Stress & Strain
or
« what to do with VT – Pplat – PEEP…»

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Few evidences on VT ≤ 6 mL/kg PBW

Table 1—*Randomized Controlled Trials Evaluating Strategies of Mechanical Ventilation for the Treatment of ARDS**

Study	Patients, No.	Intervention	Mortality Rates†	p Value
Amato et al[10]	53	≤ 6 mL/kg ABW; V_T; < 20 cm H_2O Pdriving	38% vs 71%‡	0.001
Stewart et al[11]	120	≤ 8mL/kg IBW; V_T; ≤ 30 cm H_2O Pplat	50% vs 47%	0.72
Brochard et al[12]	116	6–10 mL/kg IBW; V_T; 25–30 cm H_2O Pplat	47% vs 38%§	0.38
Brower et al[13]	52	≤ 8 mL/kg PBW; V_T; ≤ 30 cm H_2O Pplat	50% vs 46%	0.61
ARMA[14]	861	≤ 6mL/kg PBW; V_T; ≤ 30 cm H_2O Pplat	31% vs 40%	0.007

*ABW = actual body weight; V_T = tidal volume; Pdriving = driving pressure; IBW = ideal body weight; Pplat = plateau pressure; PBW = predicted body weight; HFOV = high-frequency oscillatory ventilation.

†Values are given as the in-hospital mortality rates of intervention vs control group, unless otherwise noted.

‡28-day mortality rate.

§60-day mortality rate.

||30-day mortality rate.

¶180-day mortality rate.

Girard, CHEST 2007

Few evidences on VT ≤ 6 mL/kg PBW

Table 2. Effect of Different Lung-Protective Ventilation Strategies on Mortality and Other End Points

Author, Year (Reference), by Study End Point	Patients, *n*	Patients With Study End Point, by Ventilation Strategy, *n/n*		Odds Ratio (95% CI)	*P* Value	I^2 Statistic	*P* Value
		Low VT at Similar PEEP	High VT at Similar PEEP				
Hospital mortality							
Brochard et al, 1998 (17)	116	–	–	–			
Brower et al, 1999 (18)	52	13/26	12/26	1.17 (0.39–3.47)*			
Brower et al, 2000 (16)	861	134/432	171/429	0.68 (0.51–0.90)*			

Low *vs* high VT – similar PEEP

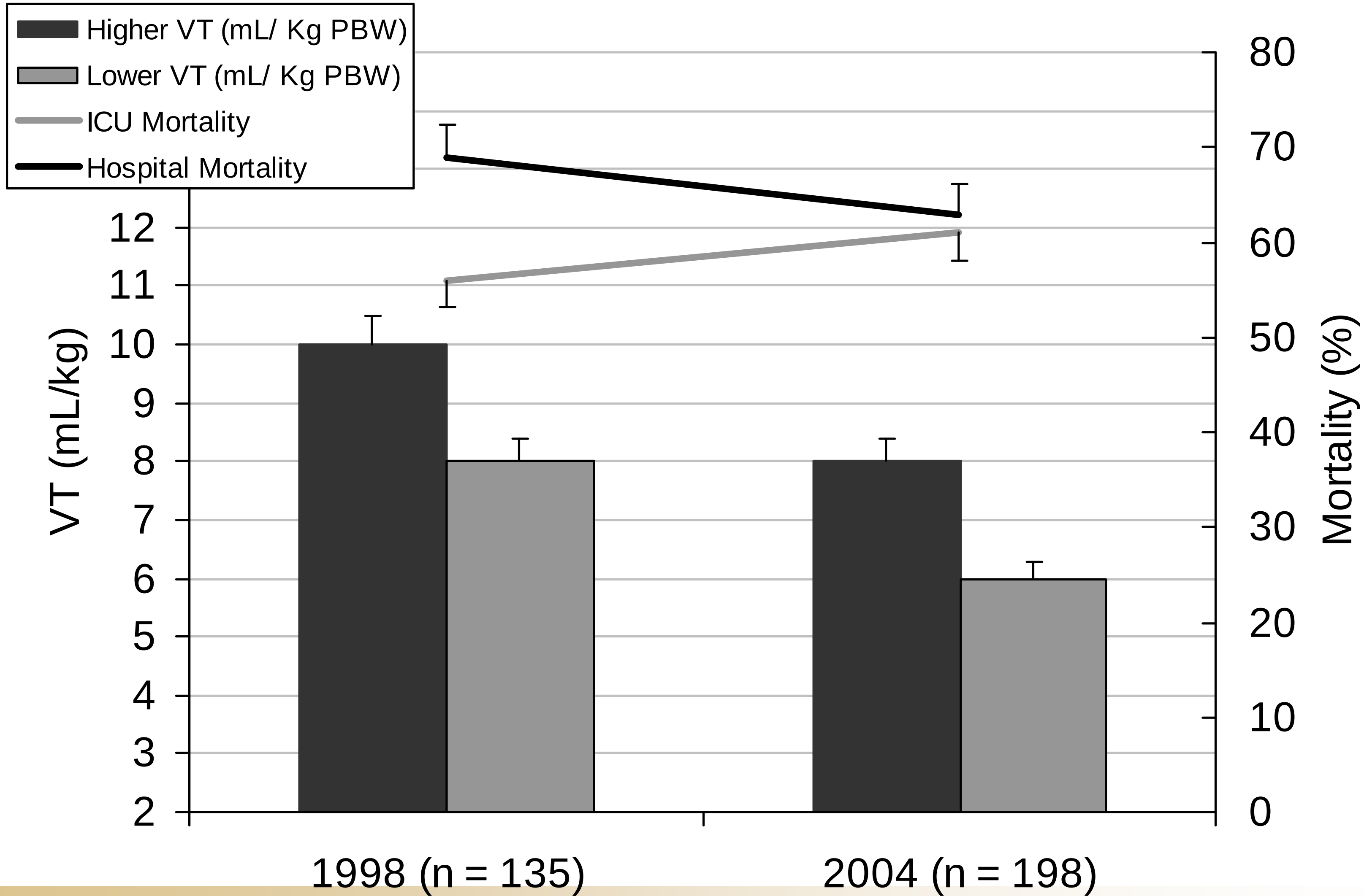
Hospital Mortality (3 studies): p = 0.020

Mortality at the end of the follow up (4 studies): p = 0.75

		High PEEP	Low PEEP				
Amato et al, 1998 (23)	53	13/29	17/24	0.33 (0.11–1.05)*			
Villar et al, 2006 (24)	95	17/50	25/45	0.41 (0.18–0.94)*			
Summary				0.38 (0.20–0.75)*	0.005	0	0.77
		Low VT at Similar PEEP	High VT at Similar PEEP				
Mortality at the end of follow-up†							
Brochard et al, 1998 (17)	116	27/58	22/58	1.43 (0.68–2.99)‡			
Brower et al, 1999 (18)	52	13/26	12/26	1.17 (0.39–3.47)‡			
Brower et al, 2000 (16)	861	134/432	171/429	0.68 (0.51–0.90)‡			
Stewart et al, 1998 (19)	120	30/60	28/60	1.14 (0.56–2.34)‡			
Summary				0.94 (0.62–1.41)‡	0.75	40.9	0.170

Putensen C. Ann Intern Med 2009

Lower better than higher?



Esteban, AJRCCM 2008

6 = 8 – 2…

Table 2. Baseline Characteristics of Included Patients

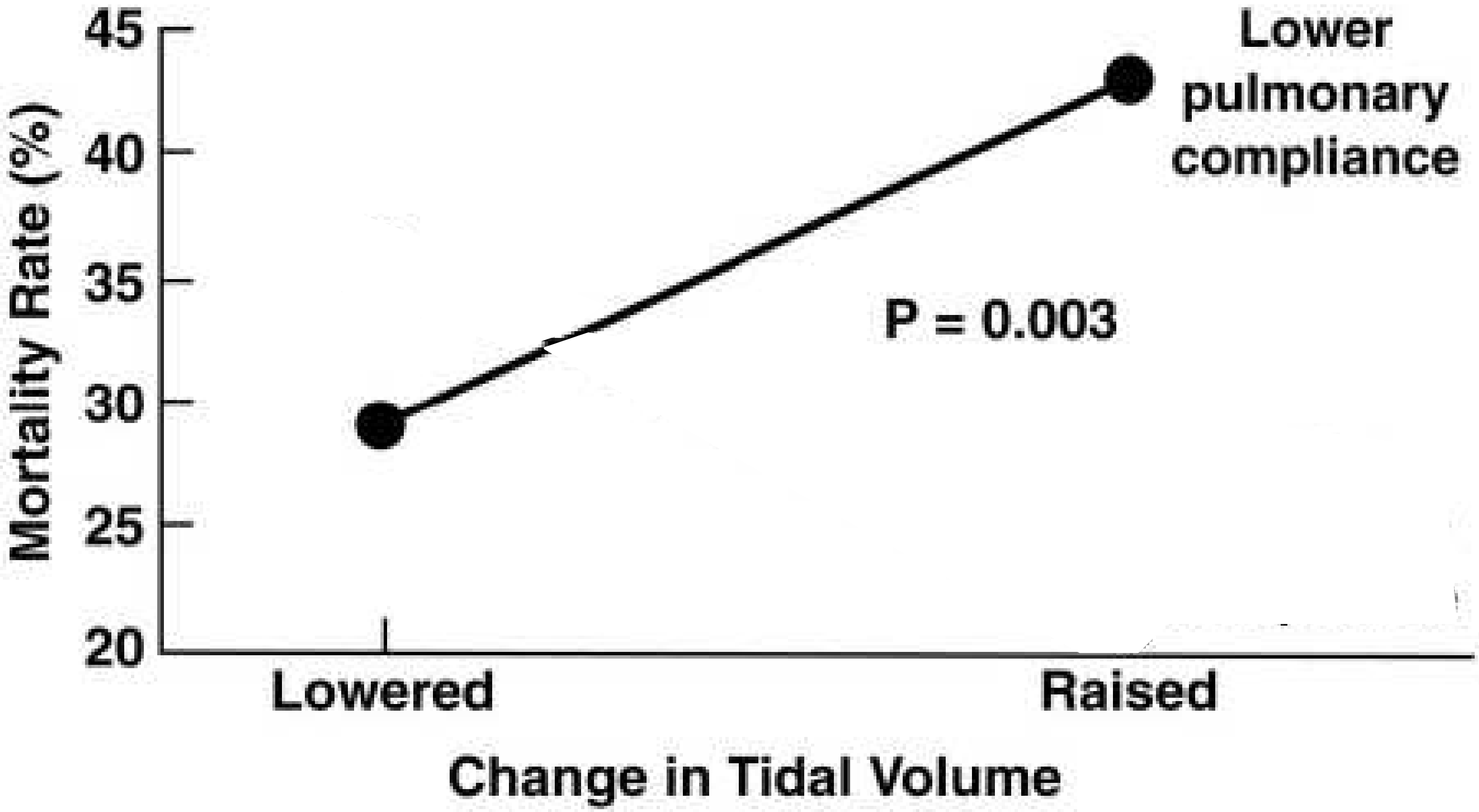
Characteristic	Higher PEEP (n = 1136)	Lower PEEP (n = 1163)
Age, mean (SD), y	56 (17) [n = 1136]	56 (17) [n = 1163]
Women, No. (%)	437 (38) [n = 1136]	455 (39) [n = 1163]

VT (mL/PBW): 8.0 ± 1.9 (n = 1107) and 8.0 ± 2.0 (n = 1135)

Oxygenation index, median (IQR)[d]	11.4 (8.2-16.8) [n = 989]	11.1 (7.7-17.0) [n = 1009]
Set PEEP, cm H_2O	9.9 (4.0) [n = 1135]	9.7 (3.8) [n = 1160]
Plateau pressure, cm H_2O	26.7 (6.4) [n = 915]	26.3 (6.6) [n = 899]
Respiratory rate, breaths/min	23.1 (6.6) [n = 1133]	23.2 (6.7) [n = 1160]
Minute ventilation, L/min	11.6 (3.2) [n = 1122]	11.7 (3.6) [n = 1151]
Tidal volume, mL/kg of predicted body weight	8.0 (1.9) [n = 1107]	8.0 (2.0) [n = 1135]
Estimated respiratory system compliance, mL/cm H_2O[e]	32.7 (14.9) [n = 909]	32.6 (13.7) [n = 892]
Cause of lung injury, No. (%)[f]		
Pneumonia	567 (50)	578 (50)
Aspiration	214 (19)	247 (21)
Severe sepsis, including septic shock	595 (52)	628 (54)
Multiple transfusions	71 (6.3)	74 (6.4)
Acute pancreatitis	37 (3.3)	48 (4.1)
Multiple trauma	60 (5.3)	73 (6.3)
Other[g]	146 (13)	119 (10)

Briel JAMA 2010

Individualized VT better than « one-fit-all »



Deans, CCM 2005

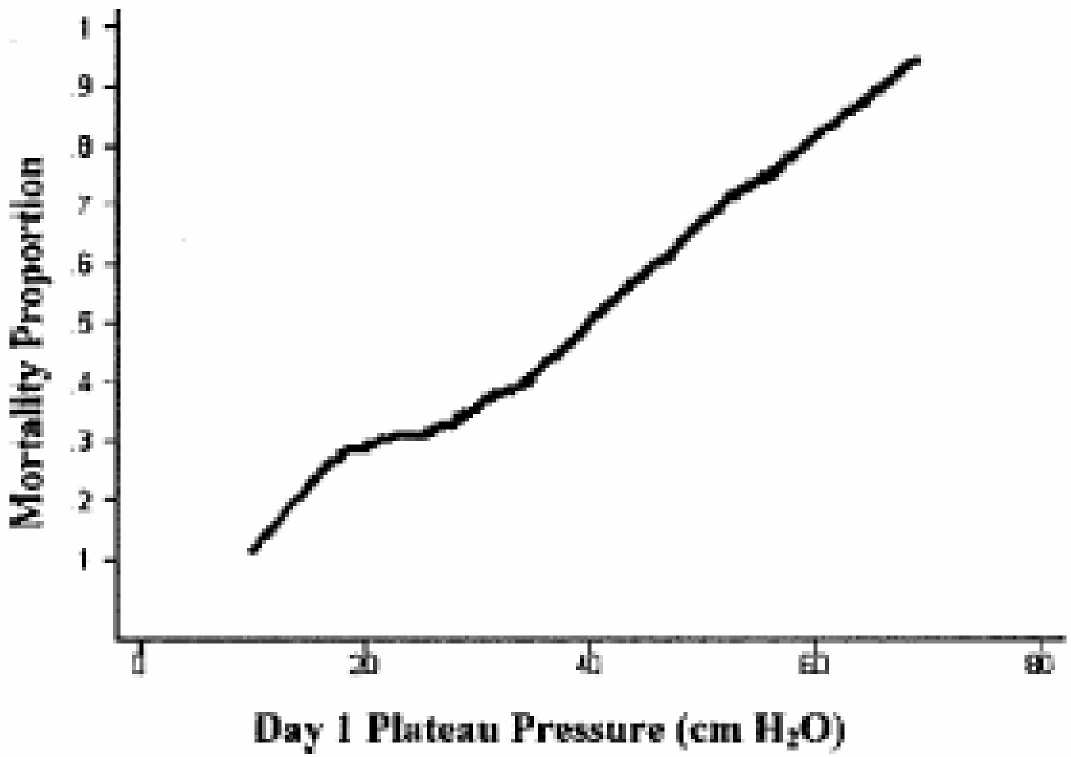
VT in non ALI/ARDS pts ???

Author [ref]	Number of patients	Reason for mechanical ventilation	Tidal volume in study groups	Effect of use of lower tidal volumes
Lee et al.[21]	103	Surgery	6 vs. 12 ml/kg	Less pulmonary infection/shorter duration of intubation
Wrigge et al.[22]	39	Surgery	6 vs. 15 ml/kg	No differences in plasma cytokine levels
Wrigge et al.[23]	64	Thoracic or abdominal surgery	6 vs. 12–15 ml/kg	No differences in time course of tracheal aspirate – or plasma cytokine levels
Wrigge et al.[24]	44	Thoracic surgery	6 vs. 12 ml/kg	Lower BALF cytokine levels, no differences in plasma cytokine levels
Koner et al.[25]	44	Thoracic surgery	6 vs. 10 ml/kg	No differences in plasma cytokine levels
Zupancich et al.[26]	40	Thoracic surgery	8 vs. 10–12 ml/kg	Lower BALF and plasma cytokine levels
Reis-Miranda et al.[27]	62	Thoracic surgery	4–6 vs. 6–8 ml/kg	Earlier decrease of plasma cytokine levels
Michelet et al.[28]	52	Thoracic surgery	9 vs. 5 ml/kg	Lower plasma cytokine levels, higher PaO2/FiO2 ratio, and shorter duration of intubation
Choi et al. [29]	40	Surgery	6 vs. 12 ml/kg	Less pulmonary coagulopathy

🚘: PEEP regimens differ between groups!

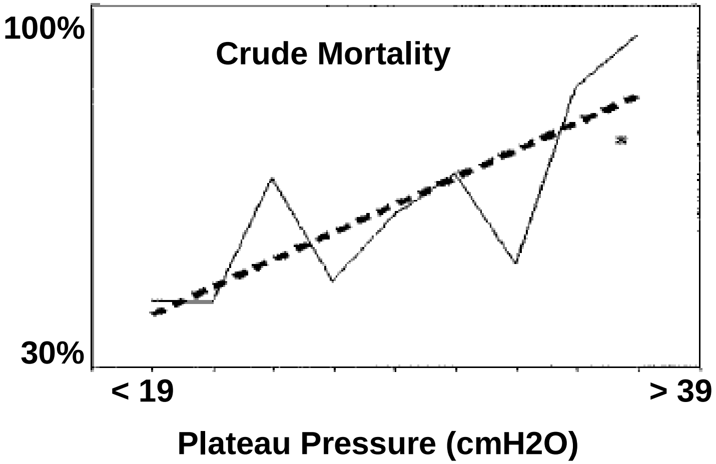
Schultz, ANESTHESIOLOGY 2007/Med Science Monitoring 2008

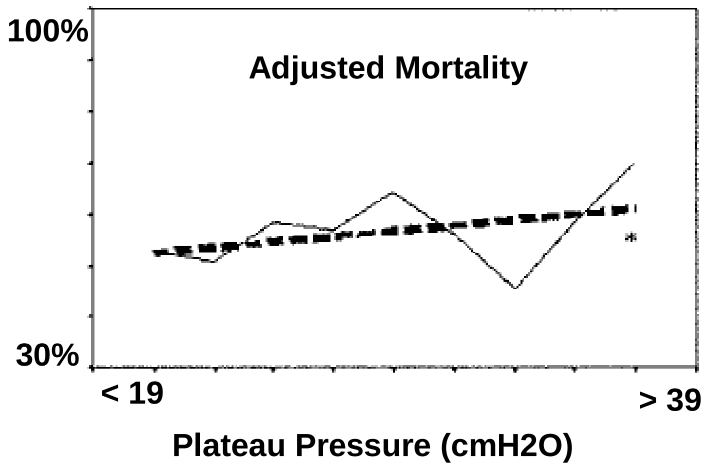
More evidences for Pplat: ARDSnet…



Hager AJRCCM 2005

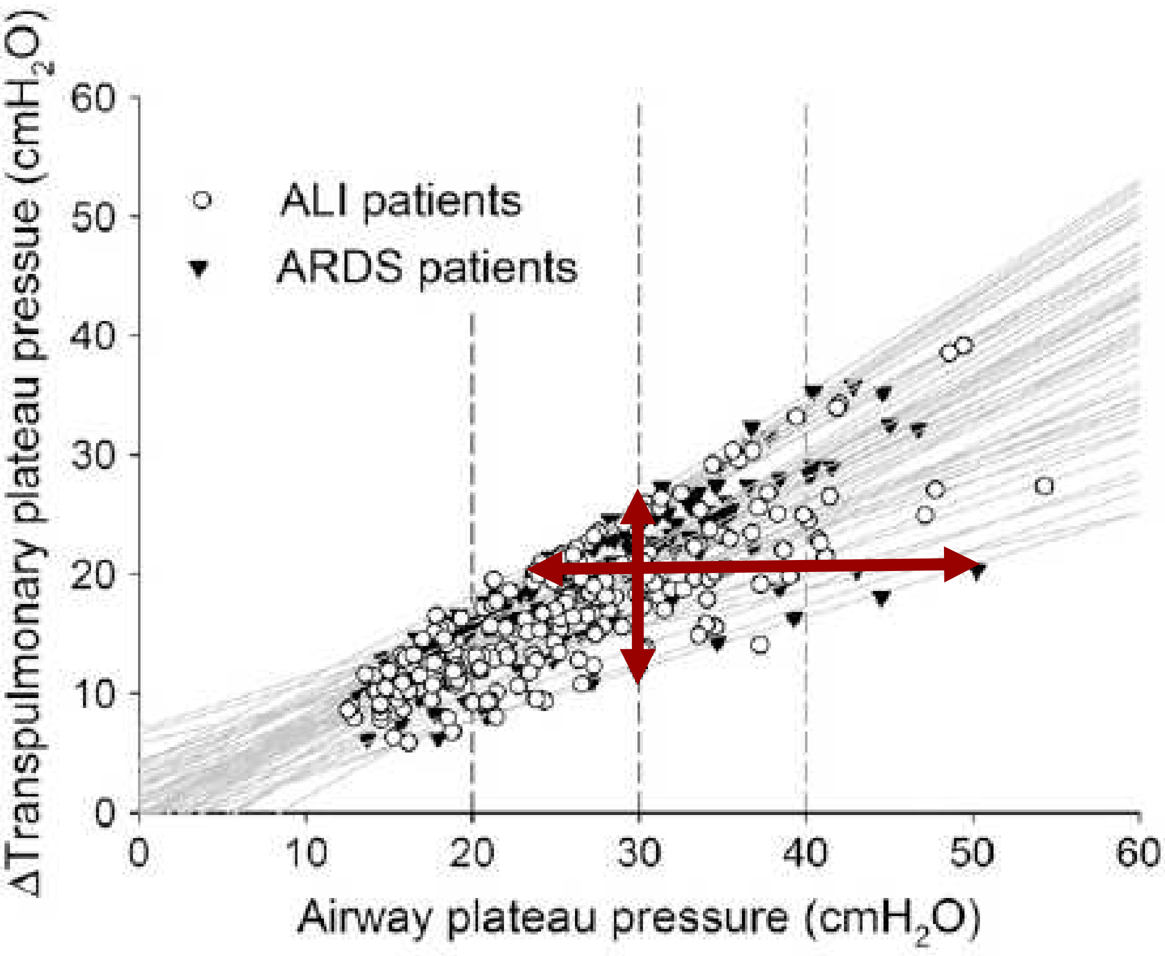
Other evidences for Pplat: MV international study group





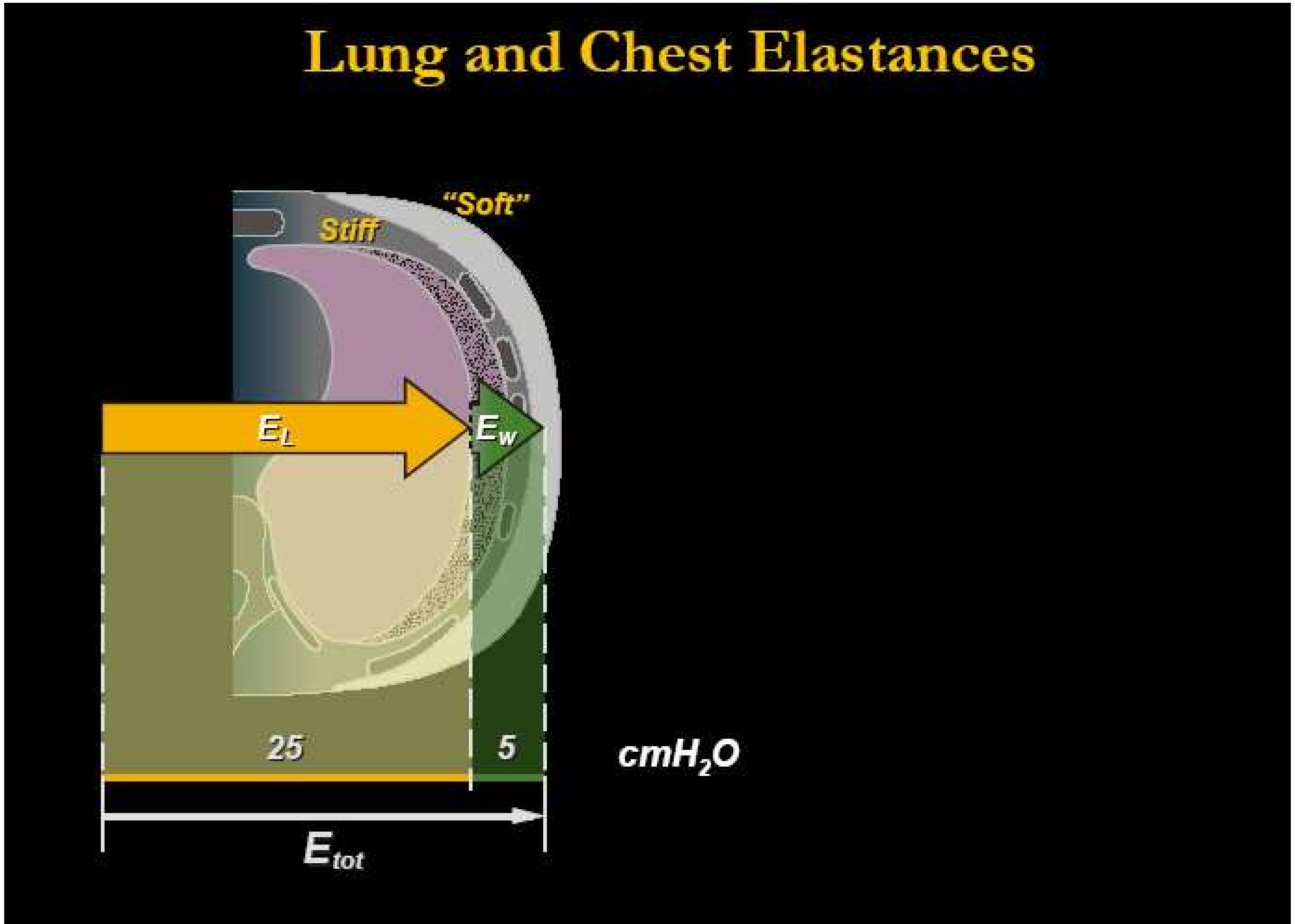
Fergusson CCM 2005

What's…Pplat?



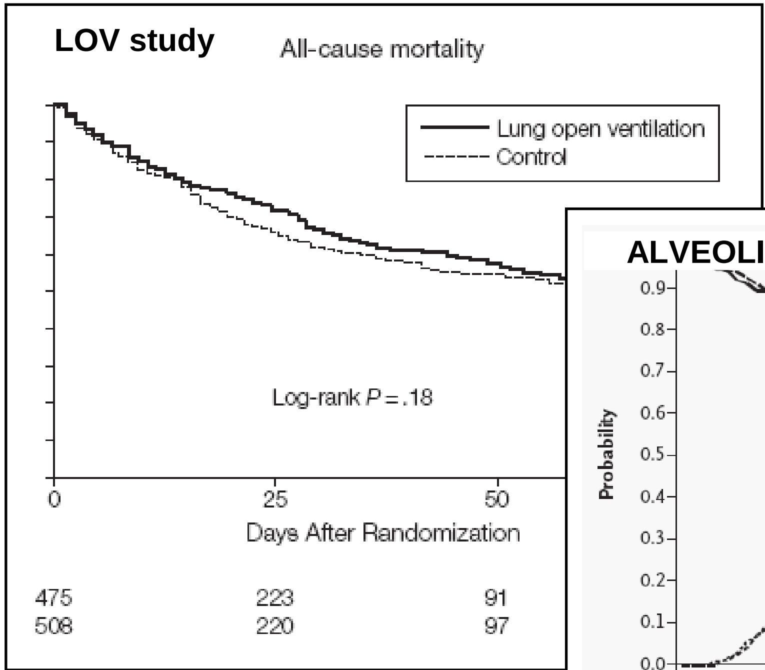
Chiumello AJRCCM 2008

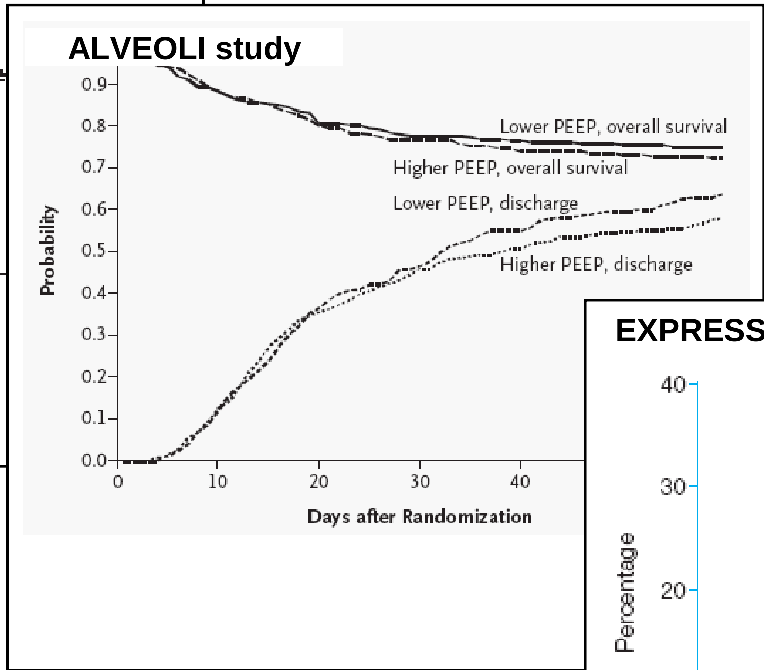
Pneumonitis is not Peritonitis…

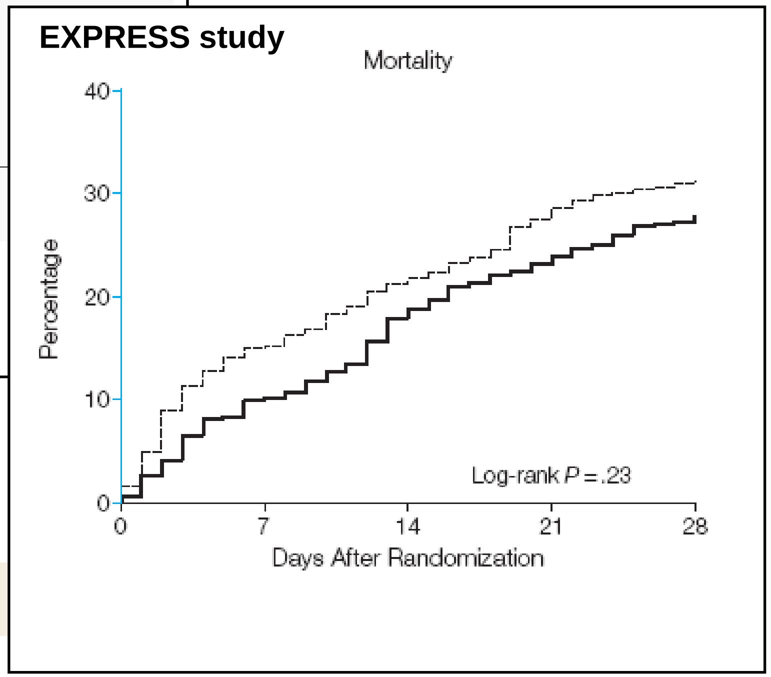


L Gattinoni 2003: Pneumonitis is not peritonitis…

What's the optimal PEEP ☹ ☹ ☹





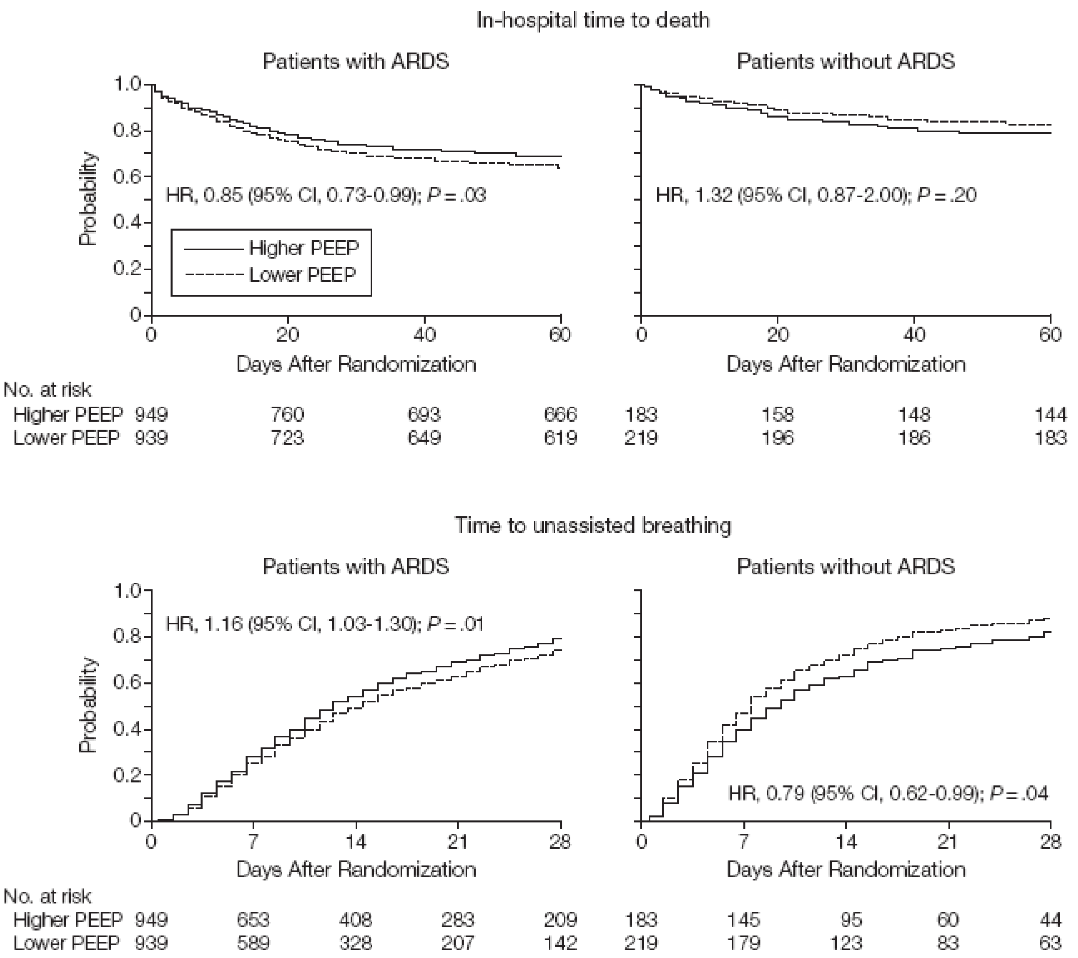


Mercat JAMA 2008, Meade JAMA 2008,

The NHL&B Institute ARDS Clinical Trials Network NEJM 2004

What's an ARDS ☺ ☺ ☺

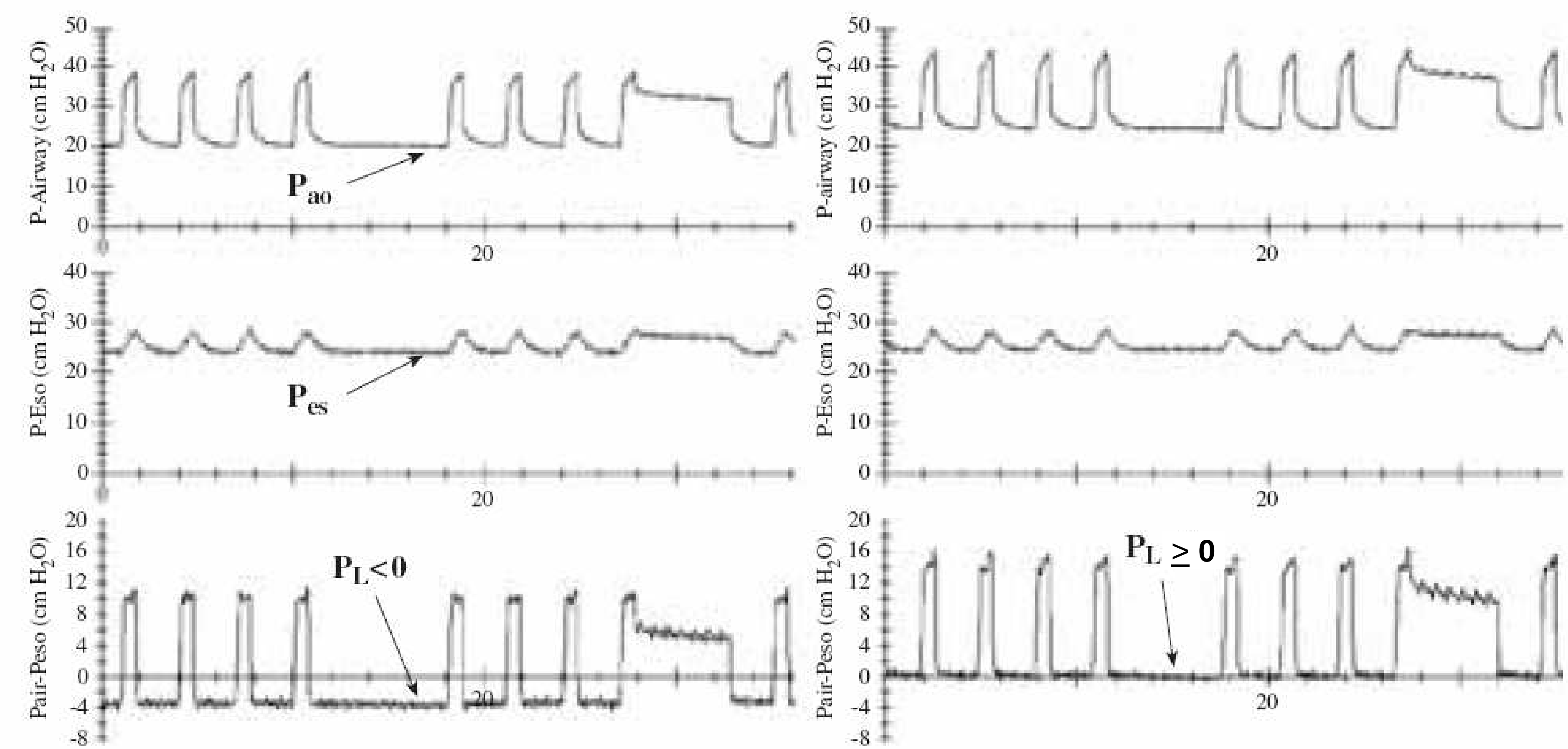
Figure 2. Time to Death in Hospital and Time to Unassisted Breathing for Higher and Lower Positive End-Expiratory Pressure (PEEP) Stratified by Presence of Acute Respiratory Distress Syndrome (ARDS) at Baseline



Briel JAMA 2010

$PEEP_{TL}$ *vs* $PEEP_{aw}$?

PEEP = 20 cmH20 **PEEP = 25 cmH20**



Sarge MA2009; Talmor NEJM 2008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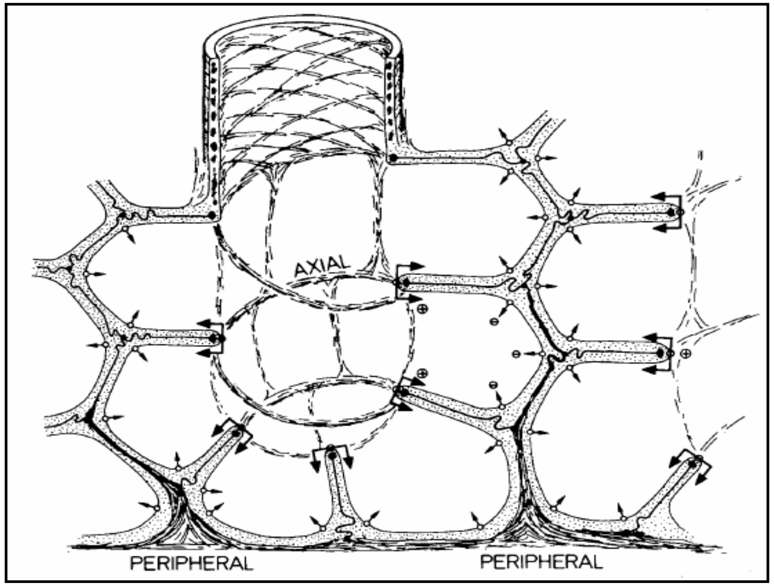
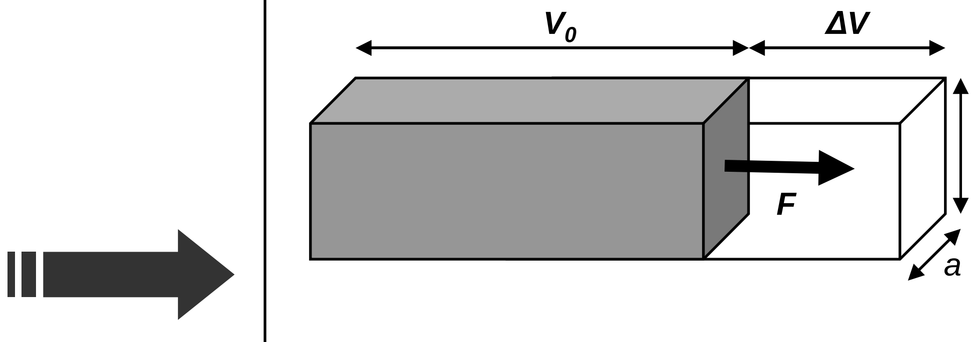
So what to do?

Stress & Strain: Definition



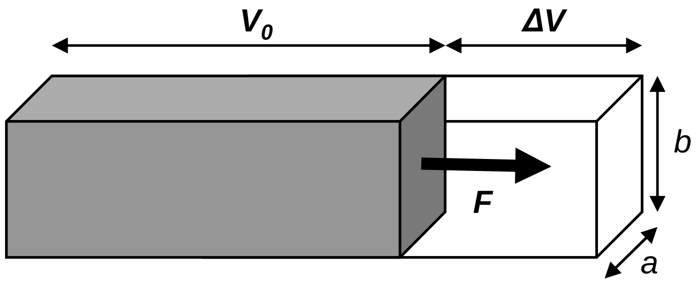


$$Stress = F^*(a^*b) = P_L$$

$$Strain = \Delta V/V_0$$

Weibel 1986; Gattinoni 2003

Strain



Stress = $F^*(a^*b)$ = P_L

Strain = $\Delta V/V_0$

$\Delta V/V_0$ = *Strain*

- ΔV = *tidal volume*
- V_0 = *FRC in healthy subject*
- $V_0 = FRC + V_{PEEP} + V_{PEEPi}$ during MV

Stress and Strain: so what?

1. To estimate P_L

- *Stress = k * Strain*
- *k = Stress/Strain = $P_L / \Delta V/V_0$ = Specific Elastance ($E_{L,s}$)*
- *Specific Elastance = 13 – 15 cmH2O*

$$P_L \simeq [13 - 15] * VT/FRC$$

Chiumello 2008, Gattinoni 2003

Stress and Strain: so what?

$$P_L \simeq [13 - 15] * VT/FRC$$

If FRC = 1500 mL and VT = 500 mL Then P_L = 15*(500/1500) = 5 cmH2O

If FRC = 1000 mL and VT = 800 mL Then P_L = 15*(800/1000) = 12 cmH2O

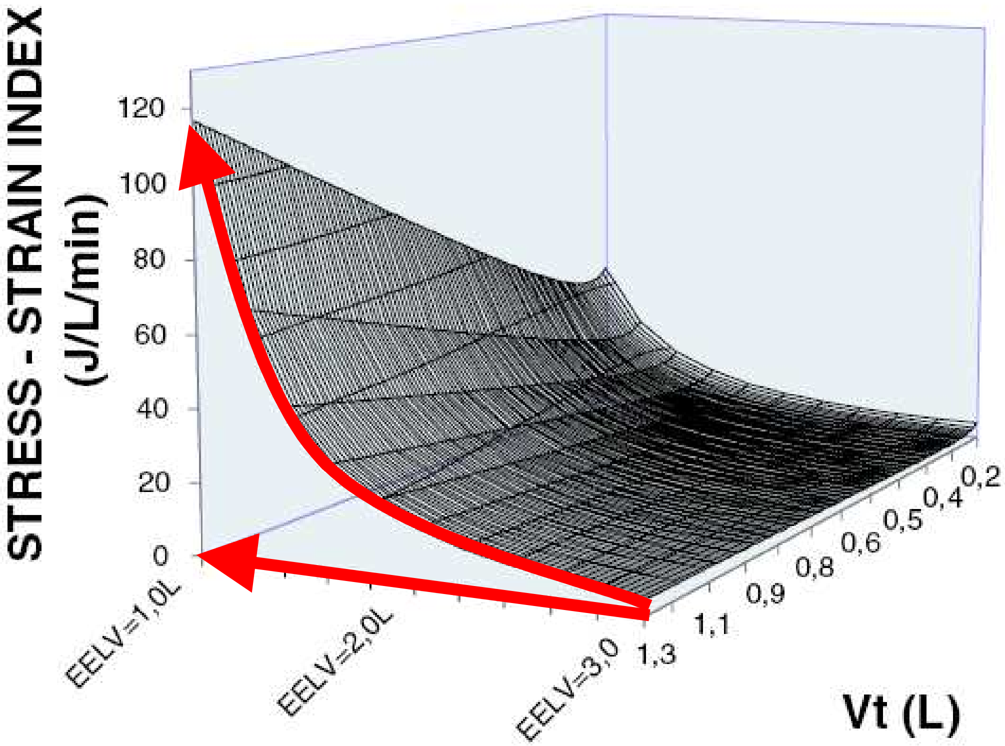
If FRC = 500 mL and VT = 800 mL Then P_L = 15*(800/500) = 24 cmH2O

Stress and Strain: so what?

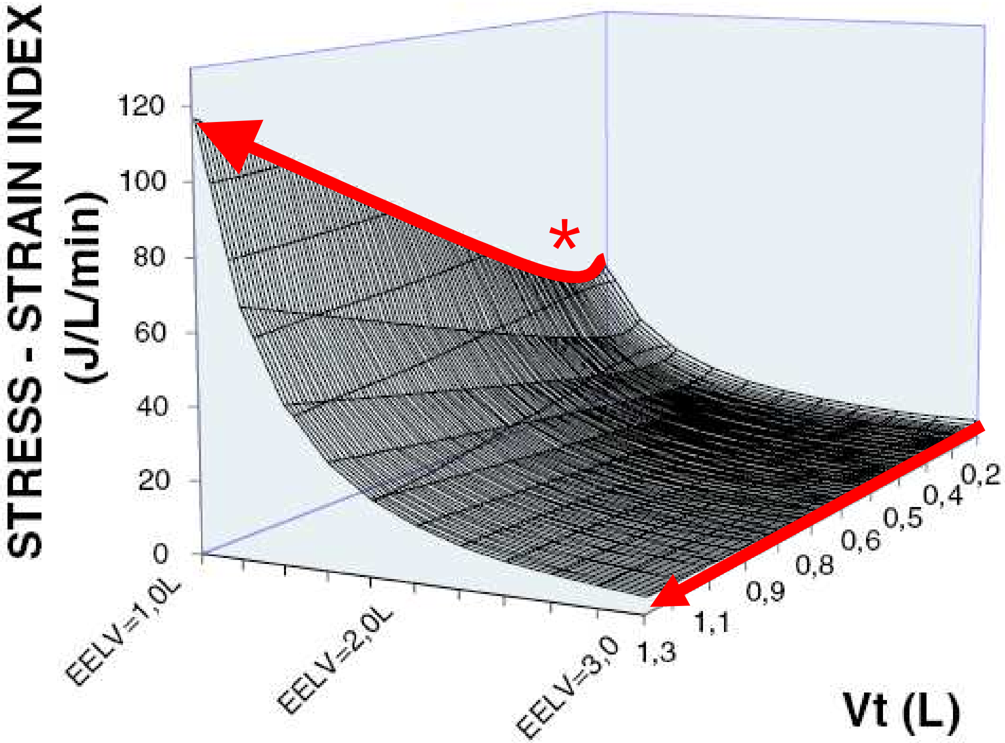
2. To find an « optimal » VT and RR

- *Stress Strain index (SSI) = Stress * Strain * RR*
- *SSI =* P_L * $\Delta V/V_0$ * *RR*
- *Optimal ΔV & RR to minimize the SSI (mSSI)*

Stress-Strain Index ⇧ when EELV ⇩



Stress-Strain Index ⇧ when VT ⇧



* VT @ mSSI = 2 * V_d

RR @ mSSI = MV/V_d

Stress and Strain: exemple VT

$$VT\ @\ mSSI = 2 * V_d$$

PBW = 70 Kg and V_{aw} = 2.2 mL/kg PBW = 154 mL

Then VT@mSSI = 308 mL (4.4 mL/kg PBW)

Chiumello 2008, Gattinoni 2003, Brunner & Wysocki ICM 2009

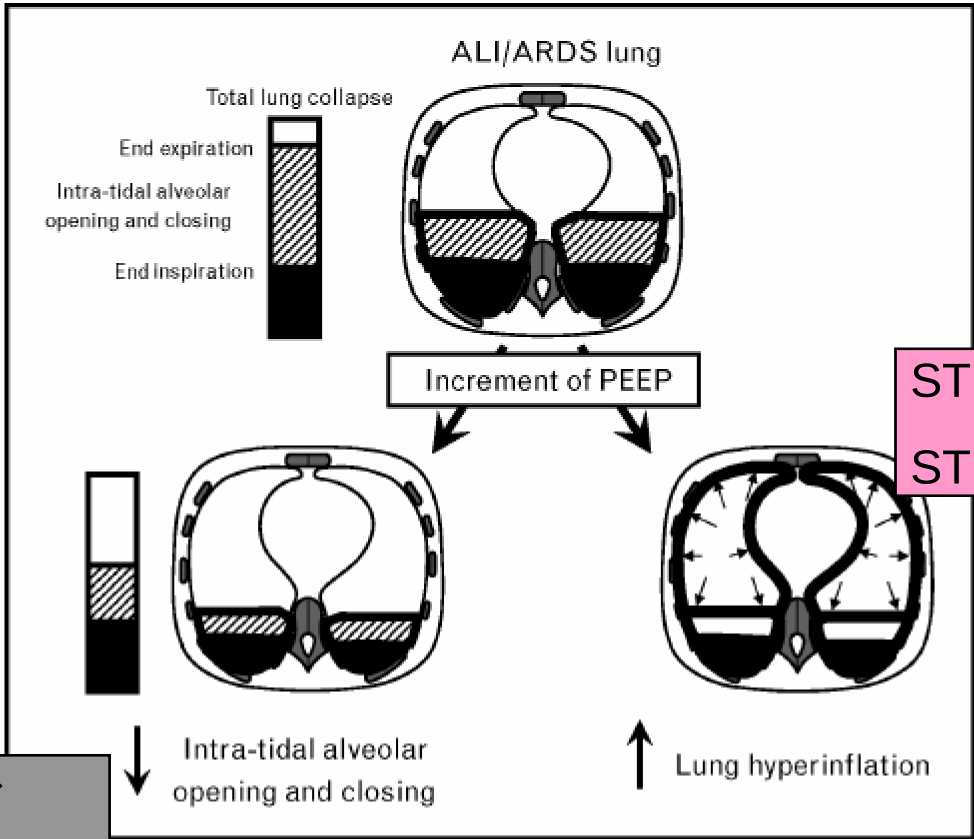
Stress and Strain: exemple RR

$$RR\ @\ mSSI = MV/V_d$$

PBW: 70 kg PBW and VM = 100 mL/kg/min = 7000 mL/min

RR = 7000/154 = 45 breath/min

Et PEEP alors?



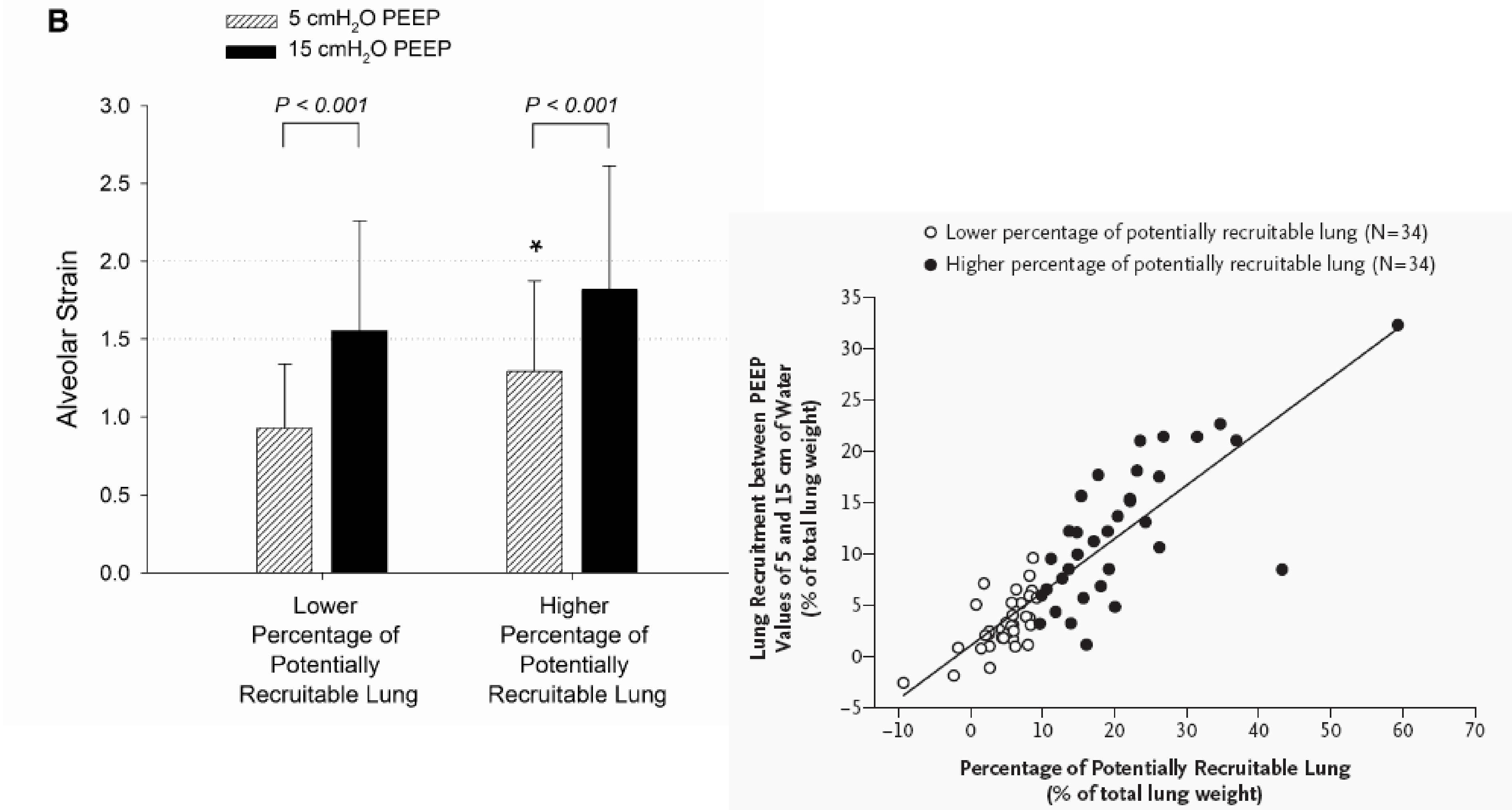
STRESS ⇔ or ⇧

STRAIN ⇧

STRESS ⇧ or ⇔

STRAIN ⇩

Et PEEP alors?

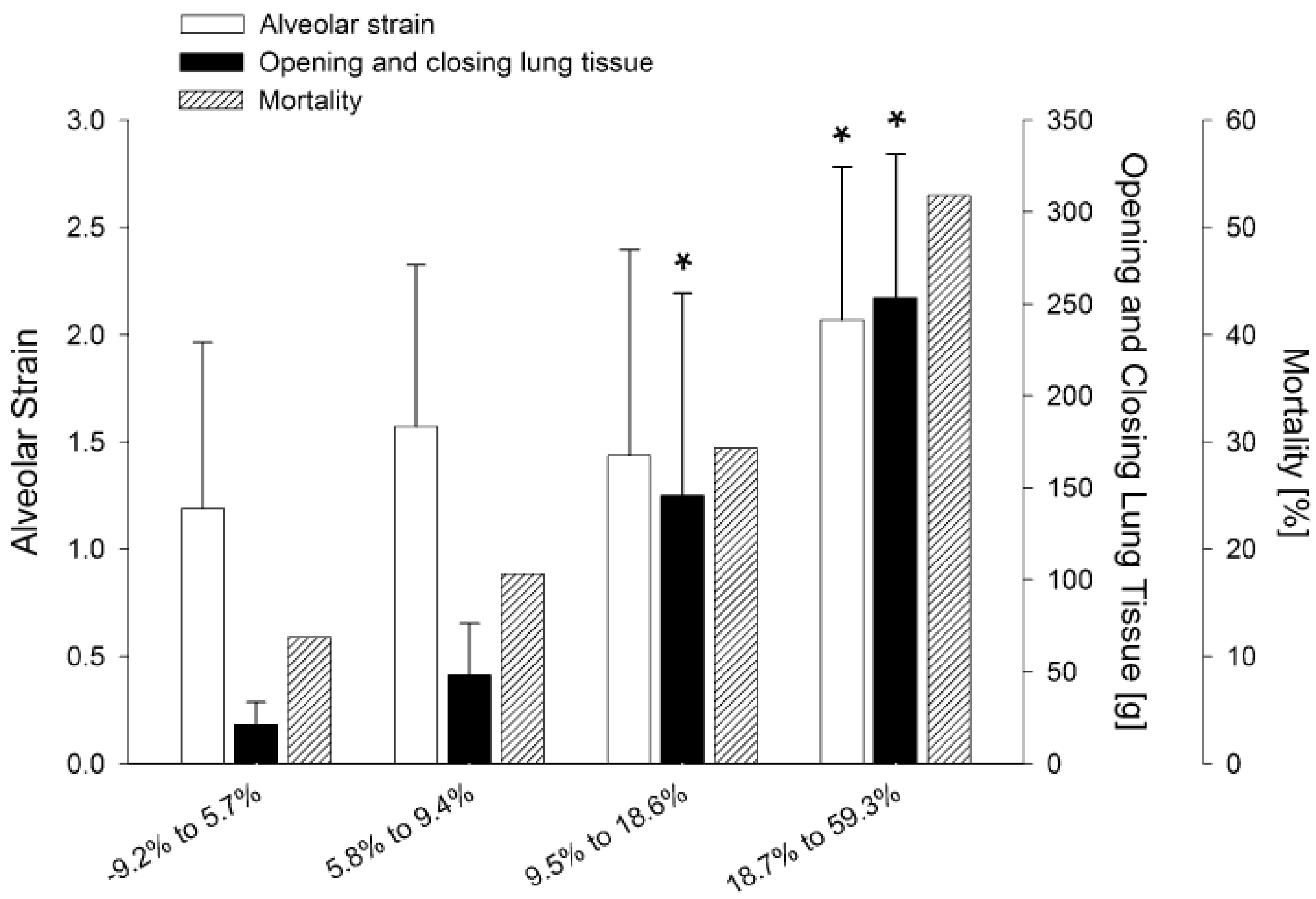


Caironi, AJRCCM 2010 – Gattinoni NEJM 2006

« what to do with VT – Pplat – PEEP…»

- VT & Paw: inadequate surrogates for VILI
- Minimizing Stress - Strain could be a strategy
- PEEP on Stress – Strain depends on the recrutability
- ⇧FRC is the most important to reduce Stress –Strain
- “Theory” is not enough...

Et PEEP alors?



Caironi, AJRCCM 2009