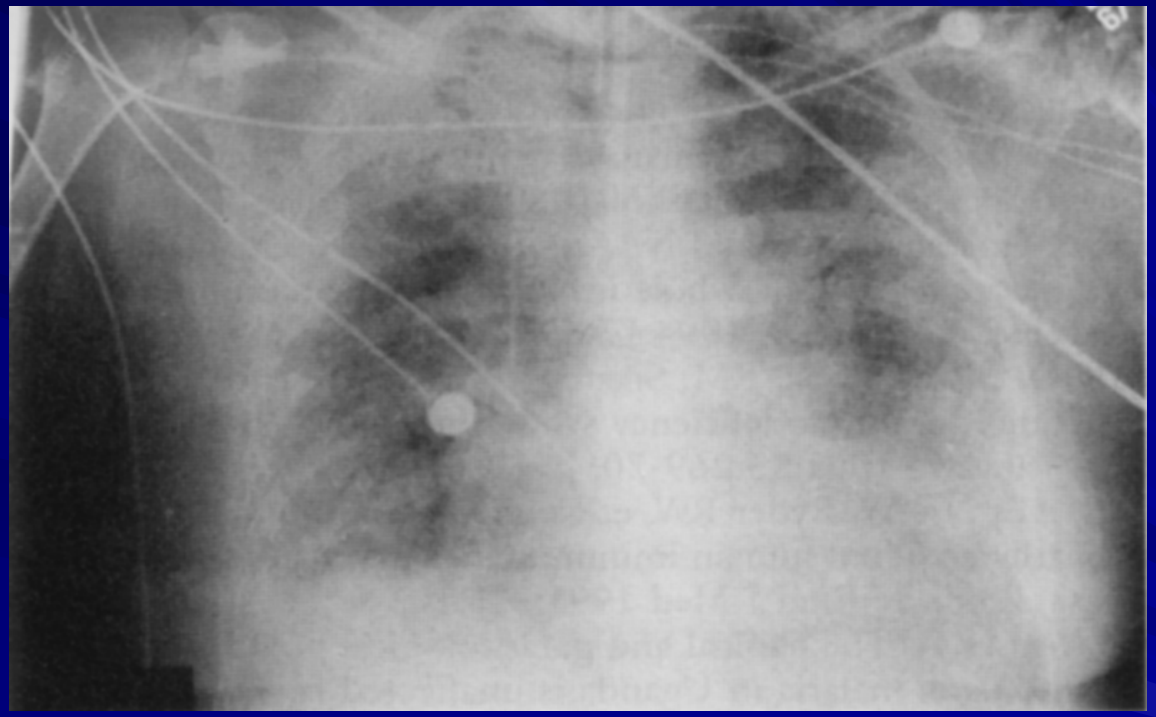
Mechanical Ventilation in ARDS



Dr C K Ching

23 August 2011

Outline

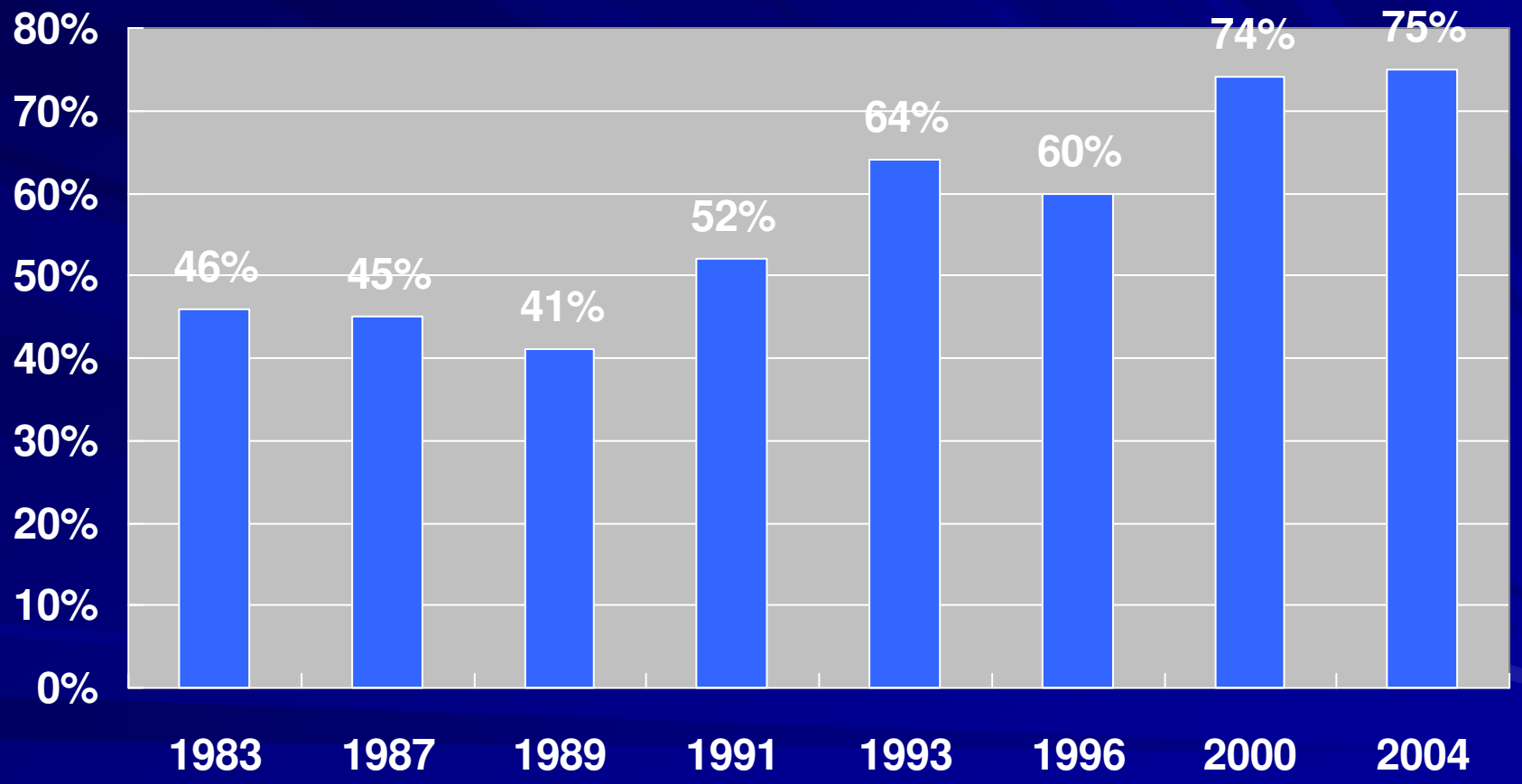
- Introduction
- Ventilator induced lung injury
- Low Tidal Volume Ventilation
- High PEEP and Alveolar Recruitment
- Prone Positioning
- Alternative modes of mechanical ventilation
- Conclusion

CLINICAL CRITERIA OF ARDS

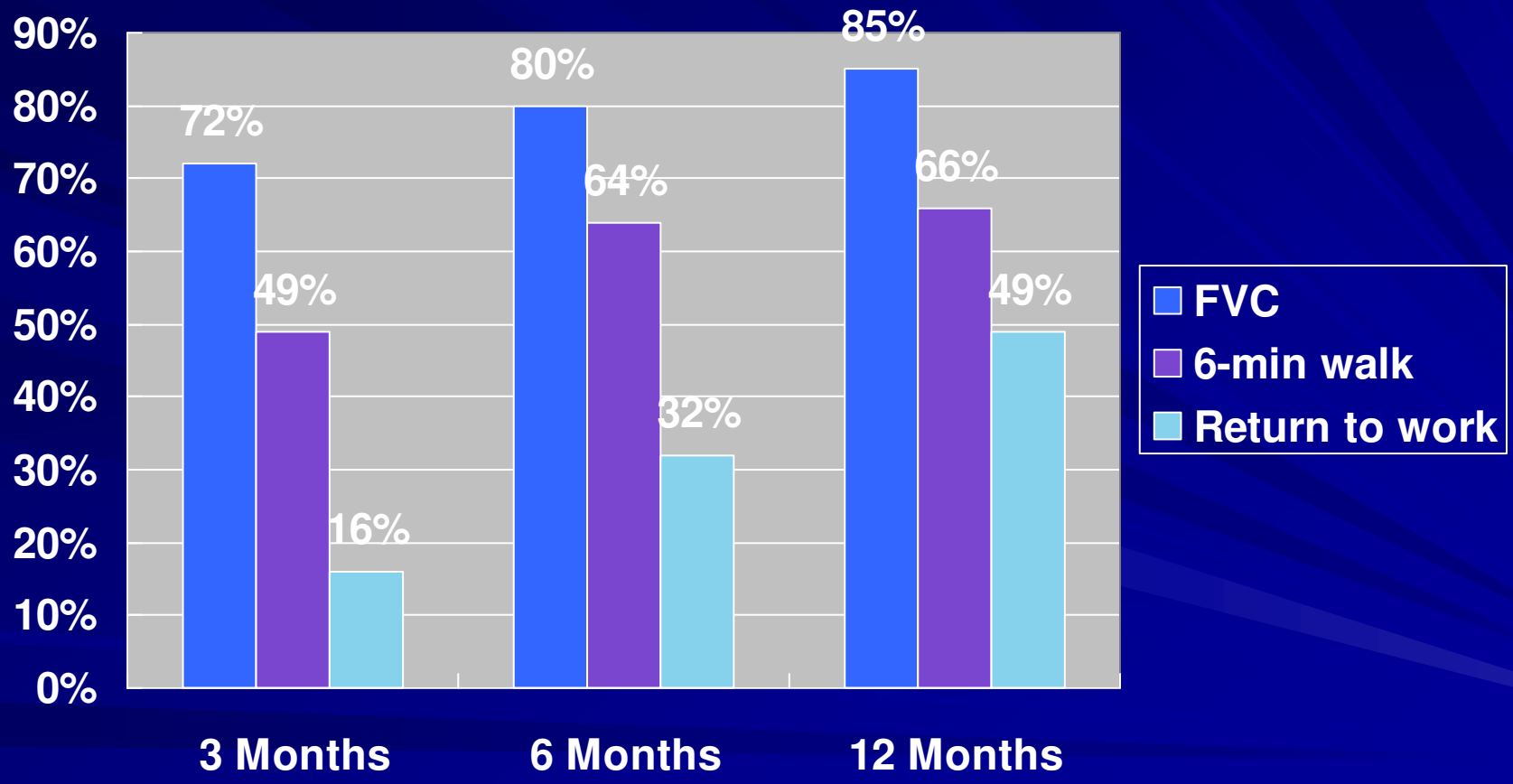
- Bilateral infiltrates on the chest x-ray
- PaO2/FiO2 ratio <200
- Pulmonary artery occlusion pressure <18 mmHg or no evidence of left atrial hypertension
- One or more underlying disease process known to be associated with the ARDS

American European Consensus Conference
AJRCCM 1994;149:818

Survival Rates for ARDS



Long-term disability in surviving ARDS patients



N Engl J Med 2003; 348:683-693

Objectives of Ventilation
ACCP Standards (Slutsky, 1993)

CLINICAL

1. Reverse hypoxemia
2. Reverse respiratory acidosis
3. Relieve respiratory distress
4. Prevent or reverse atelectasis
5. Reverse respiratory muscle fatigue

PRIMARY

Avoid Iatrogenic Lung Injury

Disease-Oriented Ventilation Strategies

Objective:

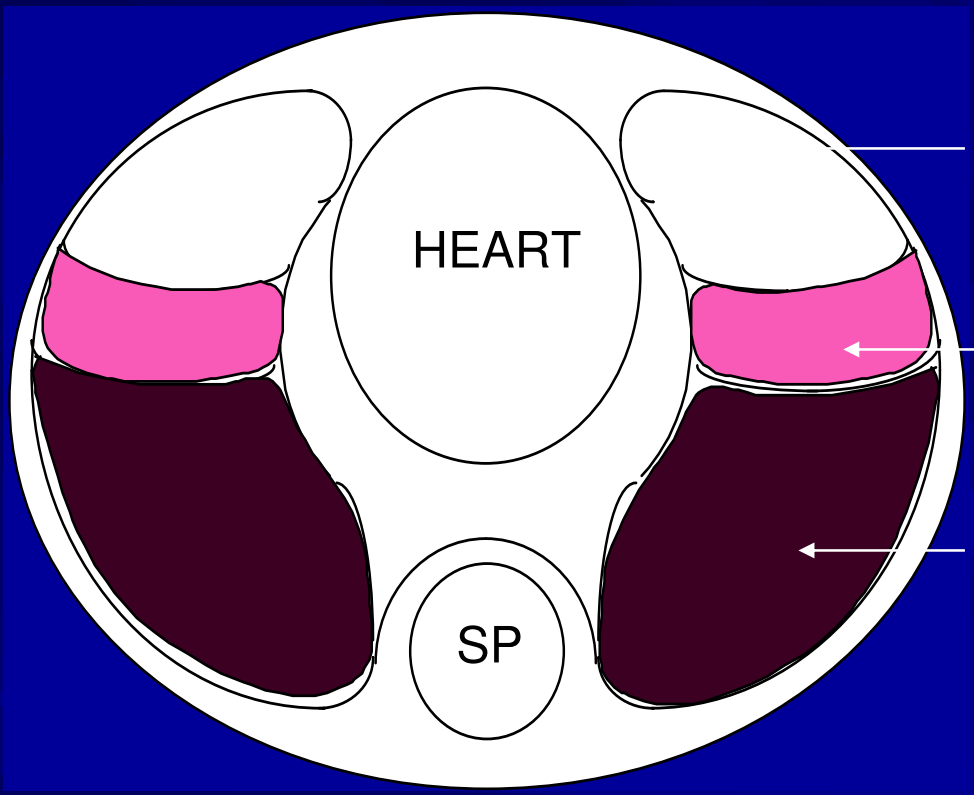
- To avoid the adverse effects of mechanical ventilation:
  - Oxygen toxicity
  - Barotrauma
  - Volutrauma
  - Shear injury
  - Biotrauma
- Tailor ventilator settings specific to the pathophysiology of the patient.

Respiratory Failure Pathology

- OBSTRUCTIVE (Resistance)
  - Asthma
  - Bronchitis
  - Emphysema
  - Smoke Inhalation
  - Small ET tube
- RESTRICTIVE (Compliance)
  - ARDS
  - Pneumonias
  - CHF
  - Pneumothorax

Neuromuscular
Abdominal distension
Chestwall deformity

ARDS - PATHOLOGY



GATTINONI - 3 ZONES

OVERINFLATED, "DRY", "BABY LUNG"

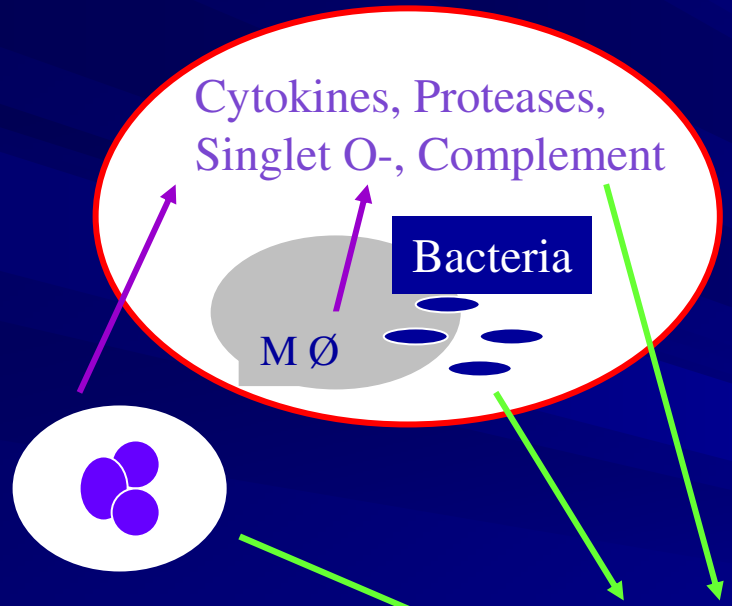
WET, PEEP-RECRUITABLE ZONE

COLLAPSED / CONSOLIDATED ZONE

Gattinoni L. J Thorac Imag 1986; 1(3): 25

MECHANICAL VENTILATION

Biochemical Injury



Biophysical Injury

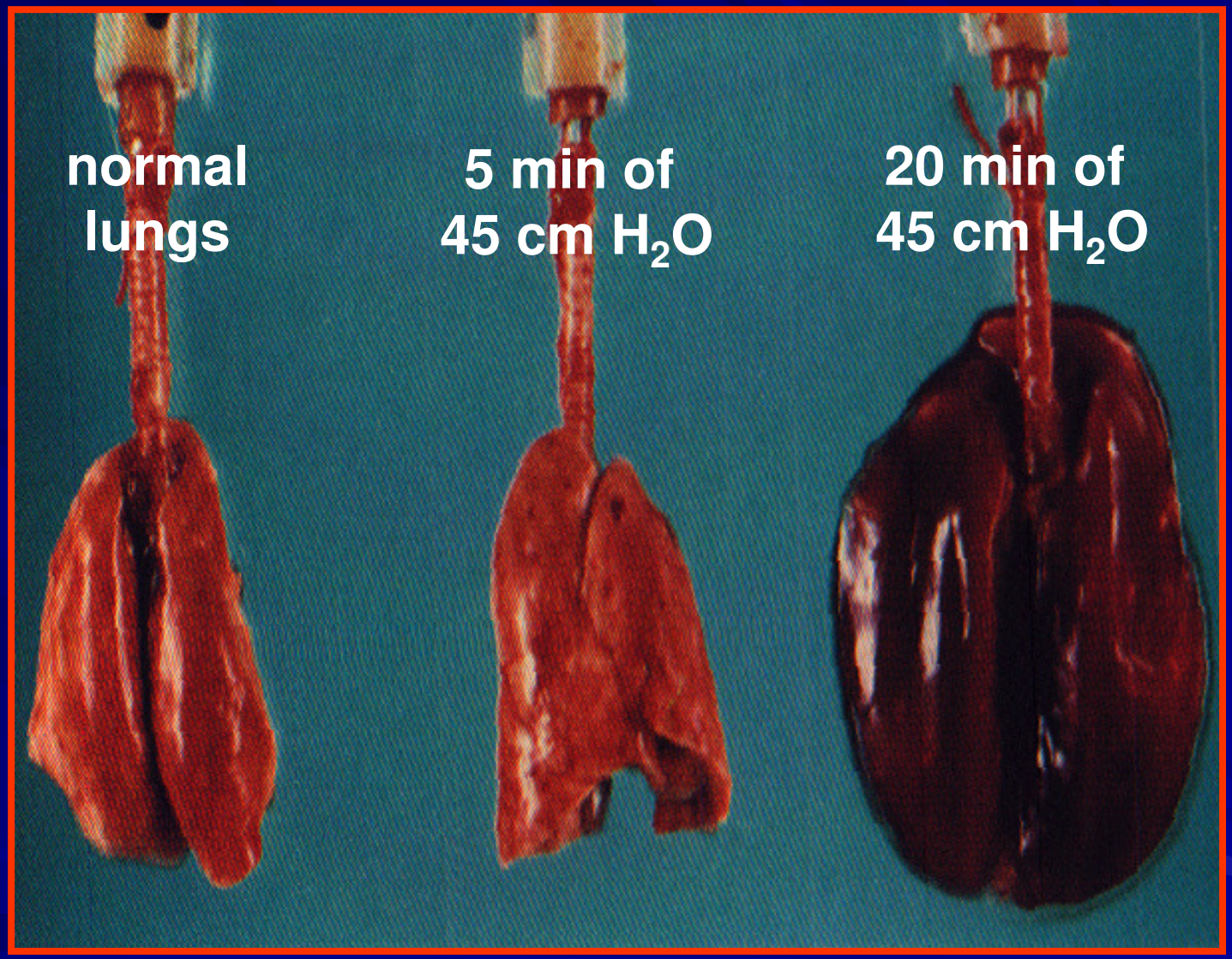
- Shear
- Overdistension
- ↑ Intrathoracic Pressure

- ↑ Alveolar-Capillary Permeability
- ↓ Cardiac Output
- ↓ Organ Perfusion

Distal Organs

- Tissue injury 2 to inflammatory mediators/cells
- Impaired oxygen delivery
- Bacteremia

MSOF (Slutsky & Tremblay, 1998)



Dreyfuss, Am J Respir Crit Care Med 1998;157:294-323

Fu et al, J Appl Physiol 1992; 73:123-133

VILI Prevention

- Limit intraparenchymal stress/strain maldistribution (prone position and PEEP)
- Avoid excessive stress to lung parenchyma (transpulmonary pressure)

L Gattinoni, 2003

Low Mortality associated with Low Volume Pressure Limited Ventilation with Permissive Hypercapnea in ARDS

[Hickling et al, 1990 Int Care Med]

- 70 patients with ARDS
- Patients with low lung compliance:
  - PIP limited to 30 cmH2O
  - V_T as low as 350 mL (5 mL/kg)
- Volume ventilation (SIMV), high PEEP, spontaneous breathing; no PSV resulted in high RR and higher $PaCO_2$

OUTCOMES: Actual Mortality 16% vs. Predicted Mortality 39.6%

No Pneumothoracies

Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome

[Amato et al, 1998 N Engl J Med]

- 53 Patients with early ARDS
- Randomly assigned to either Conventional or Protective ventilation strategy
- All patients were treated with identical hemodynamic and general support.

	Conventional Ventilation	Protective-ventilation strategy
Vt	12ml/kg	< 6 mL/kg
PEEP	Lowest PEEP to FiO2	Set from the lower inflection point PV curve
PCO2	35 - 45 mmHg	Permissive Hypercapnea
PPLAT	38 - 46 cm H2O	Limited to 20 cm above PEEP

Results

	Conventional	Lung Protection
Mortality	71%	38%
Barotrauma	43%	7%
Weaning	29%	66%

Protective Lung Strategy - Low Tidal Volume, Low Lung Pressure ARDS Network Study

- Large NHLBI study results (New Engl J Med 2000)
  - 10 centers, 24 hospitals, 800 ARDS patients
  - 2 ventilator strategies tested - 12ml/kg & 6ml/kg
  - 25% less mortality in the low volume category
- Best strategy - Volume or Pressure Ventilation?
  - low volume settings adjusted to maintain plateau pressures between 25 - 30 cm H20 simulating PCV

NIH NHLBI ARDS Clinical Trials Network
Mechanical Ventilation Protocol Summary
www.hedwig.mgh.harvard.edu

Ventilation strategies and outcomes of the ALI/ARDS : a Meta-analysis

Putensen C, Theuerkauf N, Zinserling J, Wrigge H, Pelosi P

Ann Intern Med 2009; 151: 566-576

Hospital Mortality: Lower vs Higher V_T at the same PEEP

	Patients,n	Low VT Similar PEEP	High VT Similar PEEP	Odds ratio (95% CI)
Brower, 1998	52	13/26	12/26	1.17(0.39-3.47)
Brower, 2000	861	134/432	171/429	0.68(0.51-0.90)
Stewart, 1998	120	30/60	28/60	1.14(0.56-2.34)
Summary				0.75(0.58-0.96)
				P<0.02; I^2 =18.3

Ventilation strategies and outcomes of the ALI/ARDS : a Meta-analysis

Putensen C, Theuerkauf N, Zinserling J, Wrigge H, Pelosi P

Ann Intern Med 2009; 151: 566-576

- Low V_T ventilation did not improve outcome when higher V_T ventilation resulted in P_{ei} less or equal to 30 cm H_2O.
- Low V_T ventilation was associated with greater use of NMBAs
- Low V_T ventilation may not be beneficial if:

- pH<7.20 (administering sodium bicarbonate, increasing V_T , ECMO)

- side effects (hypercapnia/respiratory acidosis) are contraindicated

Setting PEEP

- Aims
  - Prevent alveolar collapse
    - Reduce shear injury
    - Improve oxygenation

Lung Recruitment Maneuver

- Prolonged high alveolar pressure to recruit collapsed lung units
- Method used at Massachusett General Hospital, Boston

  PEEP 30 - 40 cm H_2O

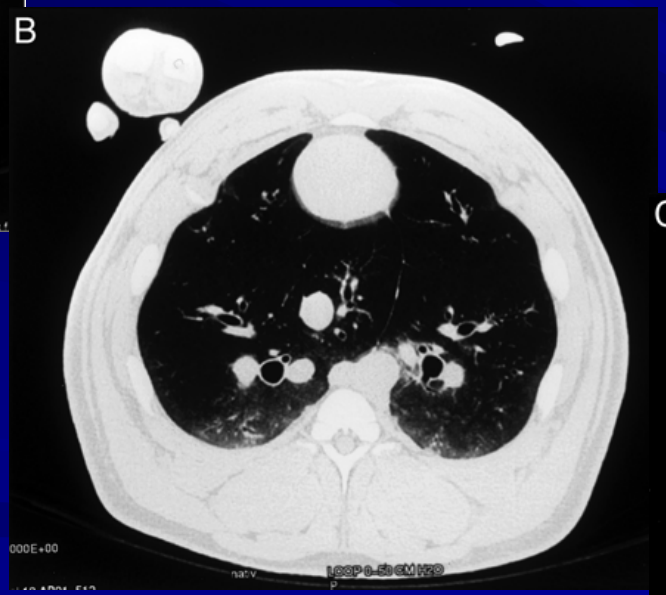
  ± PC of 20 cm H_2O, Rate 10/min; I:E 1:1

  1/2 - 2 min

Recruitment Maneuver

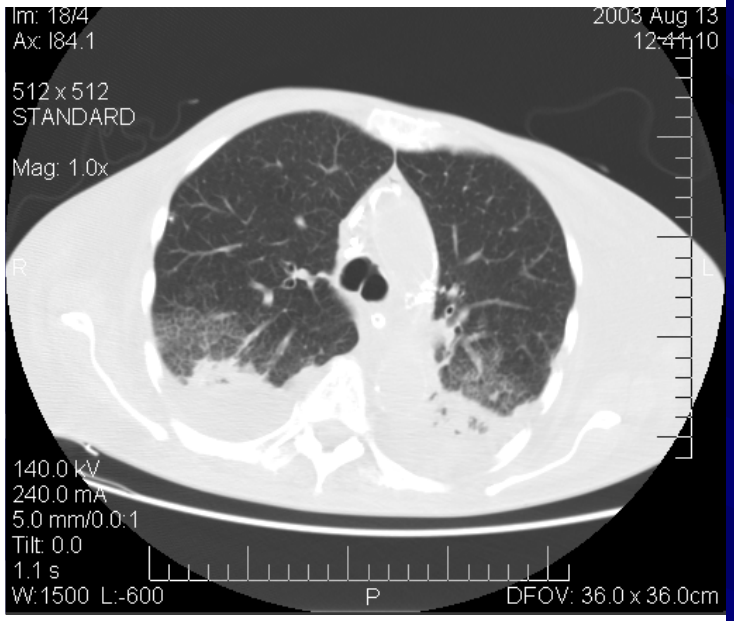
0 cmH2O

3 sec
CPAP 50 cmH2O

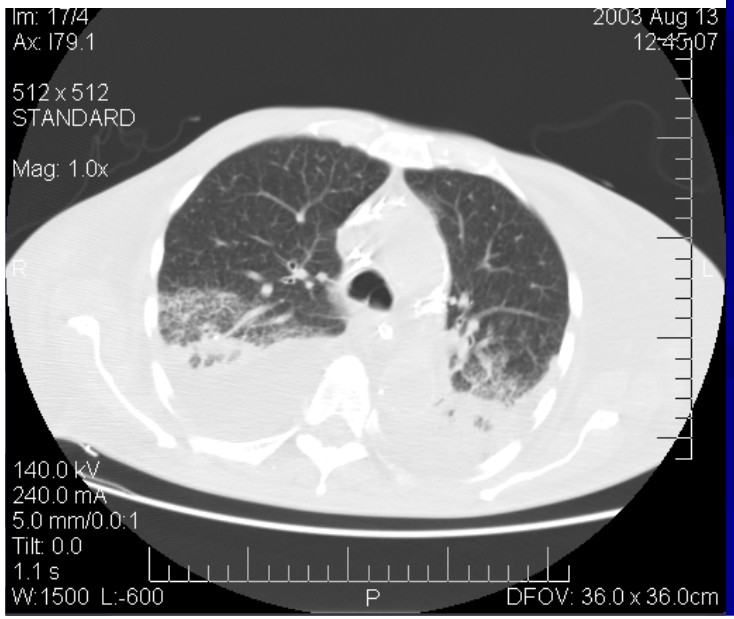


31 sec
CPAP 50 cmH2O

Paw 45cmH_2O



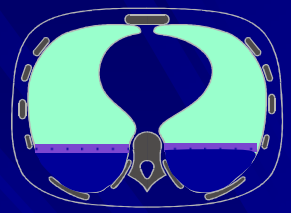
Peep 5 cmH_2O



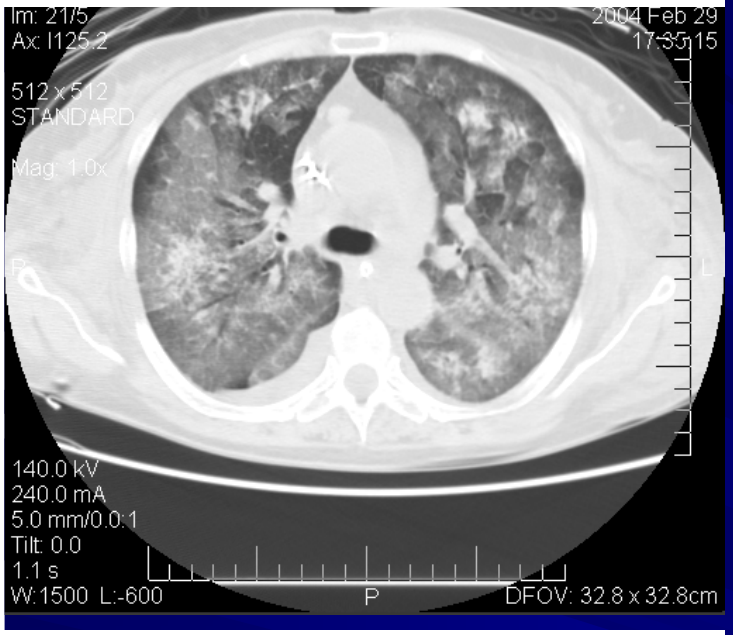
Gattinoni et al NEJM 2006, 354(17):1775-86

Non recruiter

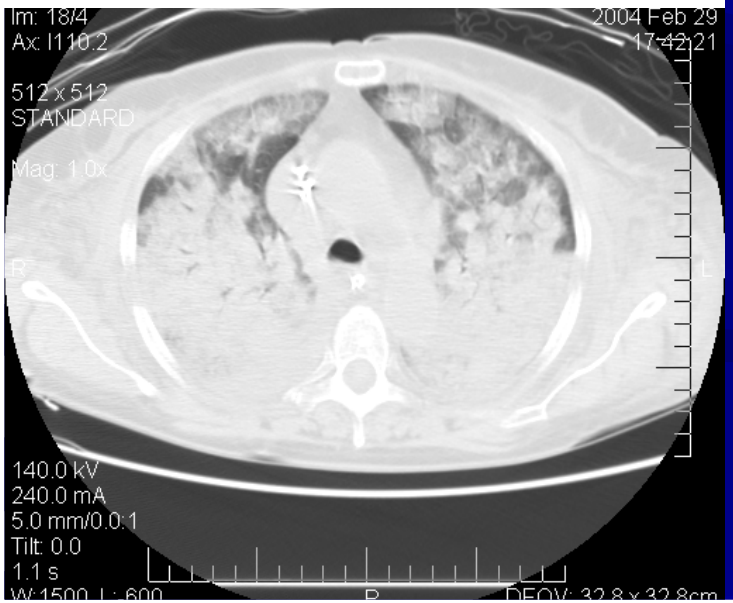
Weight (grams)



Paw 45cmH_2O

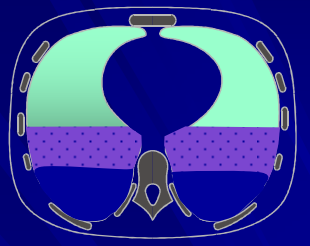


Peep 5 cmH_2O



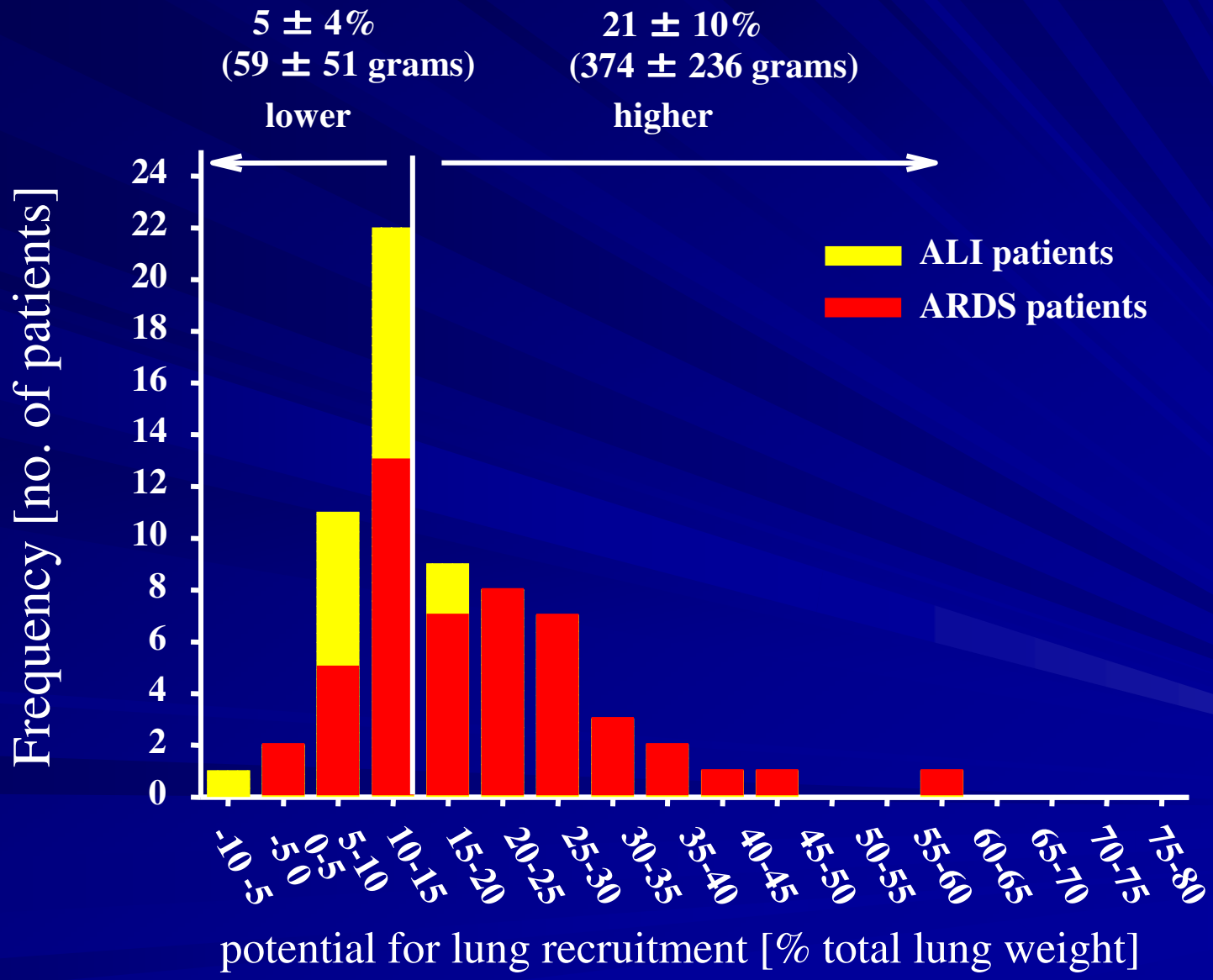
Gattinoni et al NEJM 2006, 354(17):1775-86

Recruiter



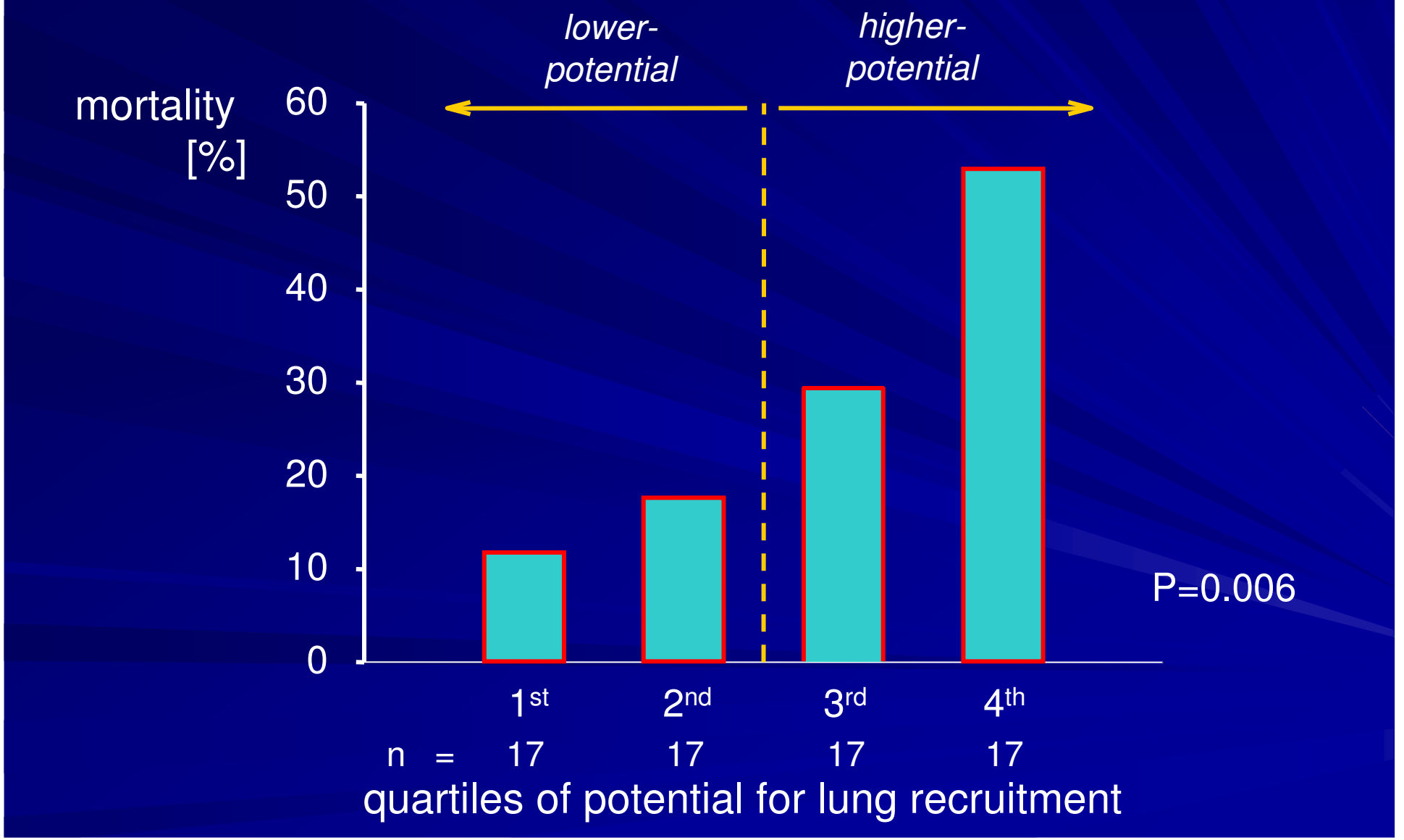
Potential for lung recruitment

Gattinoni et al NEJM 2006, 354(17):1775-86



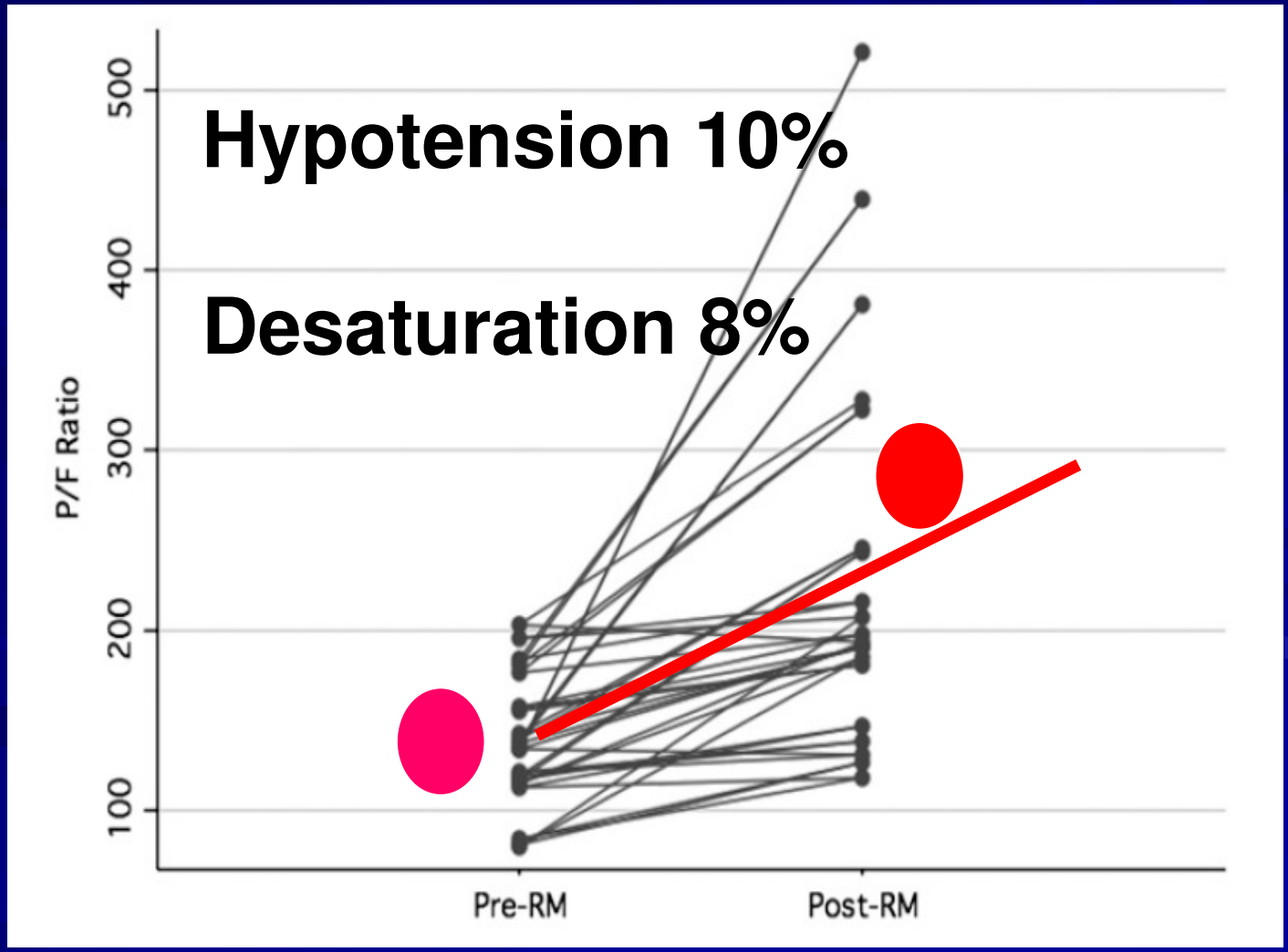
Mortality at ICU-discharge

Gattinoni et al NEJM 2006, 354(17):1775-86



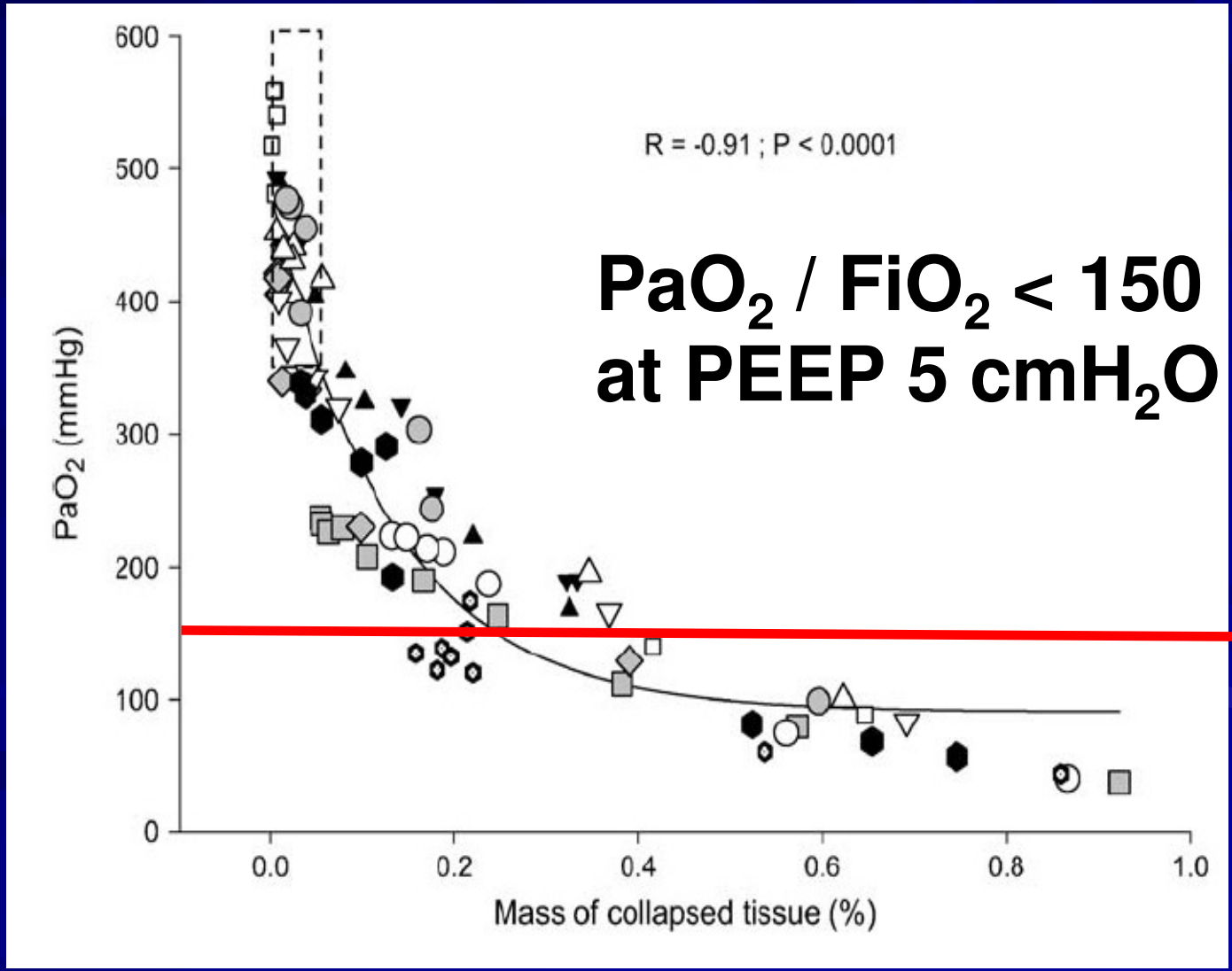
Recruitment Maneuvers for Acute Lung Injury: A Systematic Review

Fan E et al. Am J Respir Crit Care Med Vol 178. pp 1156–1163, 2008



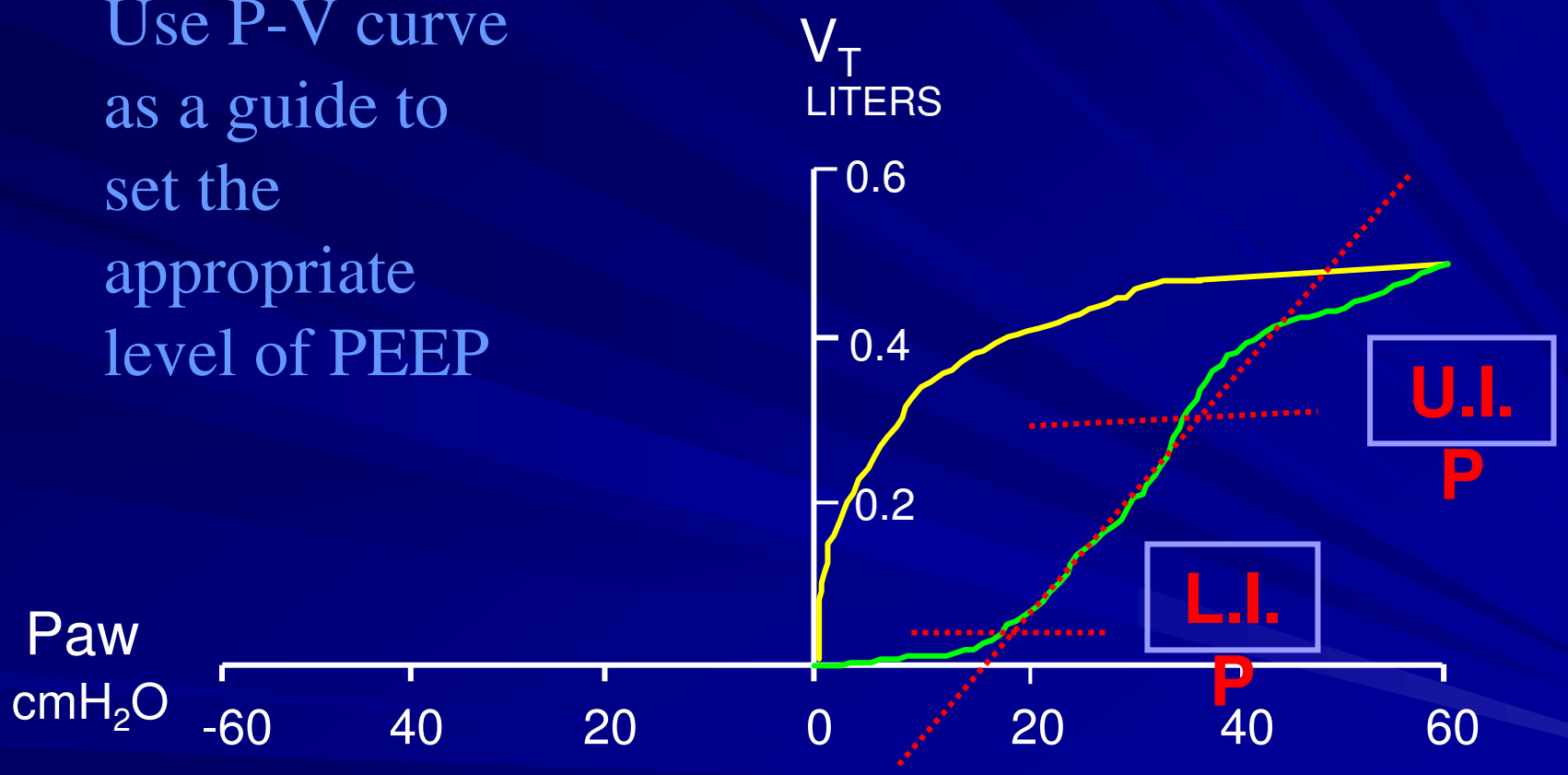
Oxygenation and collapsed tissue

Borges et al Am J Respir Crit Care Med 174; 268-278, 2006



Lung Compliance: Pressure-Volume Curve

Use P-V curve as a guide to set the appropriate level of PEEP

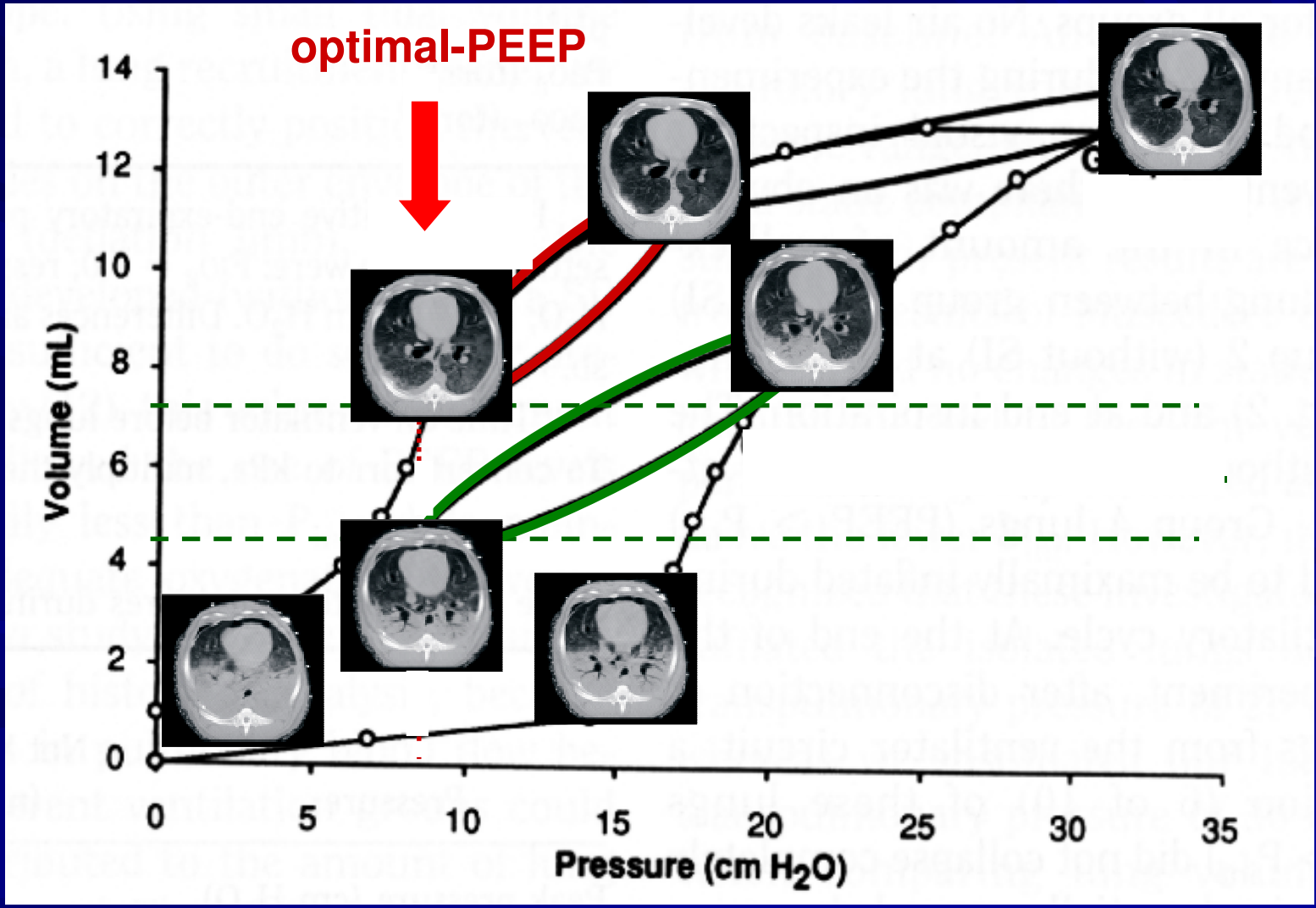


Setting PEEP

- First maximally re-expand consolidated areas (recruitment manoeuvre)
- Then perform decremental PEEP trial

The concept of PEEP and Recruitment

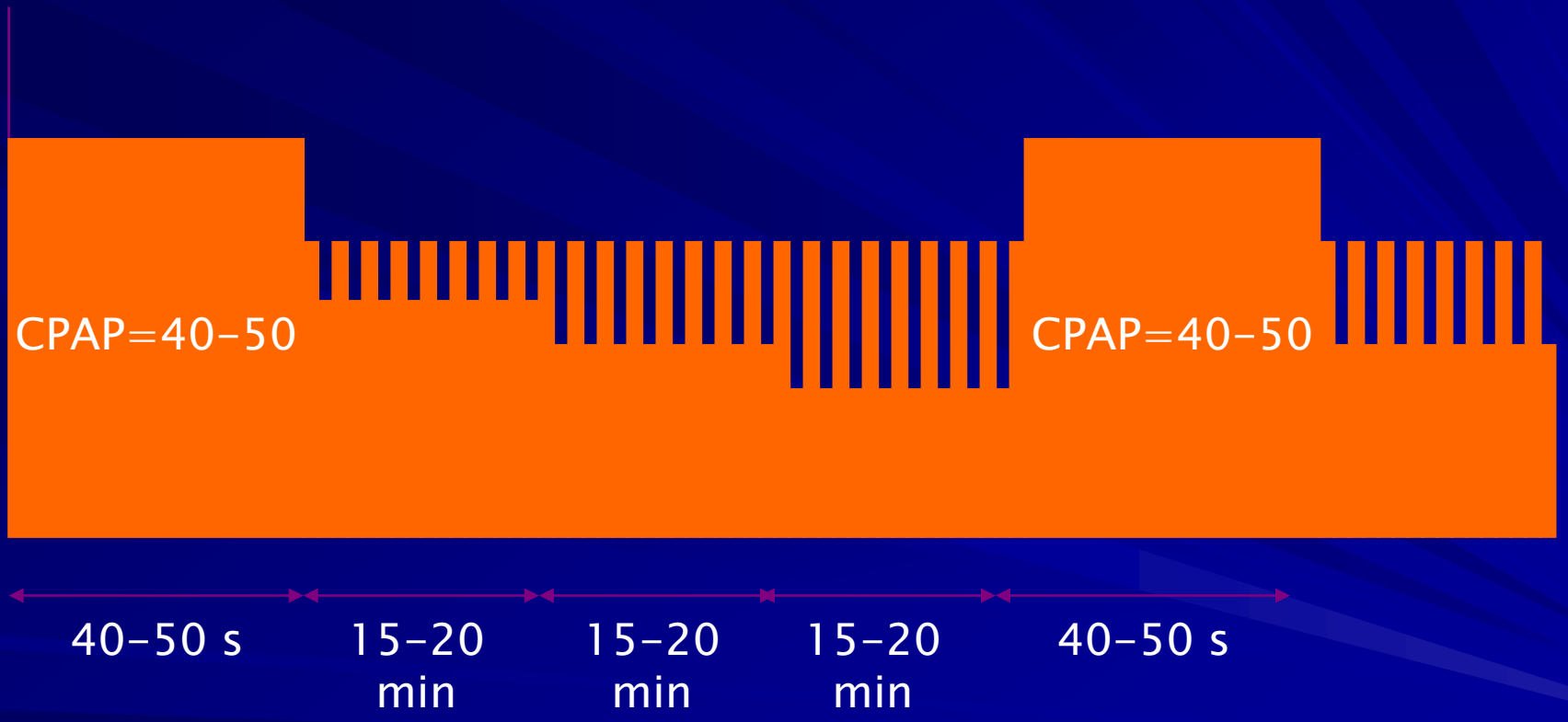
Pelosi P et al. Crit Care. 2010 Mar 9;14(2):210-218



Setting PEEP

- Find PEEP that results in greatest lung compliance and oxygenation
- Should represent optimal balance between re-expansion and over-distension

Putting it together



The National Heart Lung and Blood Institute ARDS Clinical Trials Network. Higher versus lower positive end-expiratory pressures in patients with the acute respiratory distress syndrome.

N Engl J Med 2004; 351:327-336

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

* Complete ventilator procedures and eligibility criteria are listed in the Supplementary Appendix (available with the full text of this article at www.nejm.org) and at www.ardsnet.org. PaO_2 denotes partial pressure of arterial oxygen, SpO_2 oxyhemoglobin saturation as measured by pulse oximetry, FiO_2 fraction of inspired oxygen, and PEEP positive end-expiratory pressure.

† In both study groups, additional increases in PEEP to 34 cm of water were allowed but not required after the FiO_2 had been increased

Table 4. Main Outcome Variables.*

Outcome	Lower-PEEP Group	Higher-PEEP Group	P Value
Death before discharge home (%)†			
Unadjusted	24.9	27.5	0.48
Adjusted for differences in baseline covariates	27.5	25.1	0.47
Breathing without assistance by day 28 (%)	72.8	72.3	0.89
No. of ventilator-free days from day 1 to day 28‡	14.5±10.4	13.8±10.6	0.50
No. of days not spent in intensive care unit from day 1 to day 28	12.2±10.4	12.3±10.3	0.83
Barotrauma (%)§	10	11	0.51
No. of days without failure of circulatory, coagulation, hepatic, and renal organs from day 1 to day 28	16±11	16±11	0.82

* Plus–minus values are means ±SD.

† The primary outcome measure was the proportion of patients who died before they were discharged home while breathing without assistance. Patients who were in health care facilities at 60 days were considered to have been discharged home while breathing without assistance.

‡ The number of ventilator-free days is the mean number of days from day 1 to day 28 on which patients had been breathing without assistance for at least 48 consecutive hours.

Ventilation strategies and outcomes of the ALI/ARDS : a **Meta-analysis**

Putensen C, Theuerkauf N, Zinserling J, Wrigge H, Pelosi P

Ann Intern Med 2009; 151: 566-576

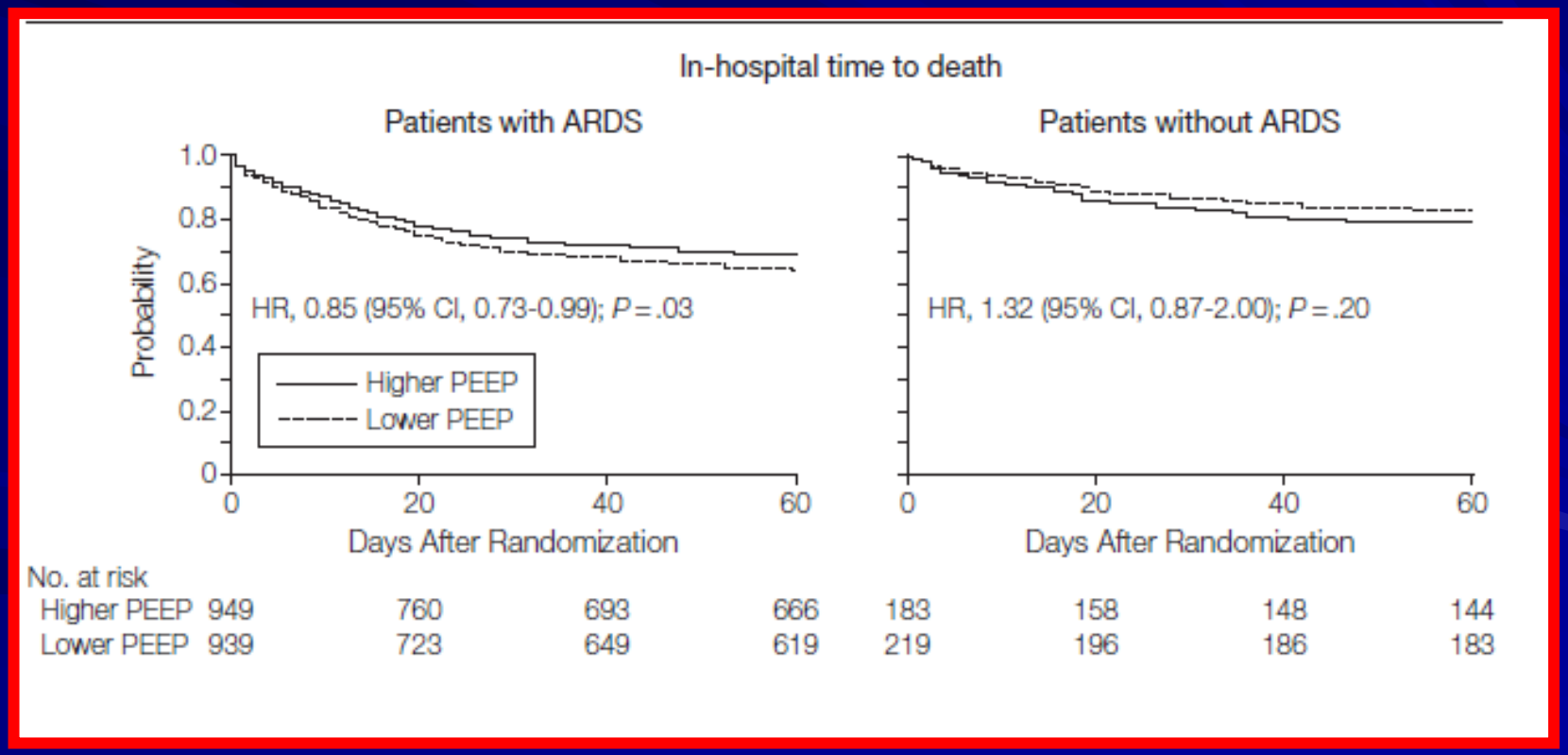
Rescue Therapies and ICU Mortality: **Lower vs Higher PEEP** at the same V_T

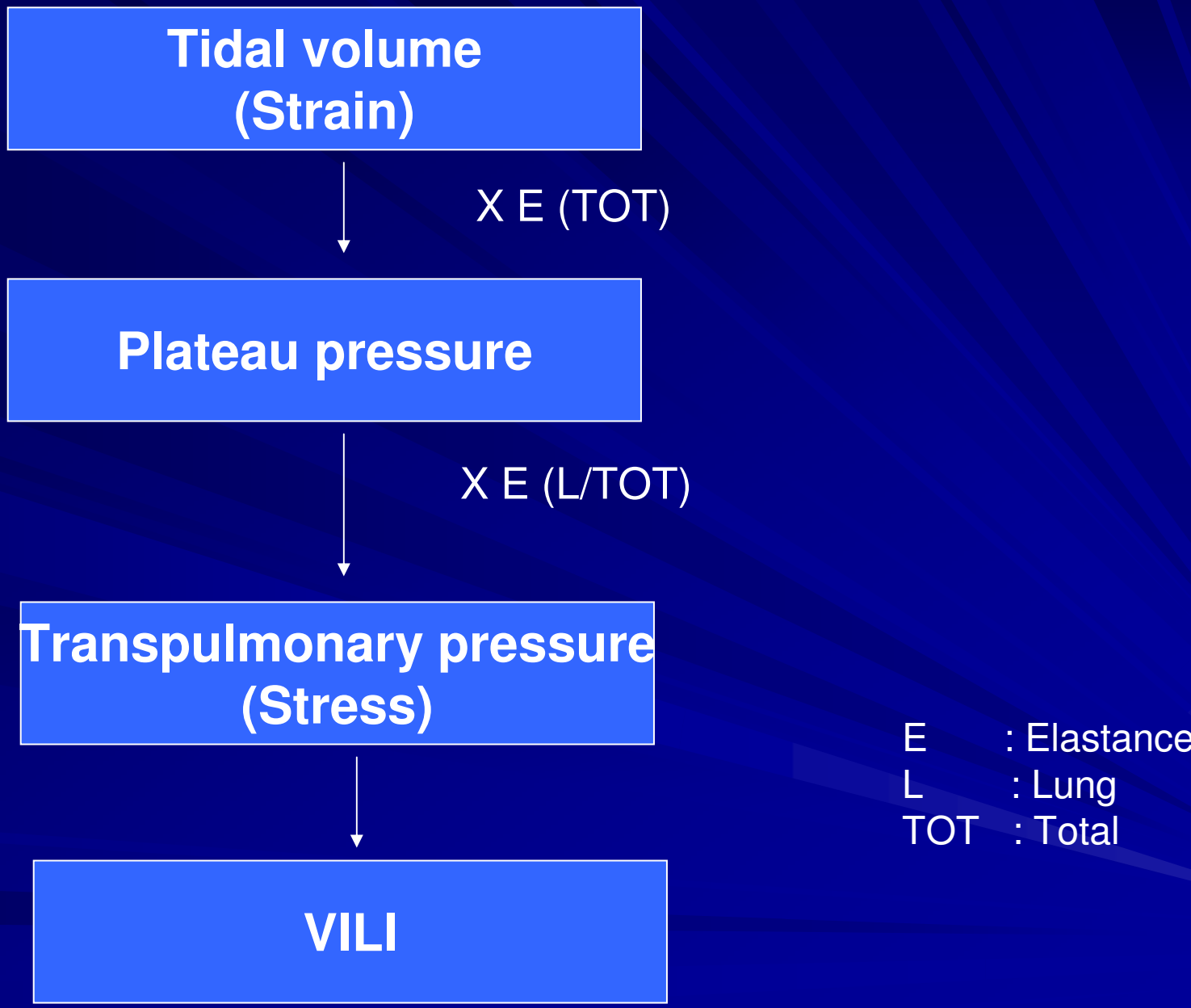
	Patients,n	Low PEEP At Low VT	High PEEP At Low VT	Odds ratio (95% CI)
Meade, 2008	983	45/508	20/475	0.45(0.26-0.78)
Mercat, 2008	767	62/382	37/385	0.55(0.36-0.85)
Summary				0.51(0.36-0.71)

$P<0.01$; $I^2 = 0$

Higher vs lower positive end-expiratory pressure in patients with ALI/ARDS : systematic review and meta-analysis

Briel M et al. JAMA. 2010;303(9):865-873




Tidal volume
(Strain)
X E (TOT)
Plateau pressure
X E (L/TOT)
Transpulmonary pressure
(Stress)
VILI
E : Elastance
L : Lung
TOT : Total

The NEW ENGLAND JOURNAL of MEDICINE

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Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

Daniel Talmor, M.D., M.P.H., Todd Sarge, M.D., Atul Malhotra, M.D., Carl R. O'Donnell, Sc.D., M.P.H., Ray Ritz, R.R.T., Alan Lisbon, M.D., Victor Novack, M.D., Ph.D., and Stephen H. Loring, M.D.

Esophageal-Pressure–Guided Group

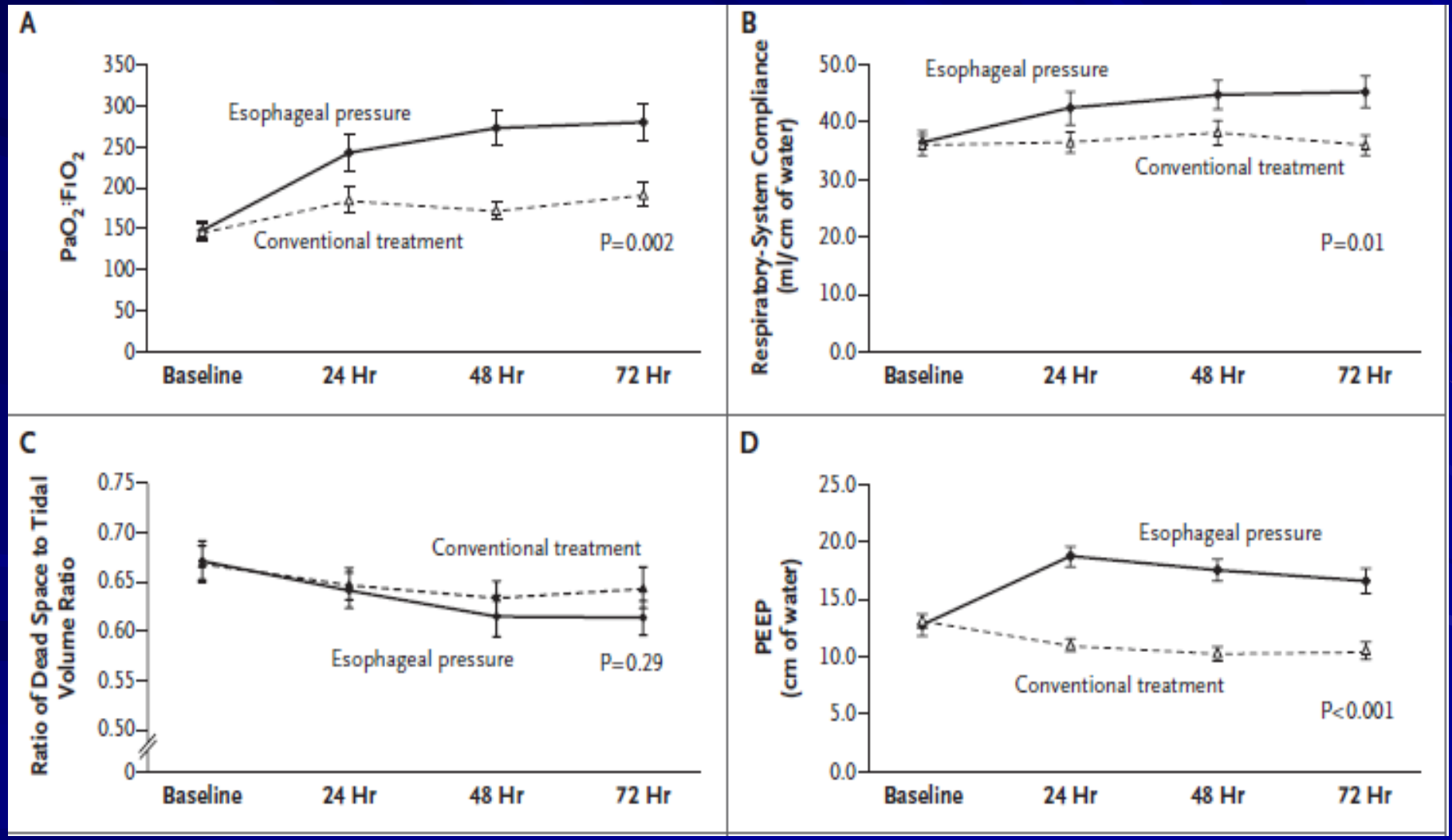
FIO_2	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0
P_{Lexp}	0	0	2	2	4	4	6	6	8	8	10	10

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

Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

Talmor D et al. N Engl J Med 2008;359:2095-104.

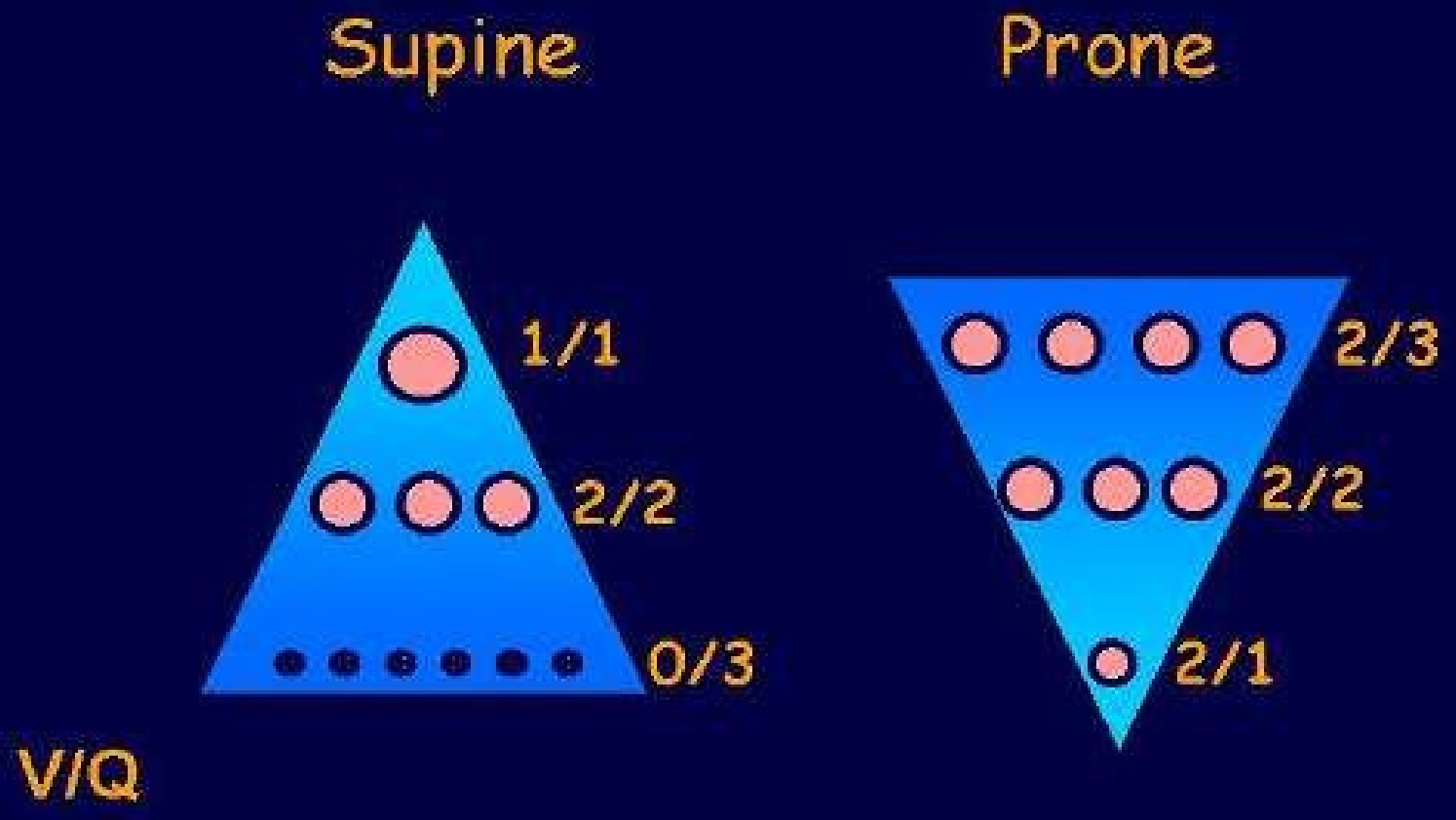


Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

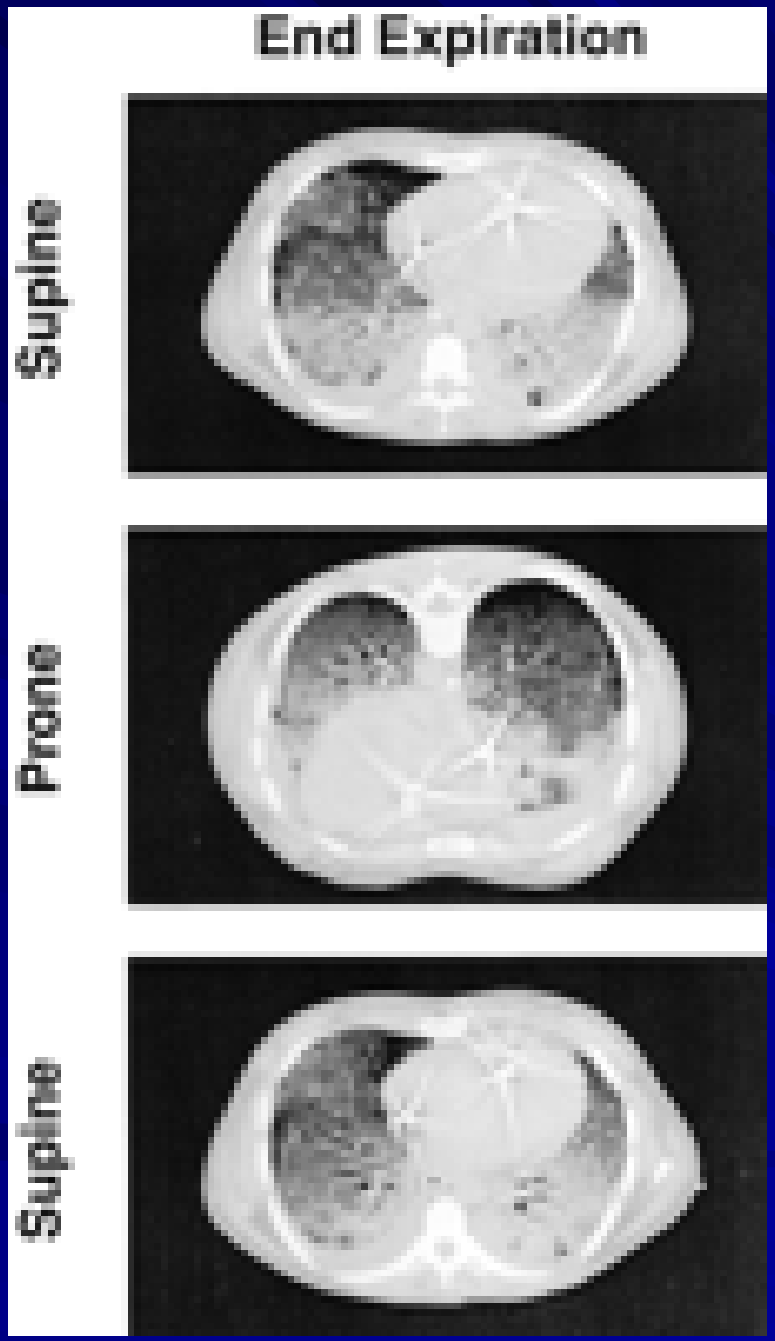
Talmor D et al. N Engl J Med 2008;359:2095-104.

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	

Effect of Position on V/Q Heterogeneity



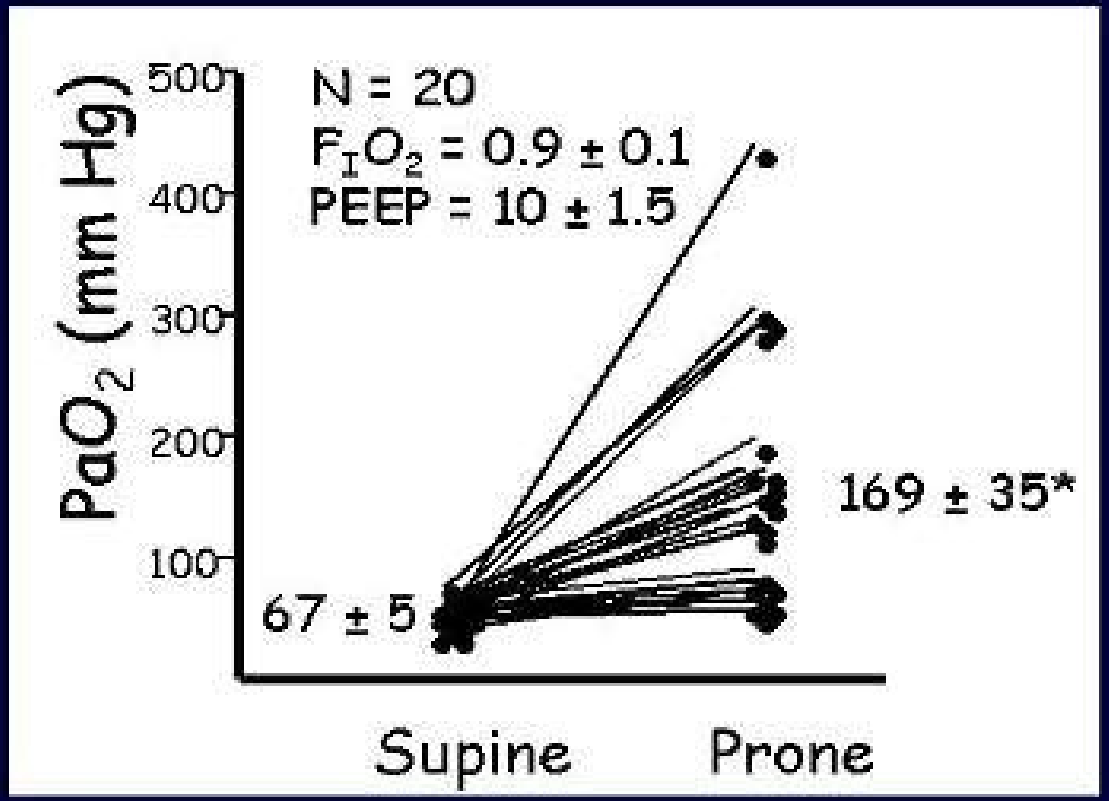
Bryan 1974



PEEP 10cm H2O

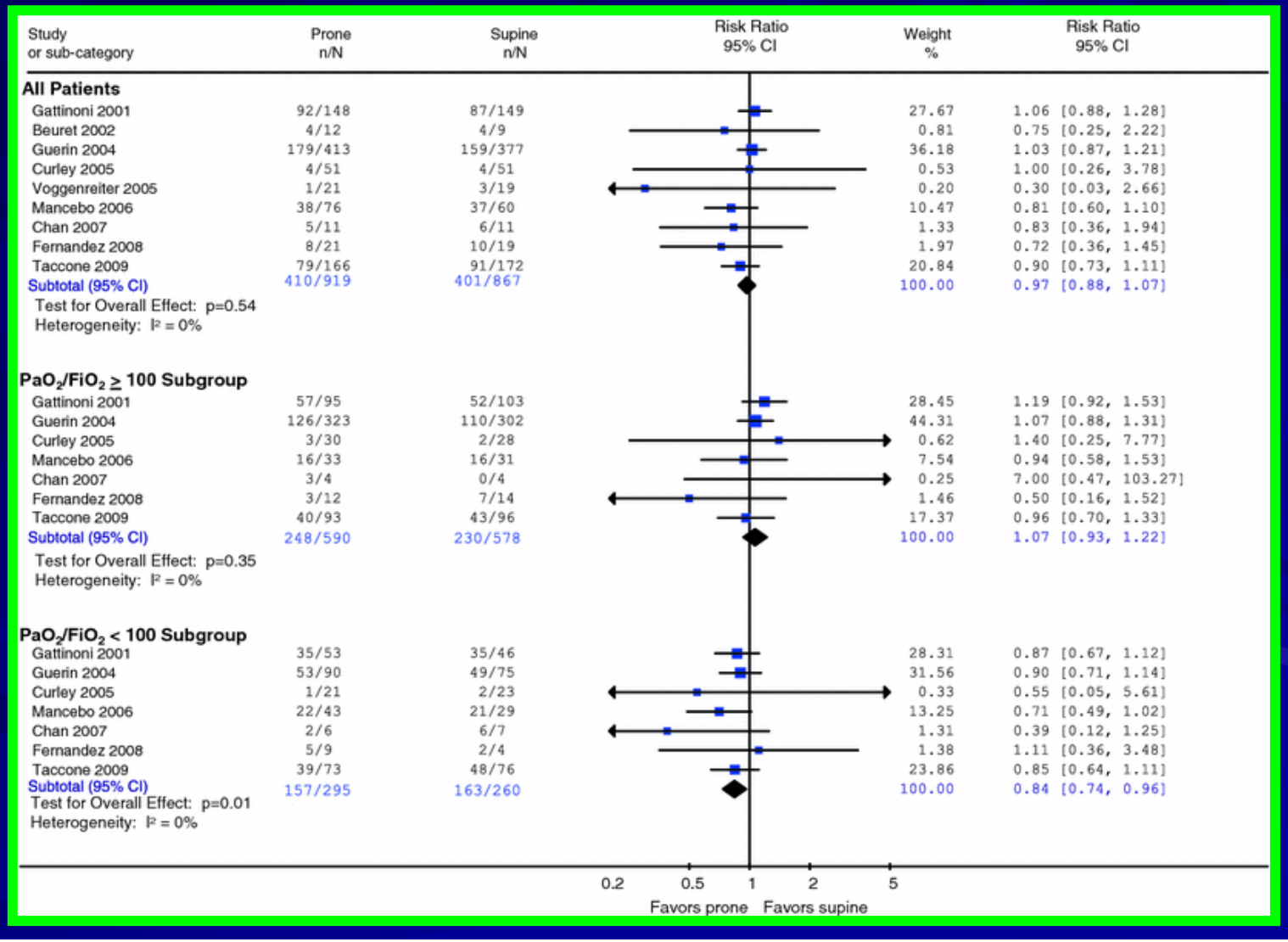
Effect of Prone Position on PaO_2

32 studies
15 countries
776 patients
66-75% response
PaO_2 ↑ 40-400 mmHg
P/F ↑ 40-80 mmHg



Effect of prone ventilation on mortality (hospital discharge or longest follow-up)

Sud S et al. Intensive Care Med. 2010 Apr;36(4):585-99



Prone position reduces mortality in pts with ARF and severe hypoxemia: systematic review & meta-analysis

Sud S et al. Intensive Care Med. 2010 Apr;36(4):585-99

Other "effects" of Prone position

	RR(95%CI)	P
Reduction in VAP	0.81 (0.67-1.00)	0.05
Increase in ET obstruction	1.58 (1.24-2.01)	0.01
Increase in pressure ulcers	1.29 (1.16-1.44)	0.01
Increase in thoracostomy tube dislodgment	3.14 (1.02-9.69)	0.05

Prone position reduces mortality in patients with ARF and severe hypoxemia: systematic review & meta-analysis.

Sud S et al. Intensive Care Med. 2010 Apr;36(4):585-99

- PP is an effective rescue maneuver for hypoxemia
- In ALI and moderate ARDS (likely low recruiters) PP does not influence mortality
- In severe ARDS (PaO_2/FiO_2 < 150 at PEEP 5 cmH2O), likely higher recruiters, the available data strongly suggest that PP may provide survival benefits (about 10%)

Inverse Ratio Ventilation (IRV)

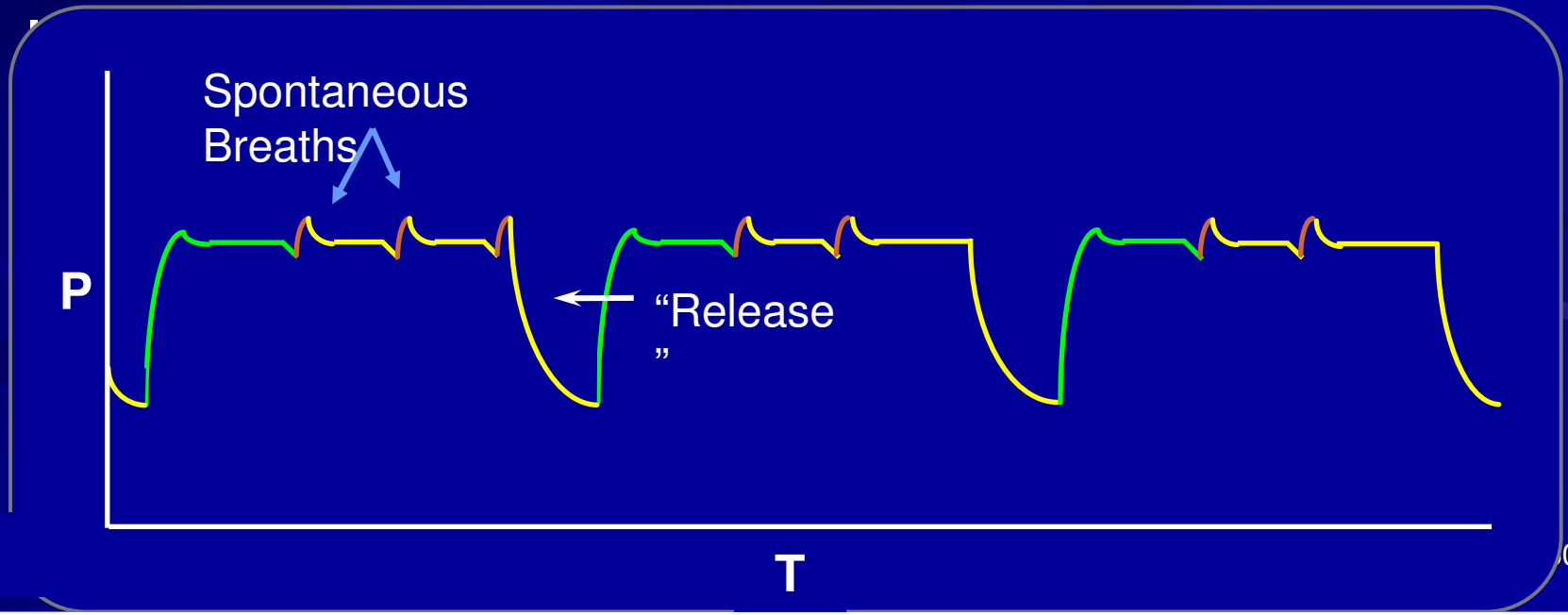
- Ratio of inspiratory to expiratory time > 1
- Using either volume or pressure modes of ventilation
- Increased mean airway pressure
- Improves oxygenation

Airway Pressure Release Ventilation (APRV)

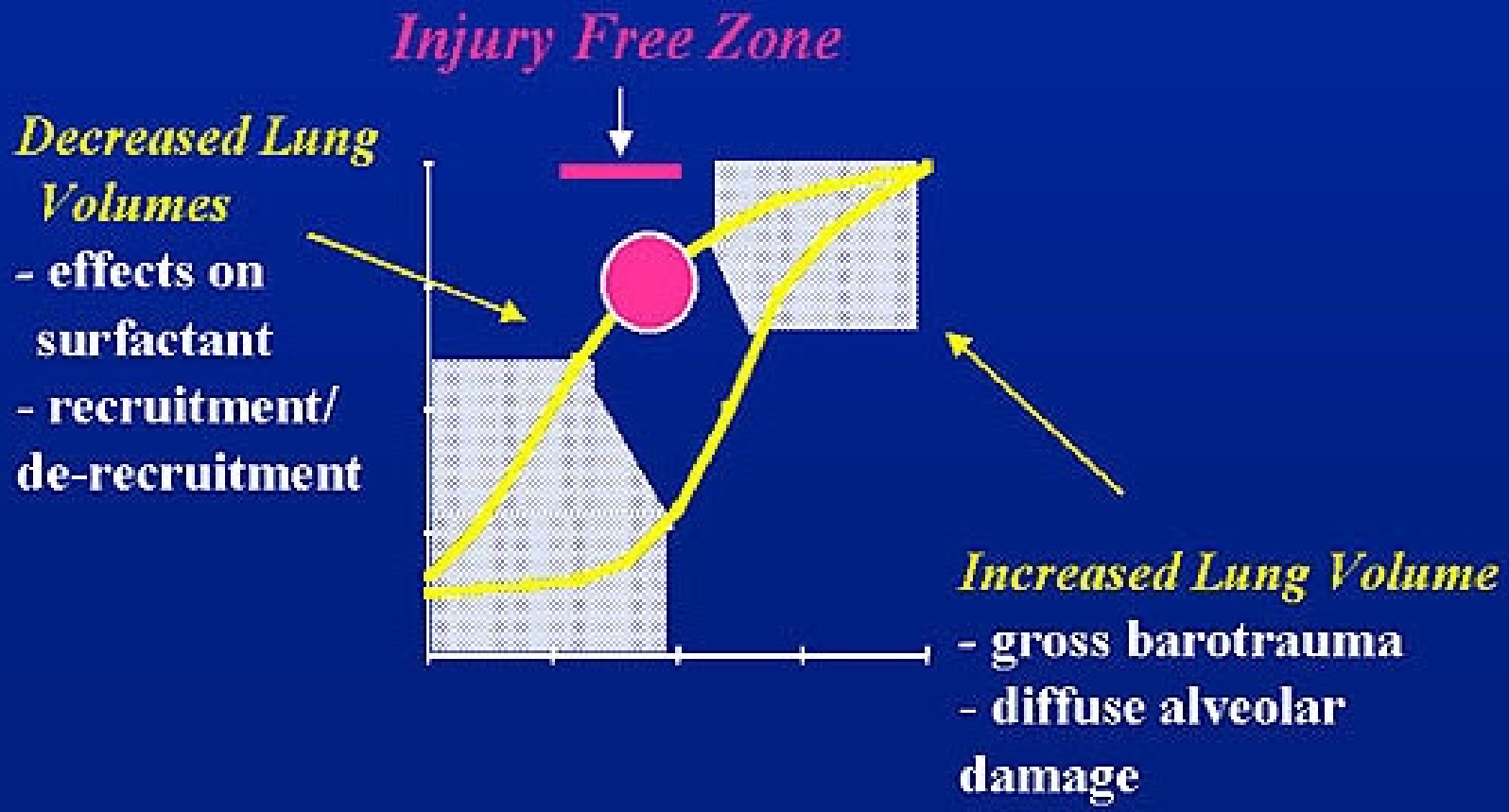
- Uses high continuous airway pressure to promote alveolar recruitment and to maintain adequate lung volume
- A time-cycled release phase to a lower pressure to supplement spontaneous minute ventilation
- By allowing unrestricted spontaneous breathing throughout the ventilator cycle, APRV allows for better ventilation of dependent lung regions
- Improved ventilation-perfusion matching and better oxygenation have been demonstrated in patients with ARDS

What Is APRV?

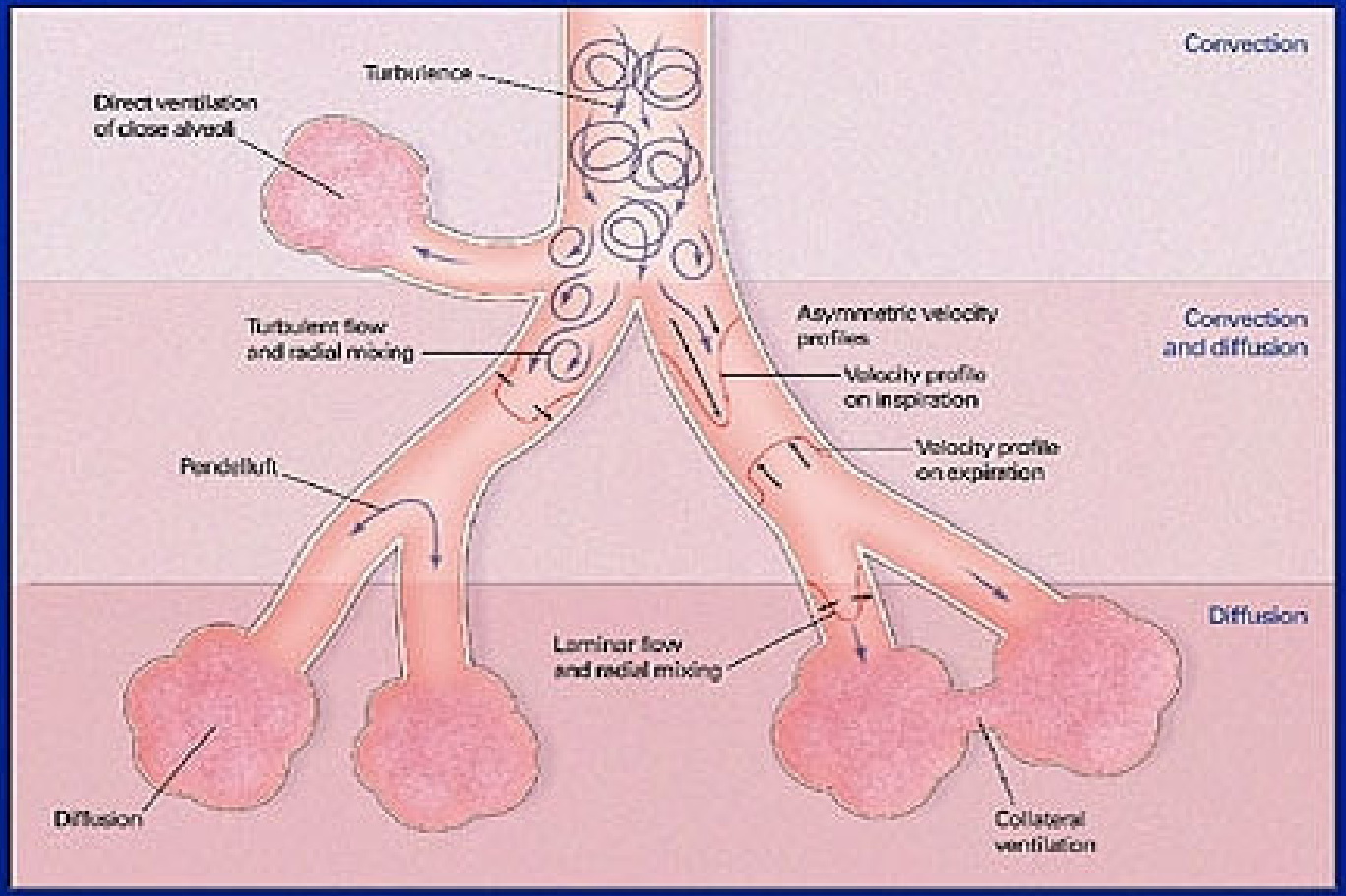
- APRV - Airway Pressure Release Ventilation
- utilizes a very short Exp. time for ***Pressure Release***
  - short time release time allows for CO2 removal
- All spontaneous breathing at upper pressure



Theoretical Advantage of HFV: Lung Protection

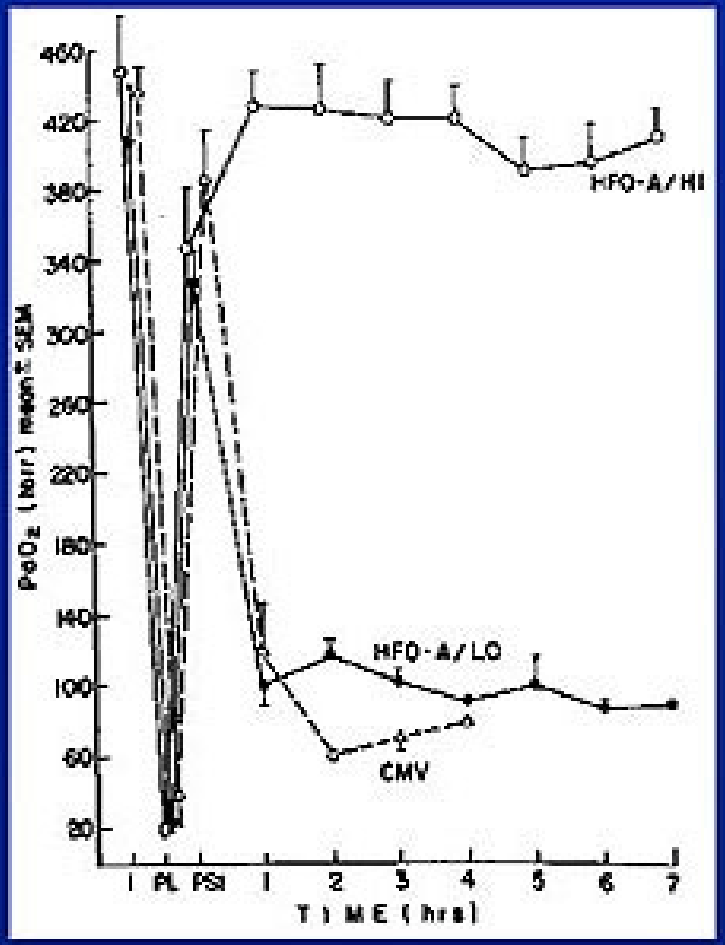


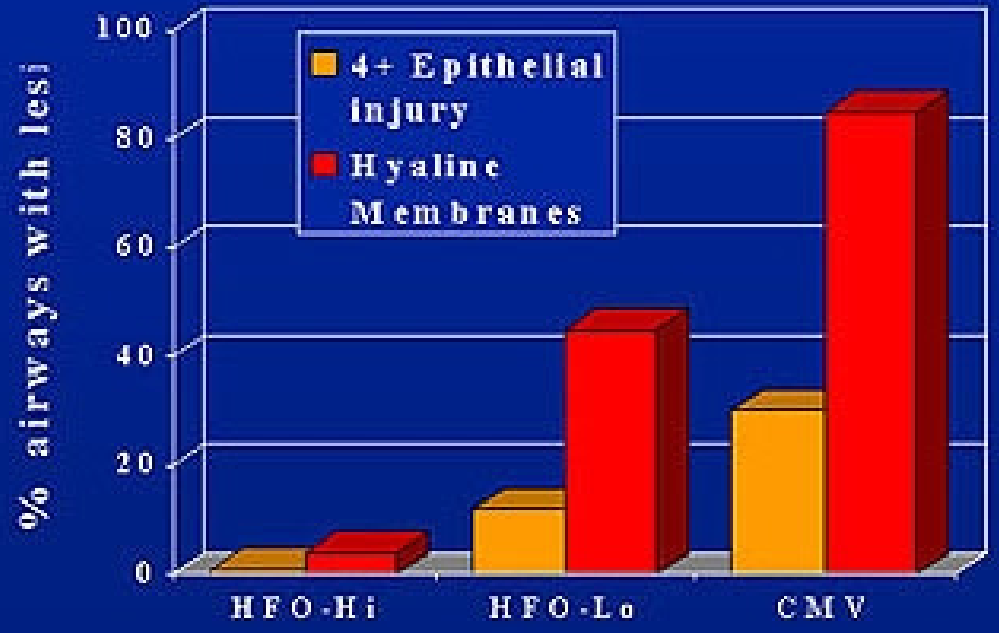
High-Frequency Ventilation: Gas Transport Mechanisms



Slutsky & Drazen **N Engl J Med** *2002;347:630-631*

Lung Volume Maintenance prevents Lung Injury during HFOV in rabbits

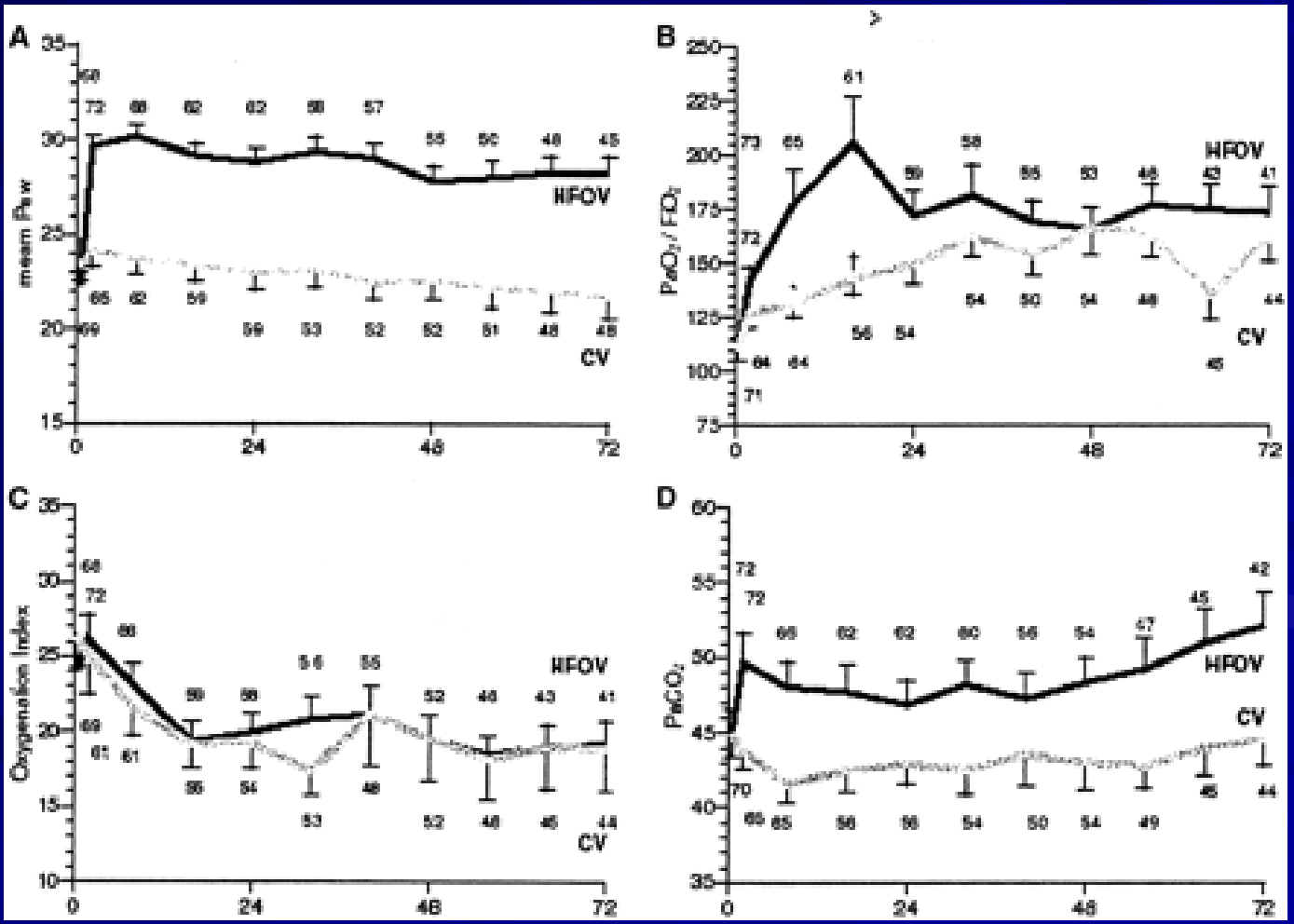




McCulloch, Forkert, Froese *ARRD 137:1185-1192,1988*

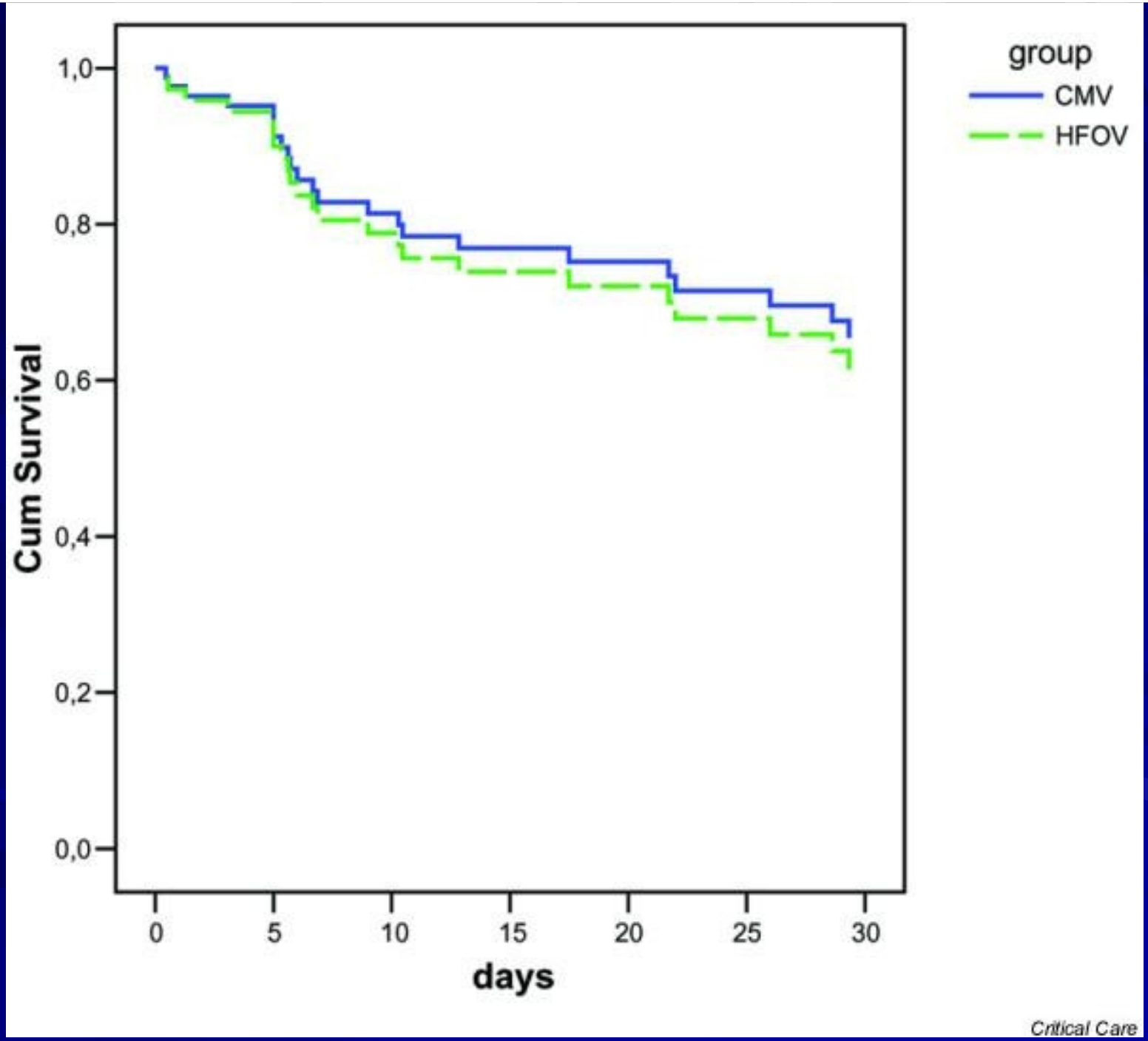
Derdak S, Mehta S, Stewart TE, et al. High-frequency oscillatory ventilation for acute respiratory distress syndrome in adults: a randomized, controlled trial.

Am J Respir Crit Care Med 2002; 166:801-808



N=148

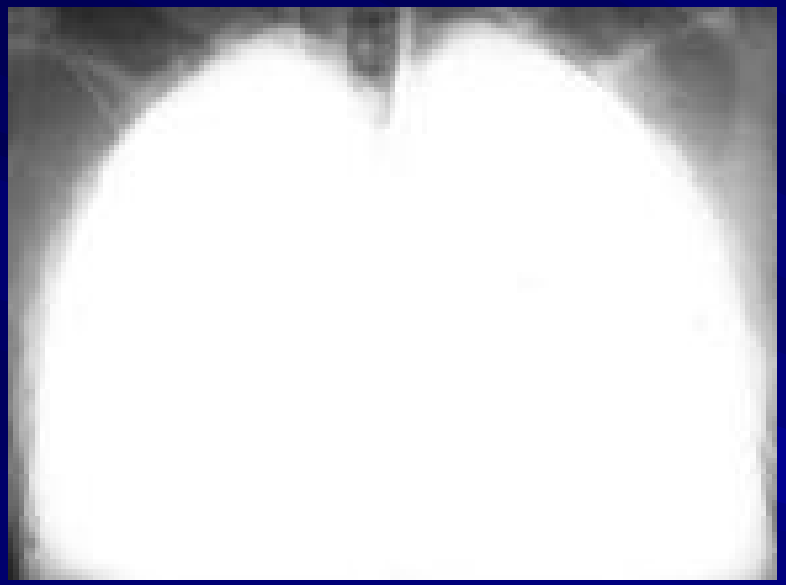
P=0.0008



Mortality
63%
48%

P=0.10

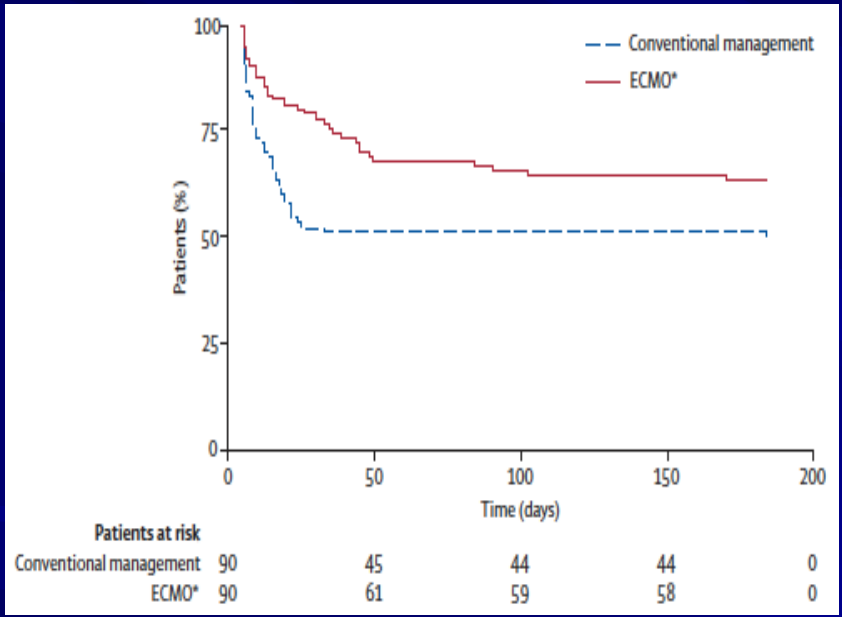
Partial Liquid Ventilation



- Use perfluorocarbons
- Hirschl et al (2002)
  - No difference in mortality or duration of MV
- Kacmarek et al (2006)
  - No improvement in outcome

Efficacy and economic assessment of conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR): a multicentre randomised controlled trial

Peek JL et al. Lancet 2009; 374: 1351–63



- Murray score > 3
- FiO_2>90% needed to to maintain SaO_2>90%
- Respiratory metabolic acidosis pHa<7.2
- Haemodynamically unstable

Transfer to a centre with an ECMO-based management protocol

Ventilation strategies and outcomes of the ALI/ARDS : a Meta-analysis

Putensen C, Theuerkauf N, Zinserling J, Wrigge H, Pelosi P

Ann Intern Med 2009; 151: 566-576

• Based on available evidence from a limited number of RCTs routine use of low V_T tends to be beneficial in all ALI/ARDS patients (if potential side effects of hypercapnia and respiratory acidosis are not contraindicated)

• Higher PEEP strategies during lower V_T ventilation did not improve hospital mortality and cannot be recommended in unselected ALI/ARDS patients.

• Higher PEEP strategies during lower V_T ventilation may be suggested in severe ARDS (PaO2/FiO2 <150 at PEEP 5) and to prevent life threatening hypoxemia

Acute Respiratory Distress Syndrome

- Ventilator Settings
  - CMV, SIMV or newer modes Bi-Level or APRV
  - VT (4-6 ml/kg), higher RR
    - Permissive Hypercapnia
  - Limit plateau pressures to < 30 cm H_2O
  - High-PEEP ventilation, alveolar recruitment maneuvers and prone positioning may be useful as rescue therapy in severe hypoxemia
  - Longer inspiratory times? ↑ MAP → ↑ PaO_2
    - Inverse ratio ventilation, I:E > 1:1?

Thank You