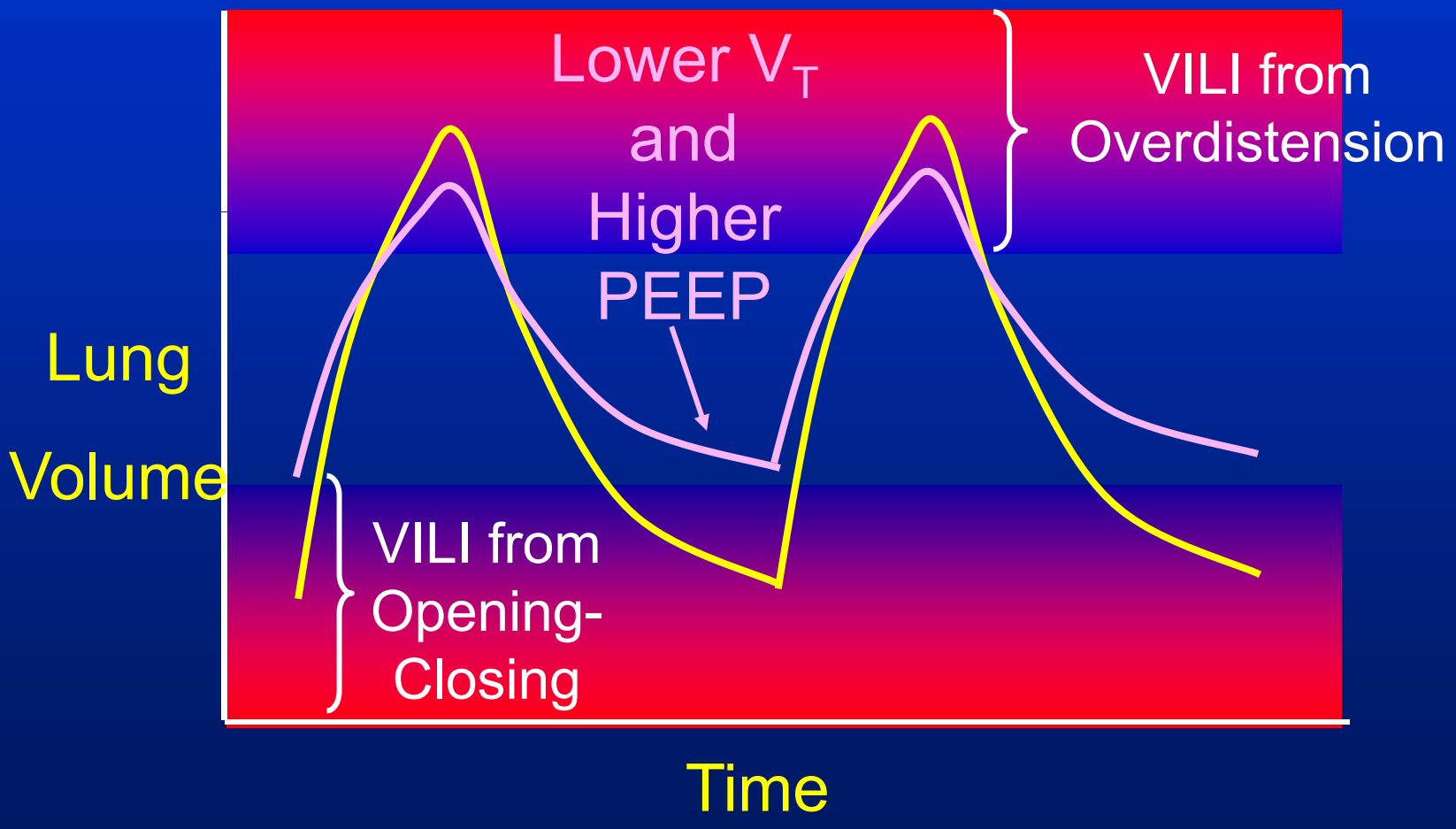
Low Volume/Low Pressure at End-expiration



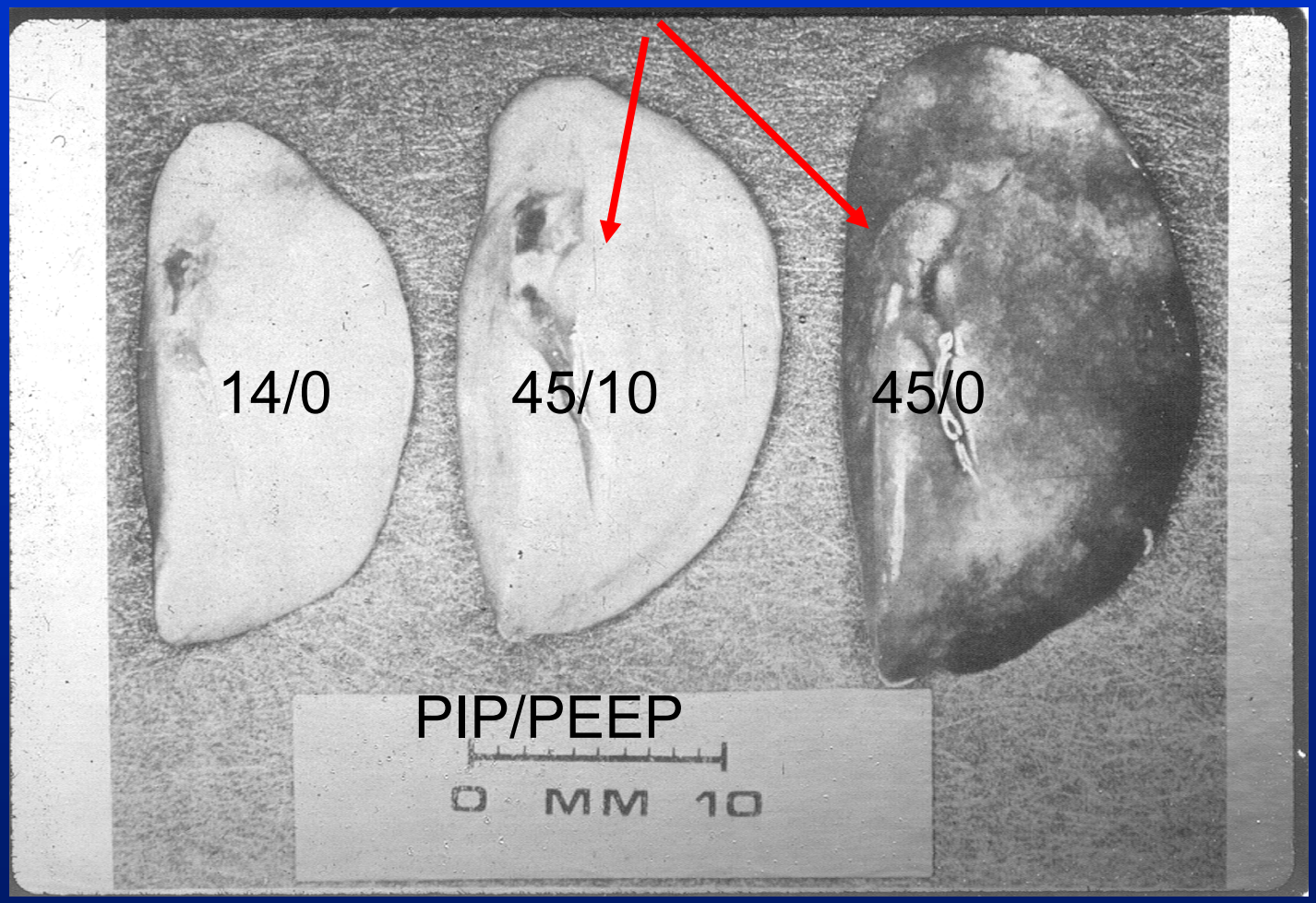
# Lower $V_T$/Pressure Ventilation



# Lower $V_T$ and Higher PEEP



# Ventilator-Induced Lung Injury




Webb and Tierney
Am Rev Resp Dis
110:556-565, 1974

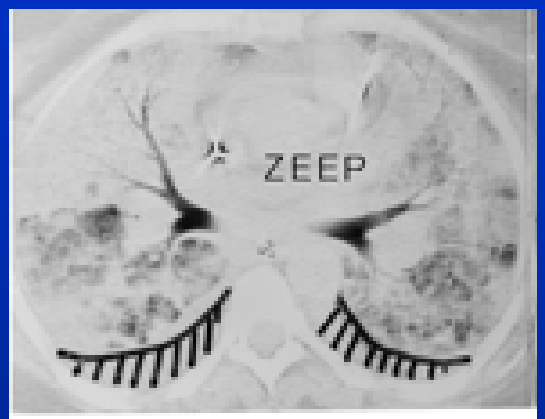
# 3 Higher PEEP Trials

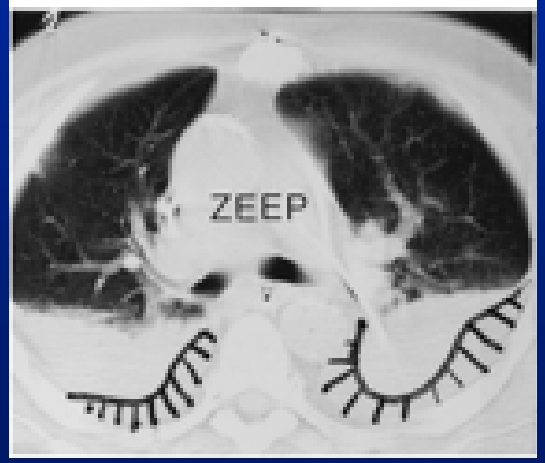
| | Mortality (%) | |
|---|---|---|
| | Higher PEEP | Lower PEEP |
| ARDSnet (549)[1] | 27.5 | 24.9 |
| Canadian (983)[2] | 36.4 | 40.4 |
| French (767)[3] | 35.4 | 39.4 |
| Combined (2299) | 33.9 | 36.2 |

1 ARDSnet NEJM 2004
2 Meade JAMA 2008
3 Mercat JAMA 2008

# Effects of PEEP are Variable

Diffuse




Lobar

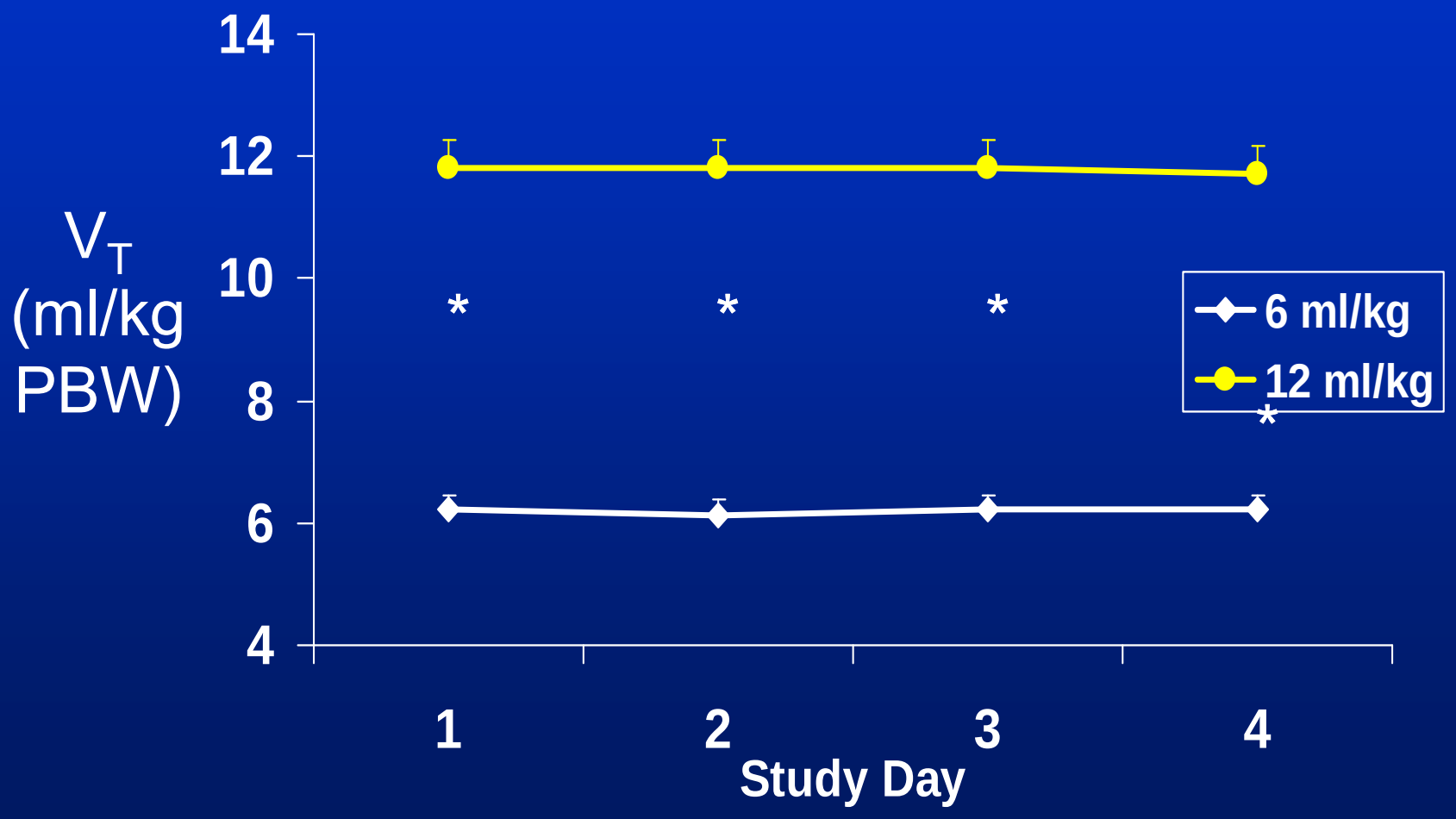
Recruitment

Overdistention

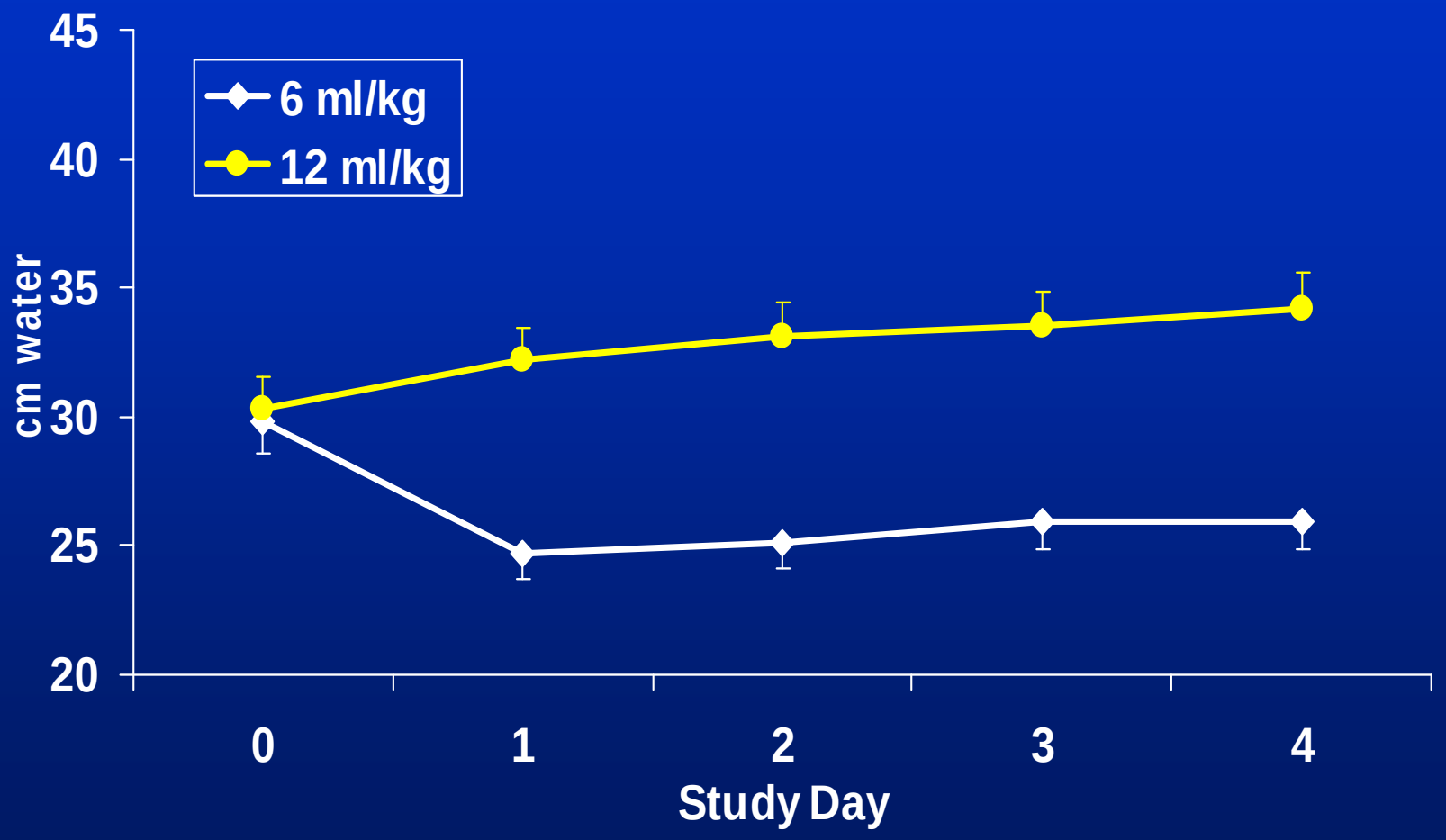
Recruitment

Overdistention

# ARDS Network Trial – Tidal Volumes



# ARDS Network Trial - Plateau Pressures

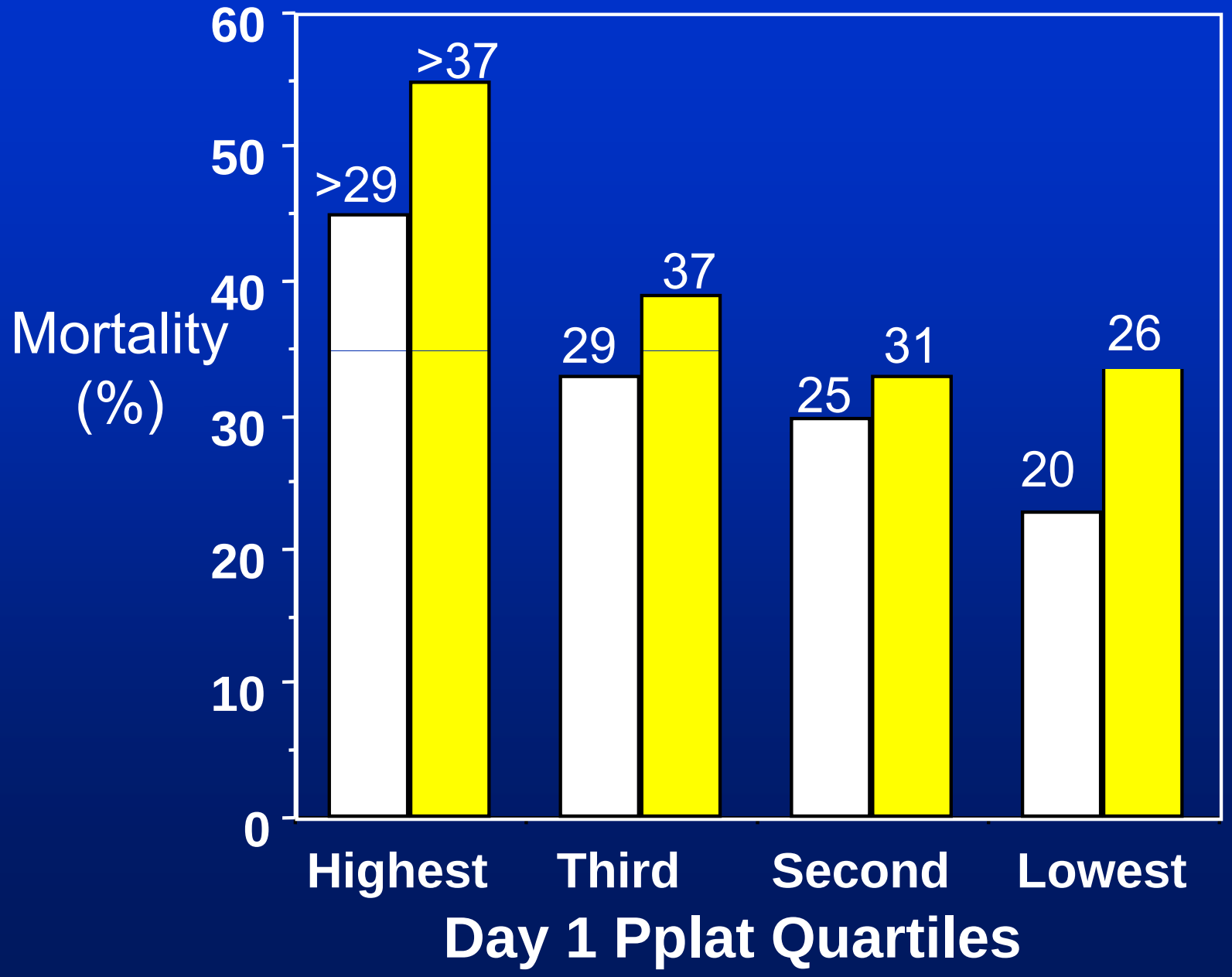


# ARDS Network Trial of Lower Tidal Volume Ventilation in ALI/ARDS

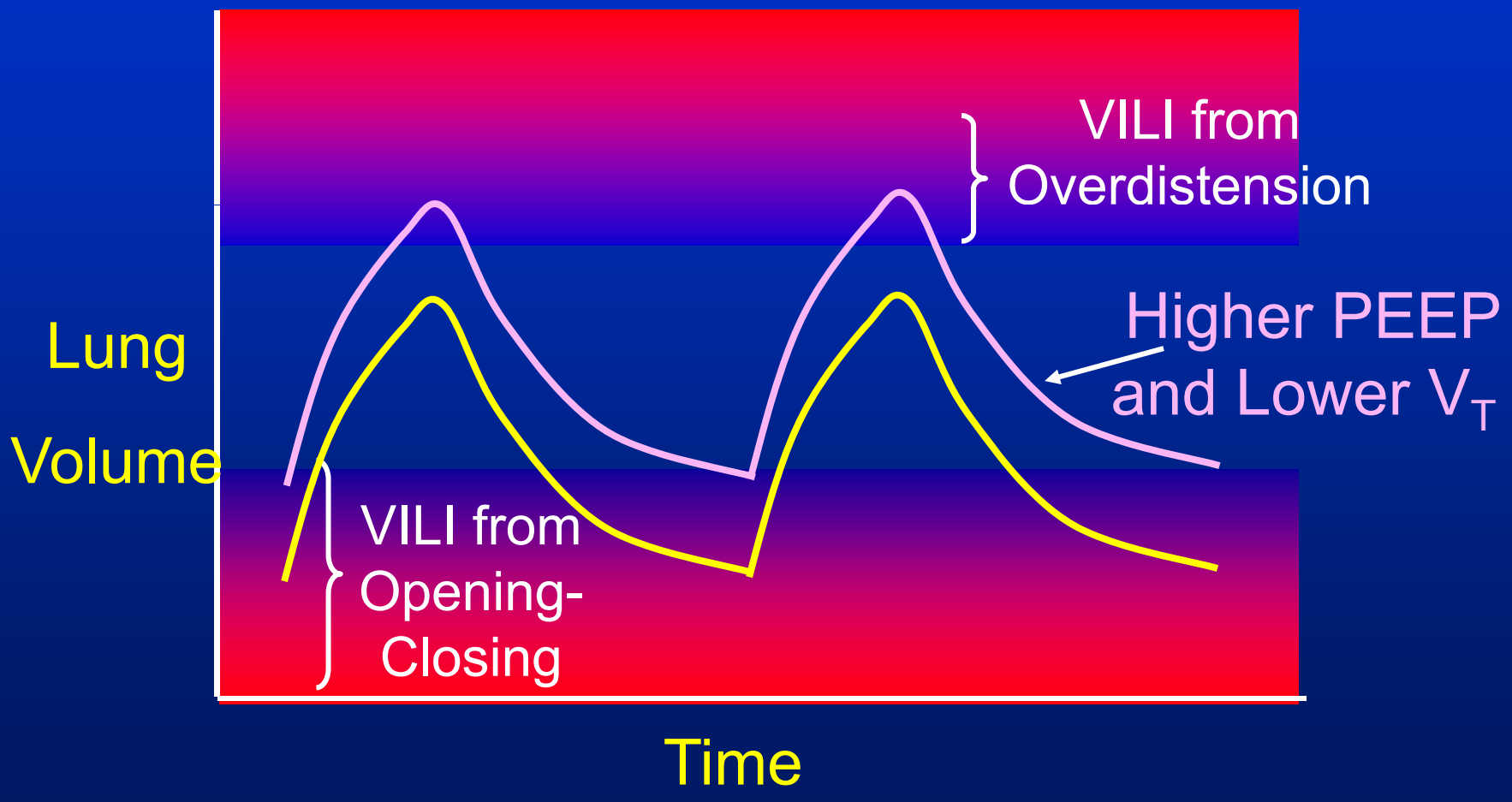
Subset analysis

*No "safe" level of Pplat identified*

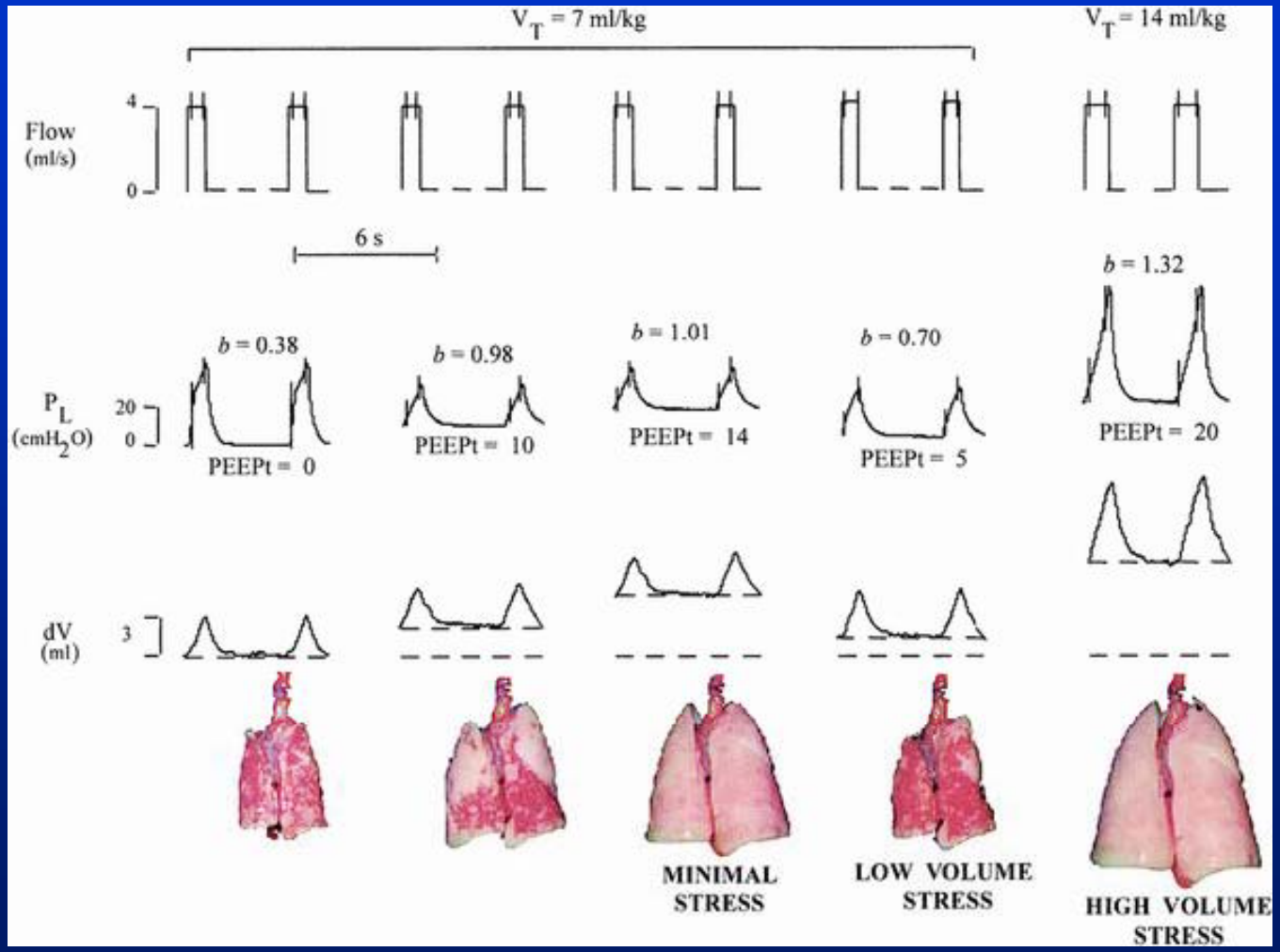
# Mortality by Day 1 Pplat Quartiles (n=822)



# Lower $V_T$/Pressure Ventilation *and* Higher PEEP



# Stress Index




Ranieri et al. Anesthesiology. 2000 Nov;93(5):1320-8.

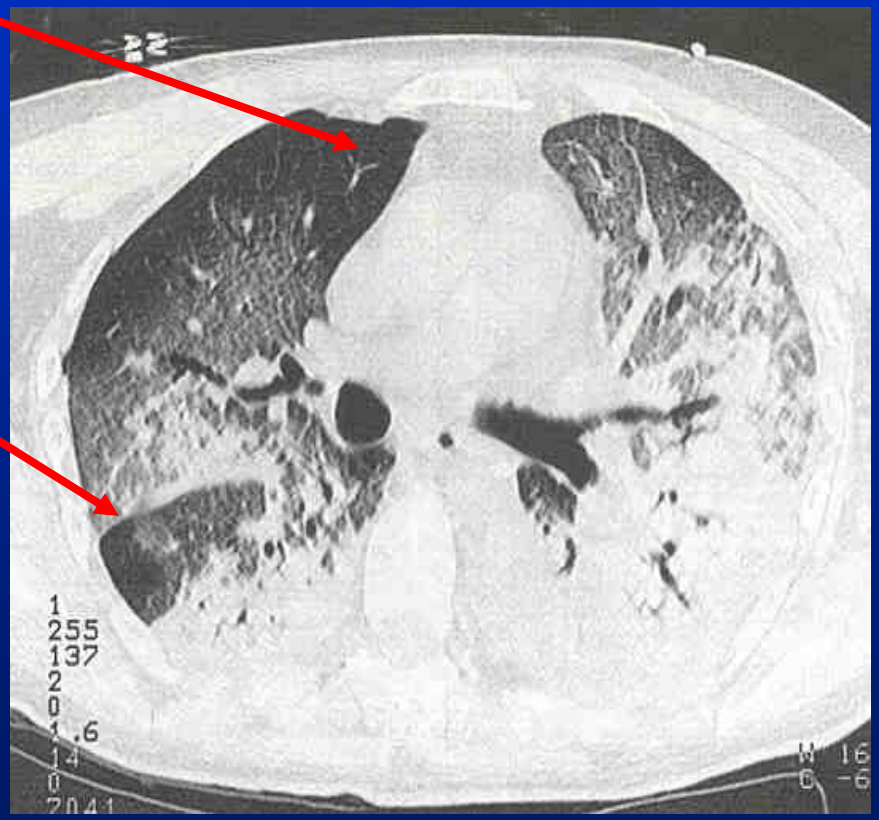
# Lung-protective Mechanical Ventilation in ALI and ARDS
# PEEP Questions

- Who are the responders?
- How much PEEP in responders?
- How much PEEP in nonresponders?
- When to decrease PEEP in responders?

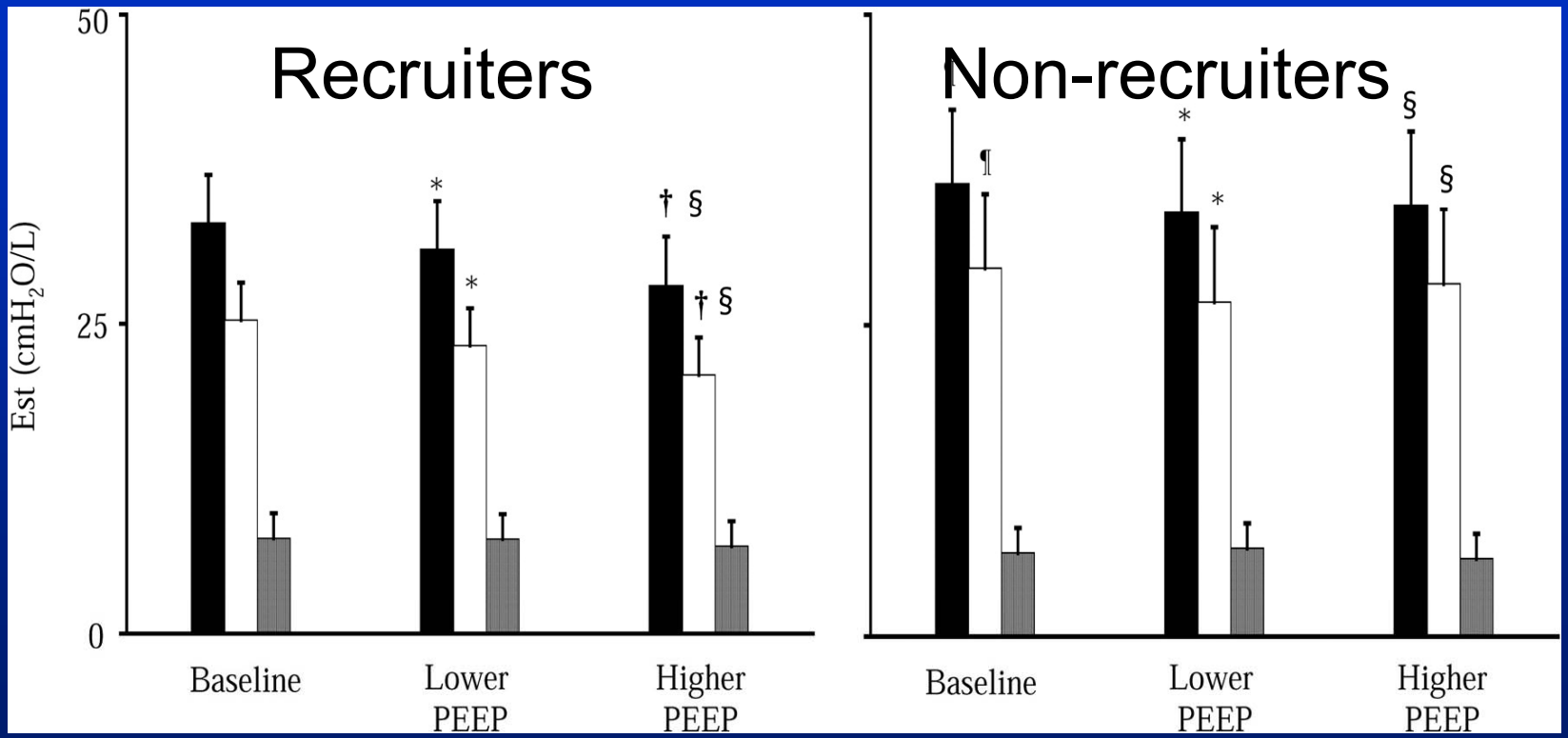
# Ventilator-Induced Lung Injury

High Volume
High Pressure
VILI

Low Volume
Low Pressure
VILI

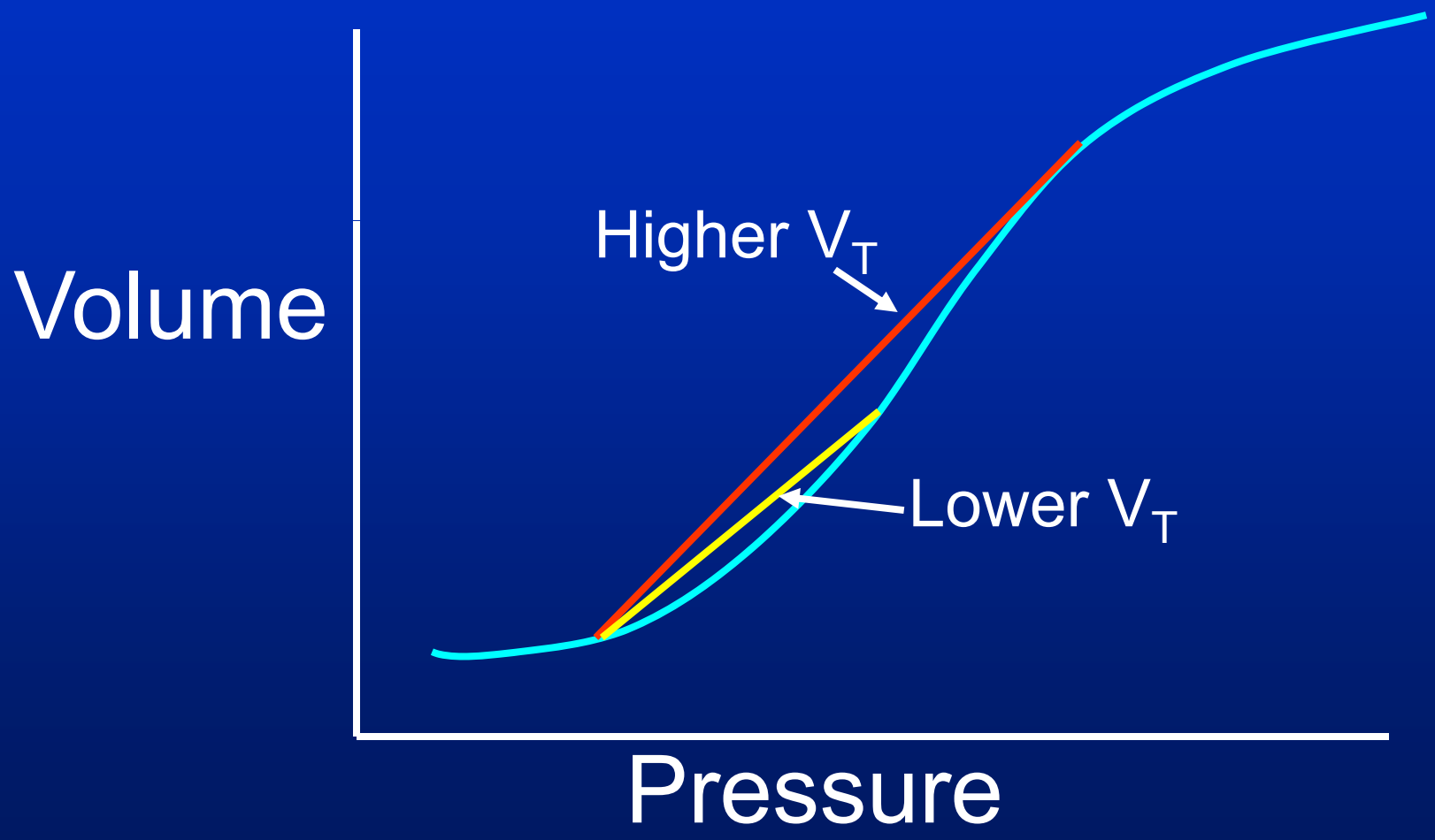


# Effects of PEEP on Elastance
## Recruiters and Nonrecruiters

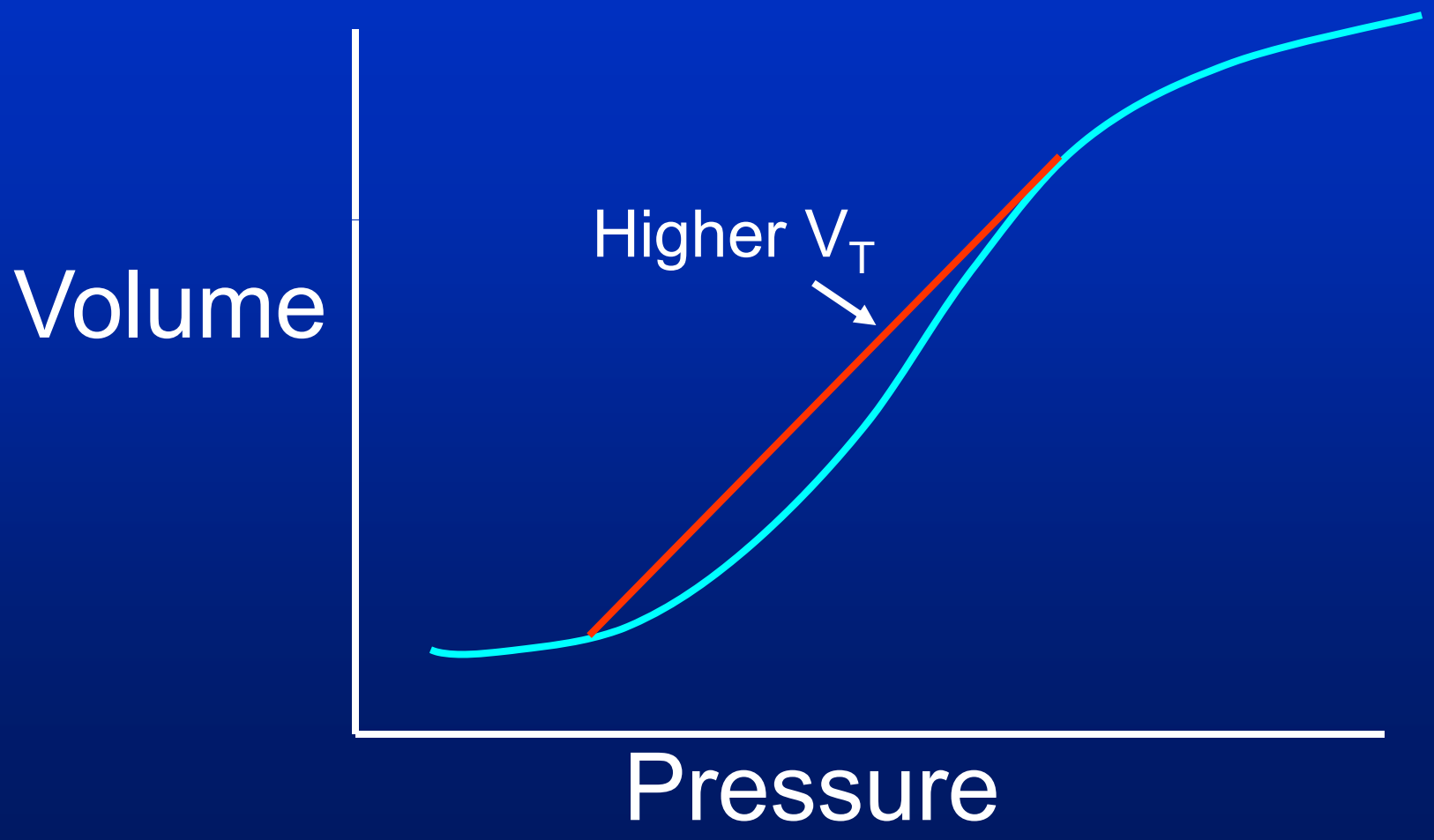



Grasso et al. Am J Resp Crit Care Med 2005; 171: 1002-1008

# Lower $V_T$ and Inspiratory Pressure Reduced Overdistention AND Opening-Closing



# Higher $V_T$ and Inspiratory Pressure



# Ventilator-induced Lung Injury

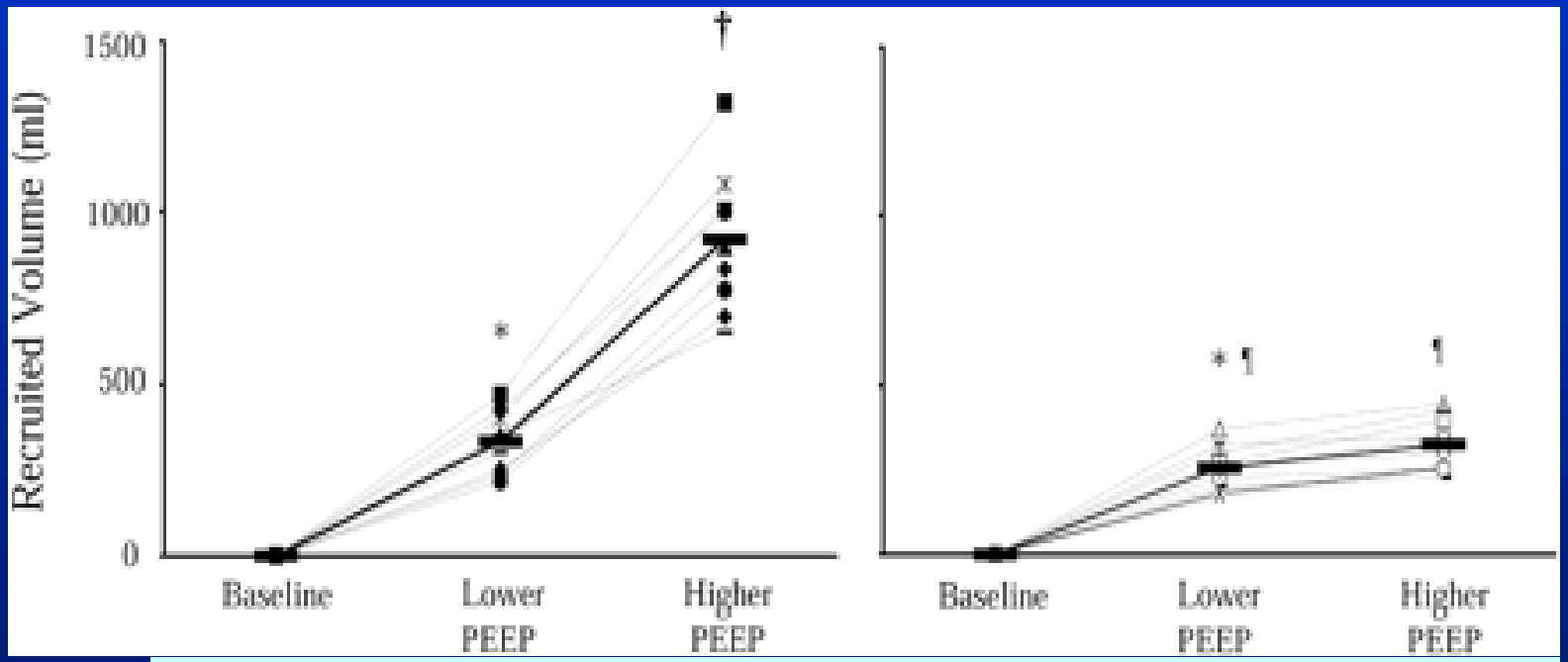
*Effect of Positive Pressure Ventilation on Surface Tension Properties of Lung Extracts*

Lazar J. Greenfield, M.D., Paul A. Ebert, M.D., Donald W. Benson, M.D., Ph.D.

Anesthesiology 1964; 312-316

# Effects of PEEP

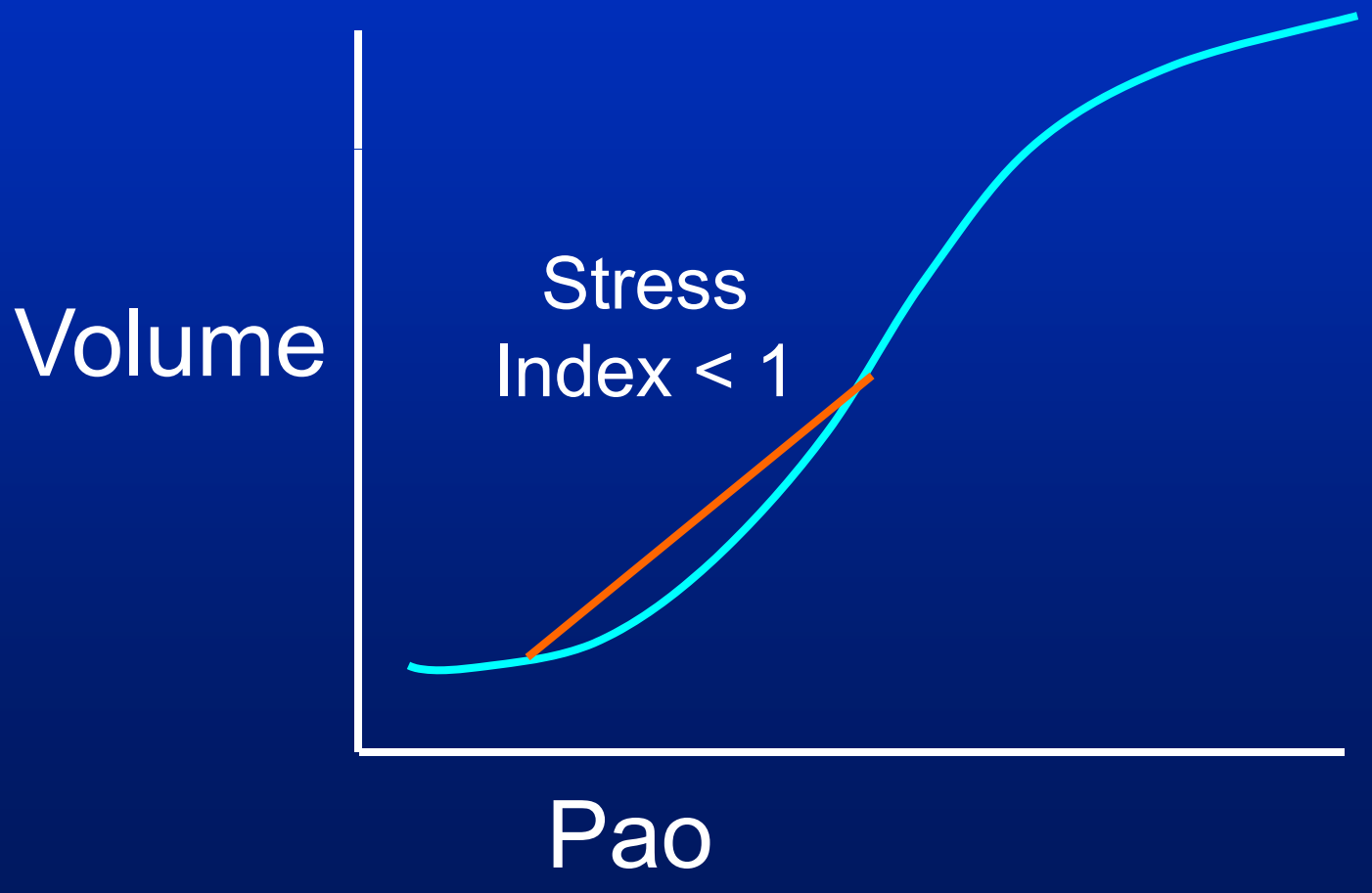
Responders Nonresponders



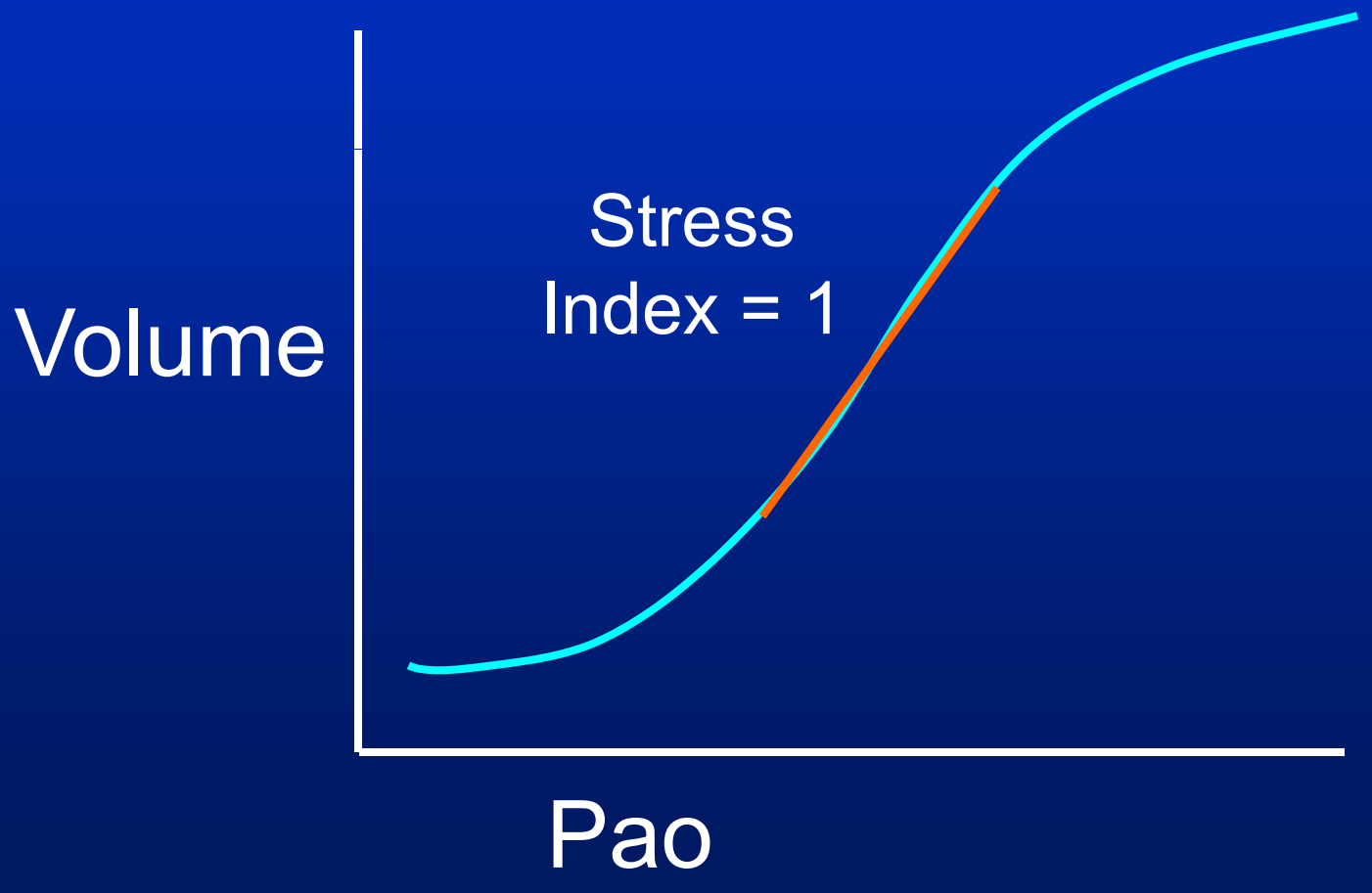

| | | | | |
|---|---|---|---|---|
| PEEP | 9 | 16 | 9 | 15 |

Grasso et al. Am J Resp Crit Care Med 2005; 171: 1002-1008

# Pressure Volume Curve
# Stress Index



# Pressure Volume Curve
# Stress Index



# Pressure Volume Curve
# Stress Index