Recruitment Maneuver and Mode Setting in Mechanical Ventilation

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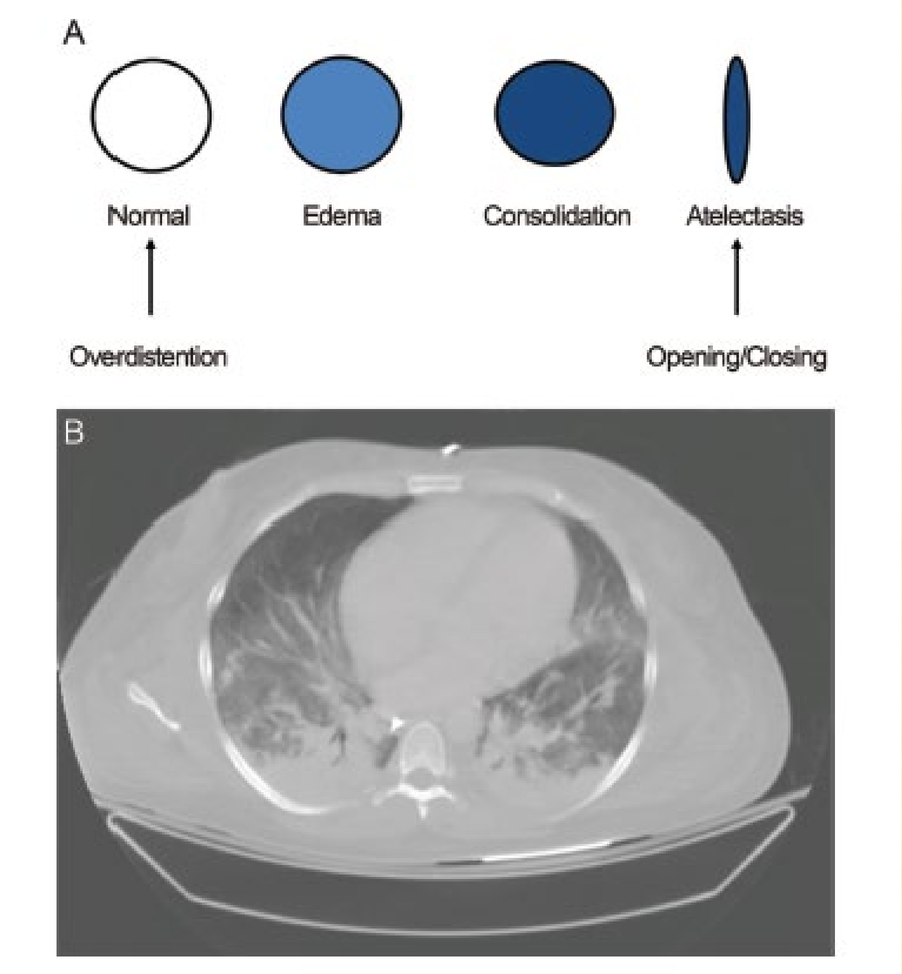
Introduction

- Ventilator management for injured lung is evolving.
- Pressure and volume limited lung protection.
- Risk of derecruitment if PEEP is not sufficient.
- Recruitment maneuvers can be used to augment other methods to improve aerated lung volume.

Curr Opin Crit Care 2014;20:63-68

ARDS

- ARDS characterized by heterogeneity, some alveoli are normal, some are collapsed, some are fluid-filled and some consolidated.



Respir Care 2015;60:1688-1704

Physiologic Concepts

- Stress: pressure applied to alveolus
- Strain: change in shape of alveolus caused by stress
  - Strain is associated with ventilator induced lung injury (VILI)

Respir Care 2015;60:1688-1704

Stress and Strain

- $P\ (\text{stress}) = \text{lung elastance} \times \dfrac{\triangle V}{\text{functional residual capacity}}$

  $\triangle V$: change in lung volume above functional residual capacity with the addition of PEEP

- A stress raiser is the result of inhomogeneity with lungs.

Respir Care 2015;60:1688-1704

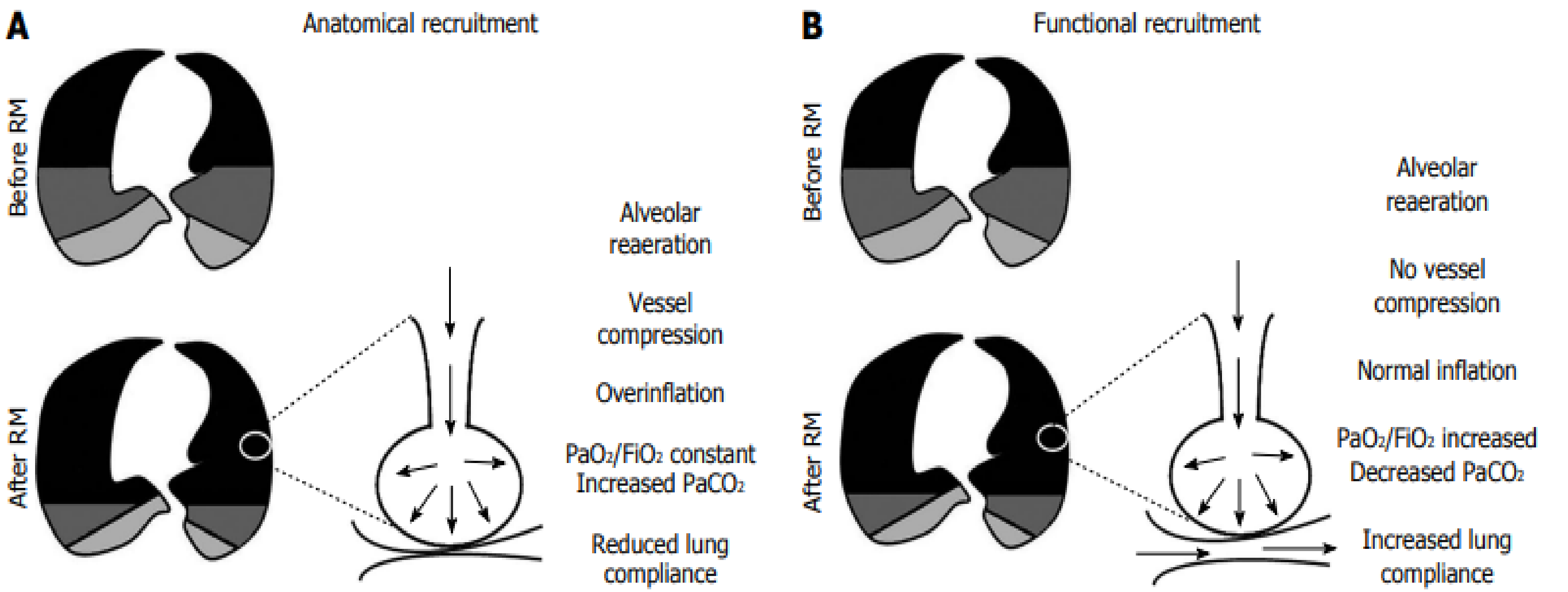


Figure 1 Schematic representation of lung morphology before and after application of recruitment maneuvers. A: Anatomical recruitment. Alveolar reopening is not accompanied by reperfusion and PaO_2/FiO_2 remains unchanged; B: Functional recruitment. Reperfusion is a landmark of functional recruitment and, after application of a recruitment maneuver, an increment in PaO_2/FiO_2 ratio is expected. RM: Recruitment maneuver.

World J Crit Care Med 2015;4(4):278-286

Potential for Recruitment

- The benefit of recruitment maneuvers might be related the potential for alveolar recruitment in the lungs.
  - Lower PaO_2/FiO_2
  - Lower compliance

Respir Care 2015;60:1688-1704

Methods to Achieve Alveolar Recruitment

- Treatment of underlying disease
  - Removal of airway obstruction
  - Diuresis
  - Treatment of infection
- Sustained inflation
- Stepwise recruitment (incremental PEEP)
- APRV
- HFOV
- Sign
- Prone position

Type of Recruitment Maneuvers

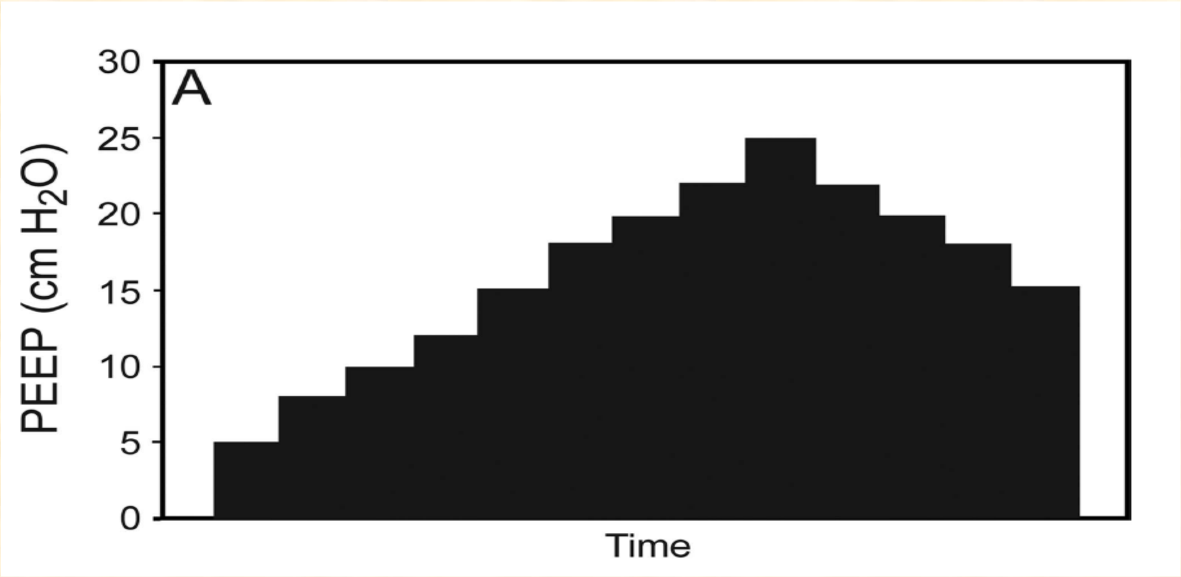
- Sustained inflation (fast RM)
  - CPAP mode
    - increased pressure to 30-40 cmH_2O for 30-40 seconds
    - 35 to 45 cmH_2O for 30 seconds (ARDS network)
  - Take notice of hypotension

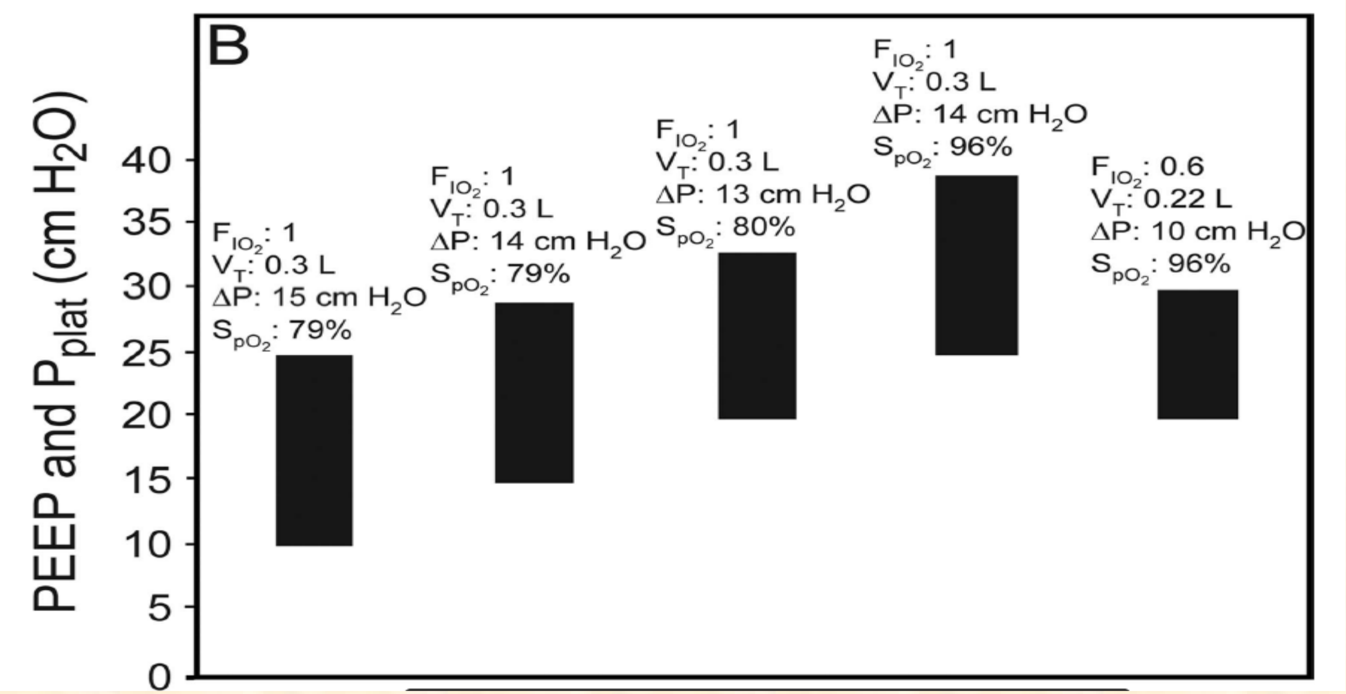
Respir Care 2002;47:308-317

Type of Recruitment Maneuvers

- Stepwise recruitment (slow RM)
  - Increased PEEP in increments of 2-5 cmH_2O with a fixed Vt 6 mL/kg (ideal body weight)
  - Driving pressure (plateau pressure-PEEP), compliance, $SatO_2$ and blood pressure are monitored
  - PEEP increased if decreased driving pressure, plateau pressure<30 cmH_2O, increased Sat O_2.
  - Decreased PEEP to previous step if increased driving pressure, plateau pressure > 30 cmH_2O, decreased Sat O_2 or hypotension.
  - Each step 3-5 minutes

Am J Respir Crit Care Med 1995;152:121-128


A
PEEP (cm H_2O)
30
25
20
15
10
5
0
Time


B
PEEP and P_{plat} (cm H_2O)
40
35
30
25
20
15
10
5
0
F_{IO_2}: 1
V_T: 0.3 L
ΔP: 15 cm H_2O
S_{pO_2}: 79%
F_{IO_2}: 1
V_T: 0.3 L
ΔP: 14 cm H_2O
S_{pO_2}: 79%
F_{IO_2}: 1
V_T: 0.3 L
ΔP: 13 cm H_2O
S_{pO_2}: 80%
F_{IO_2}: 1
V_T: 0.3 L
ΔP: 14 cm H_2O
S_{pO_2}: 96%
F_{IO_2}: 0.6
V_T: 0.22 L
ΔP: 10 cm H_2O
S_{pO_2}: 96%

Airway Pressure Released Ventilation (APRV)

- Breathe spontaneously while receive high airway pressure, high pressure for alveolar recruitment.
- By promoting spontaneous breathing, it might improve alveolar recruitment to the dorsal-caudal regions of lungs.
- APRV improves oxygenation, but lack of evidence to support improved outcome.

Respir Care 2015;60:1688-1704

APRV

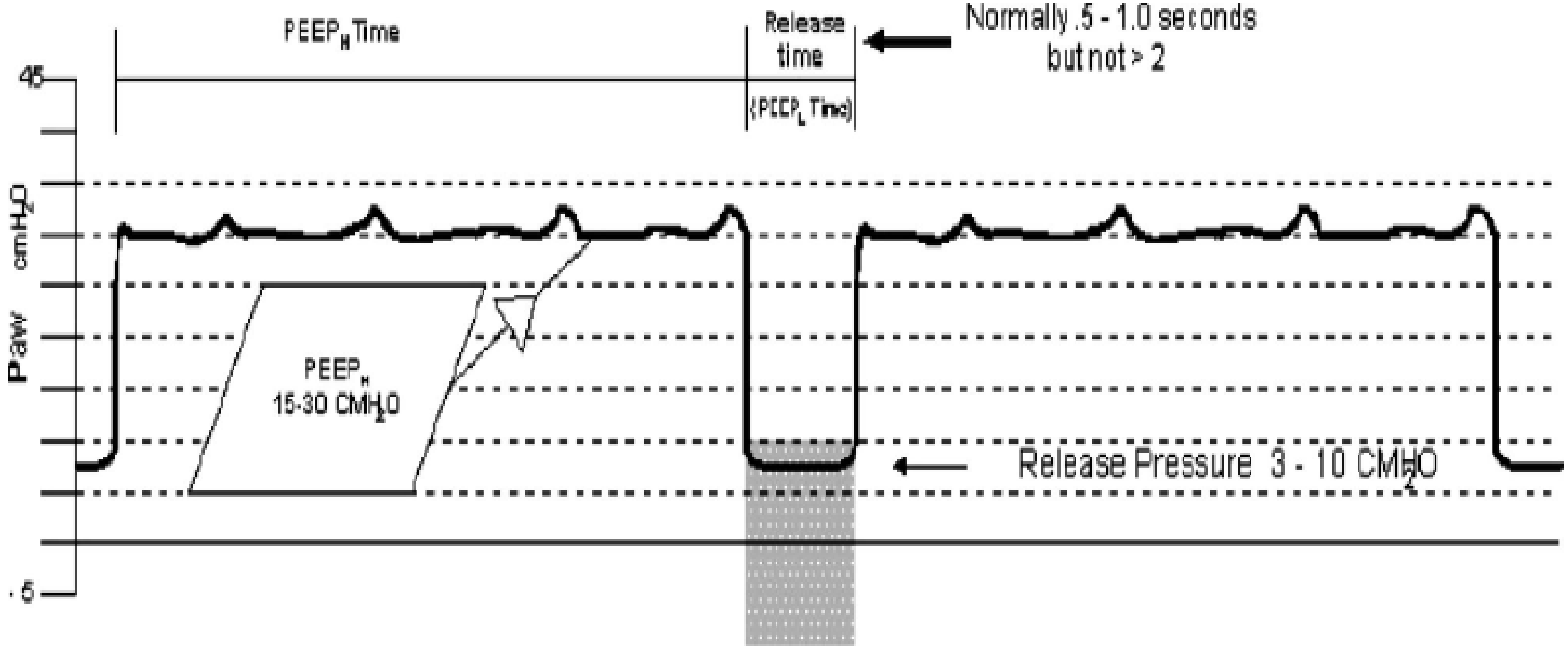


FIGURE 4. Airway pressure release ventilation (APRV) is a pressure-targeted, time-cycled mode of mechanical ventilation delivering continuous positive airway pressure with regular, intermittent and brief release in pressure. APRV allows unrestricted spontaneous breathing throughout the respiratory cycle.

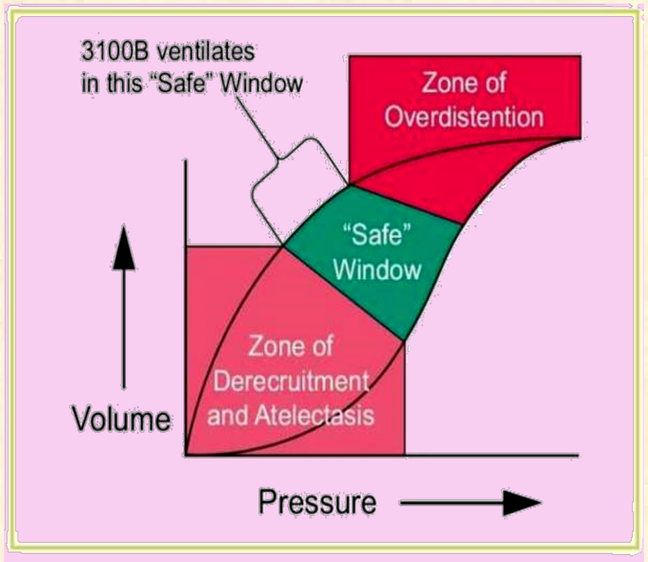
High frequency oscillatory ventilation (HFOV)

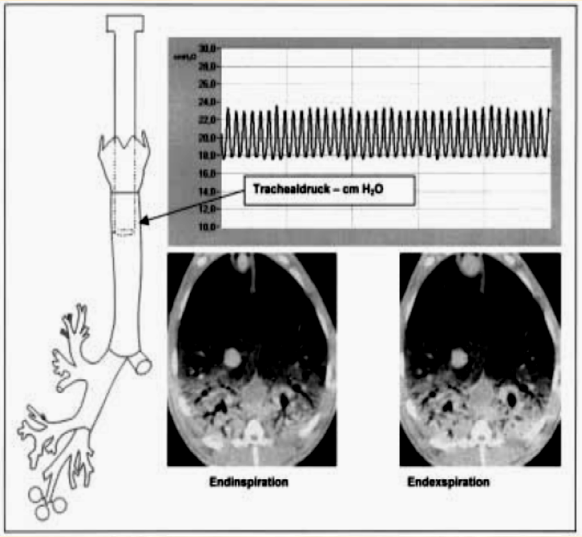
- Increase airway pressure and promote alveolar recruitment.
- Small tidal volume: 1 to 4 ml/kg, frequency: 3 to 5 Hz
- Less risk of over-distention, prevent VILI.

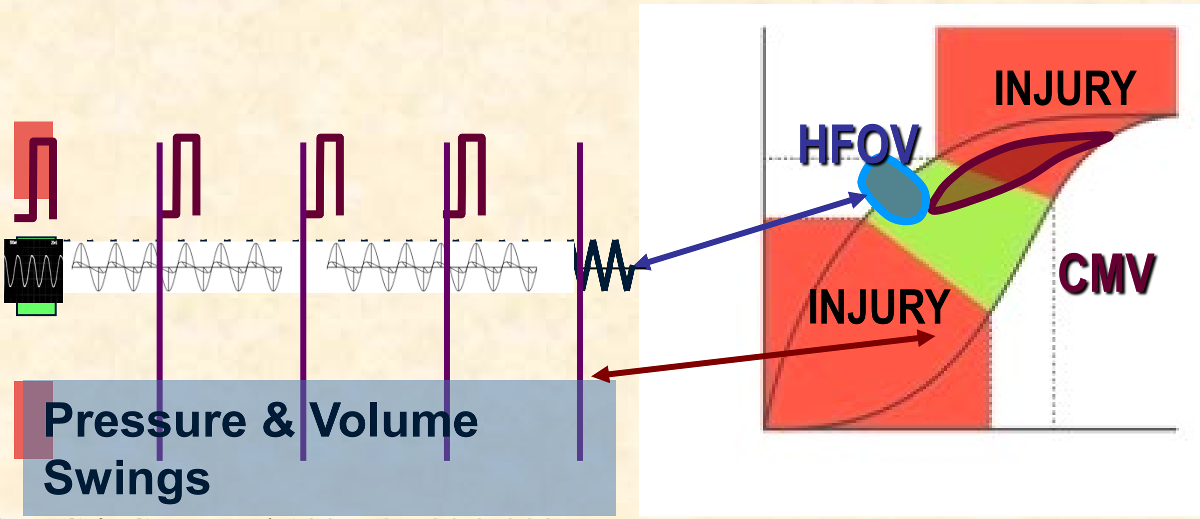
Respir Care 2015;60:1688-1704

HFOV Operates in the Safe Zone of Ventilation

- There are 2 injury zones in MV
  - Low lung volume ventilation
    -- tears adhesive surfaces
    ⇒ Atelectrauma
  - High lung volume ventilation
    -- overdistension
    ⇒ Volutrauma / Barotrauma

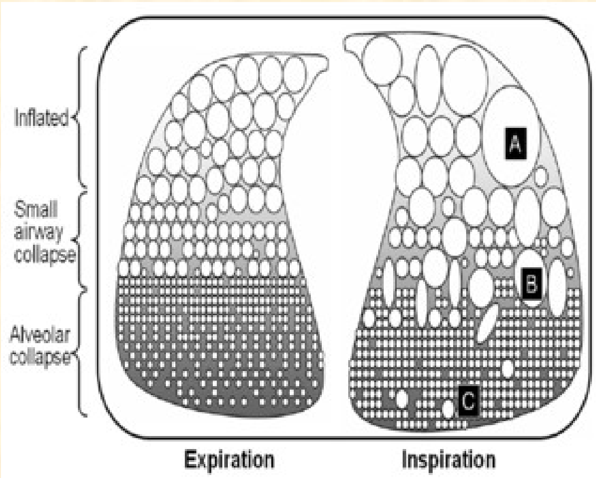




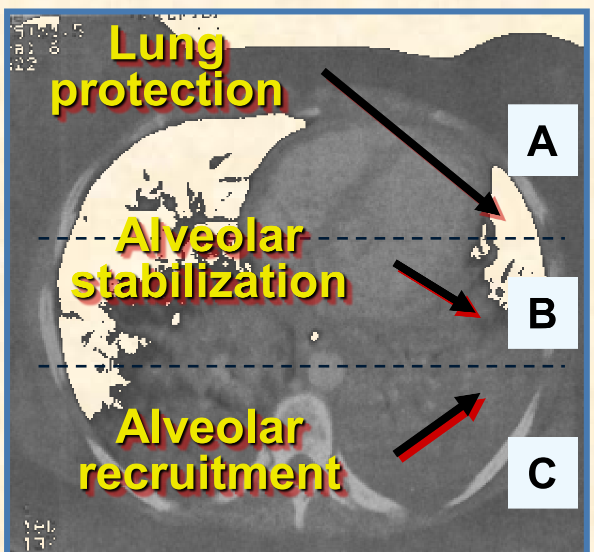


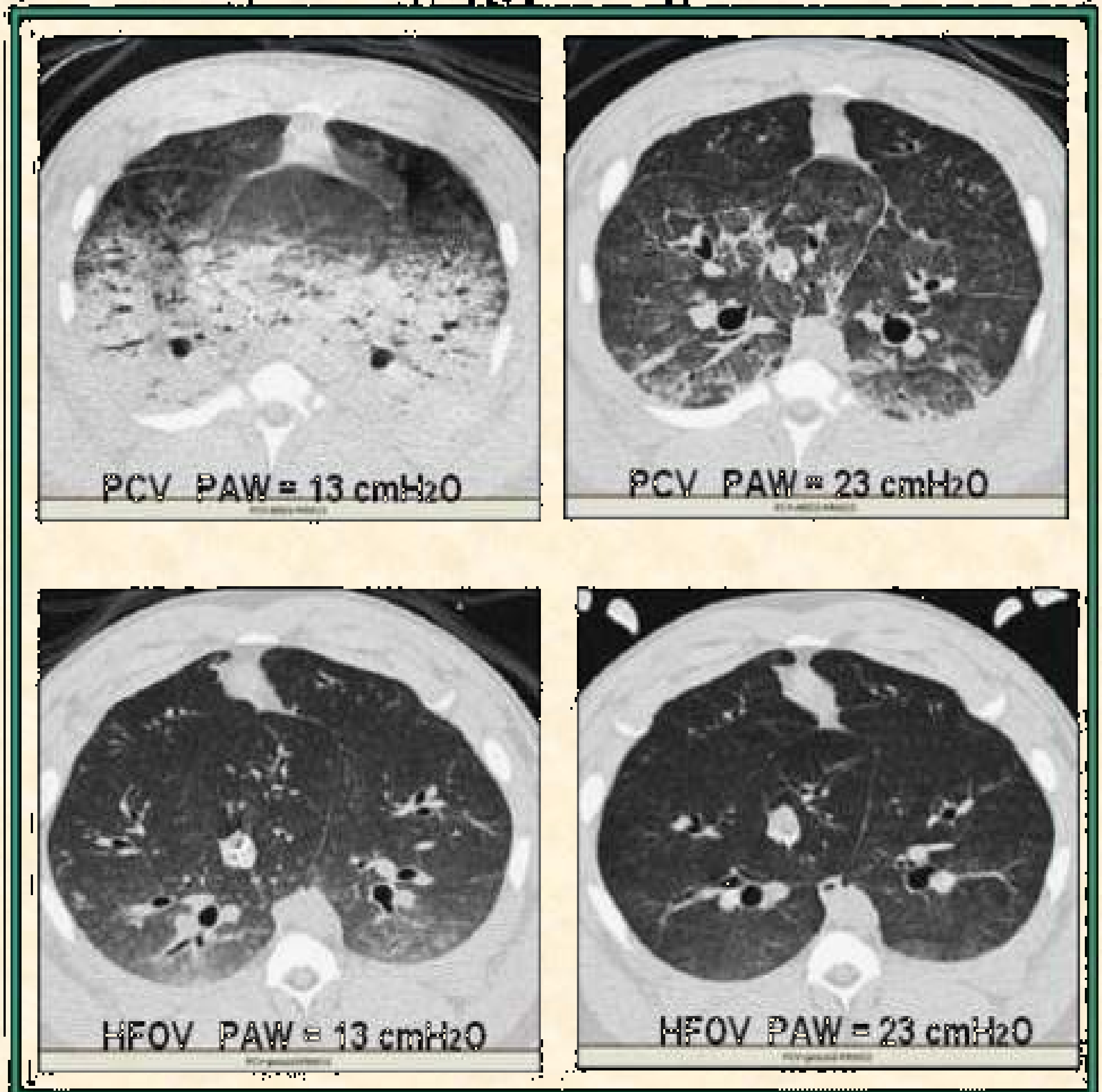
Froese AB. Crit Care Med 1997; 25:906–908
Luecke T, et al. Anaesthesist 2000; 49:972–980

Comparisons of CT images with PCV & HFOV



Ventilatory Strategies for ARDS

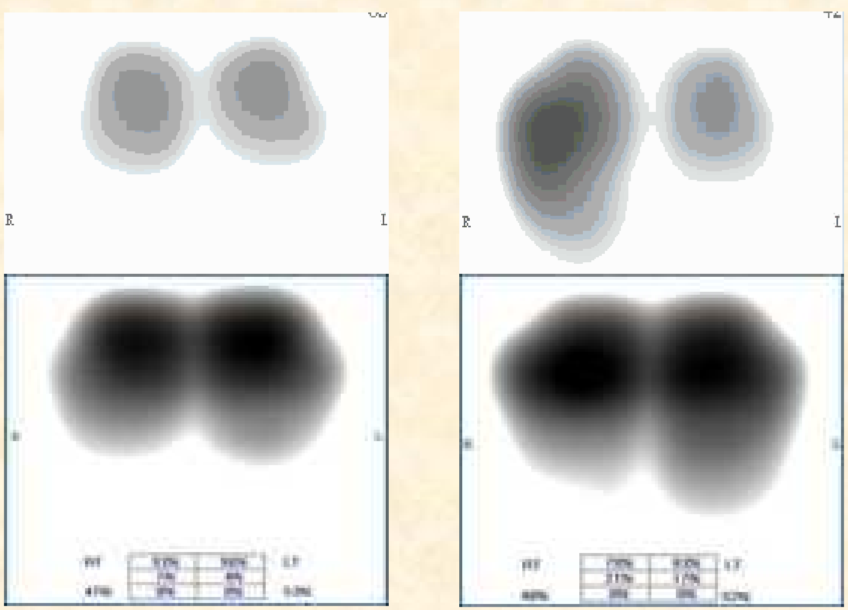


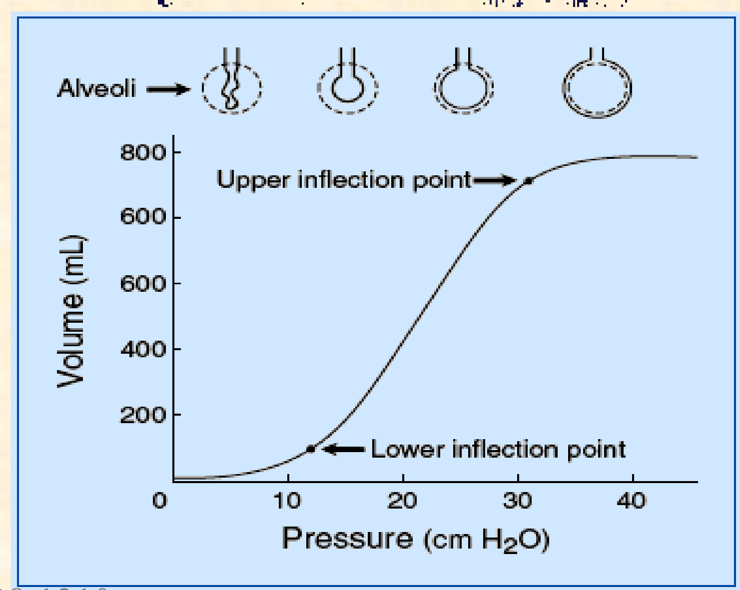


Luecke T. *Crit Care Med* 2005; 33, 155

HFOV & Lung Recruitment Maneuvers

- Intermittently increasing MAP during HFOV
- Initiate at high MAP
  - 40-50 cm H_2O
  - 40-60 seconds duration





Medoff BD et al. Crit Care Med 2000; 28:1210
Krishnan RKM et al. Intensive Care Med 2004; 30:1195–1203
Crit Care 2007, 23: 248

HFOV in Early ARDS

- Ferguson et al assigned HFOV to new-onset moderate to severe ARDS.
- This study stopped early with an in-hospital mortality of 47% in the HFOV group, compared to 35% in the control group (RR of death with HFOV:1.33, 95% CI 1.09-1.64)

N Engl J Med 2013;368:795-805

Meta-analysis of HFOV on Mortality

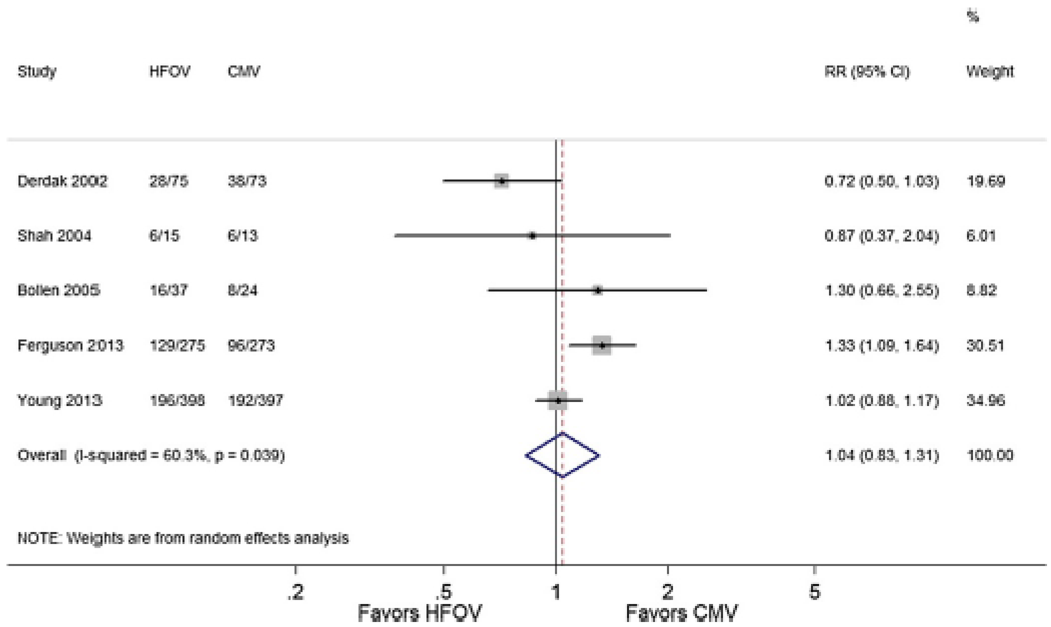


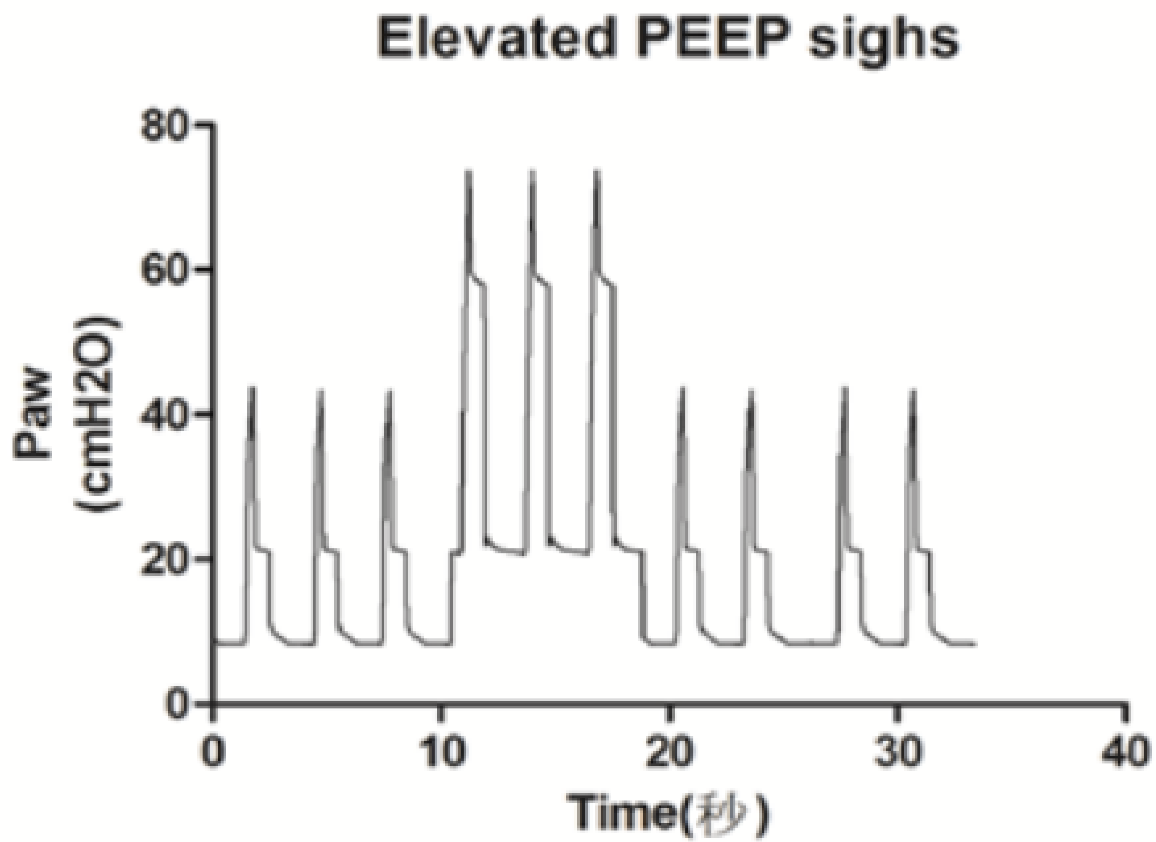
Figure 2 Forest plot showing the effect of HFOV on 30-day or hospital mortality. HFOV, high-frequency oscillatory ventilation; CMV, conventional mechanical ventilation; RR, risk ratio; CI, confidence interval.

Crit Care 2014;18:R102

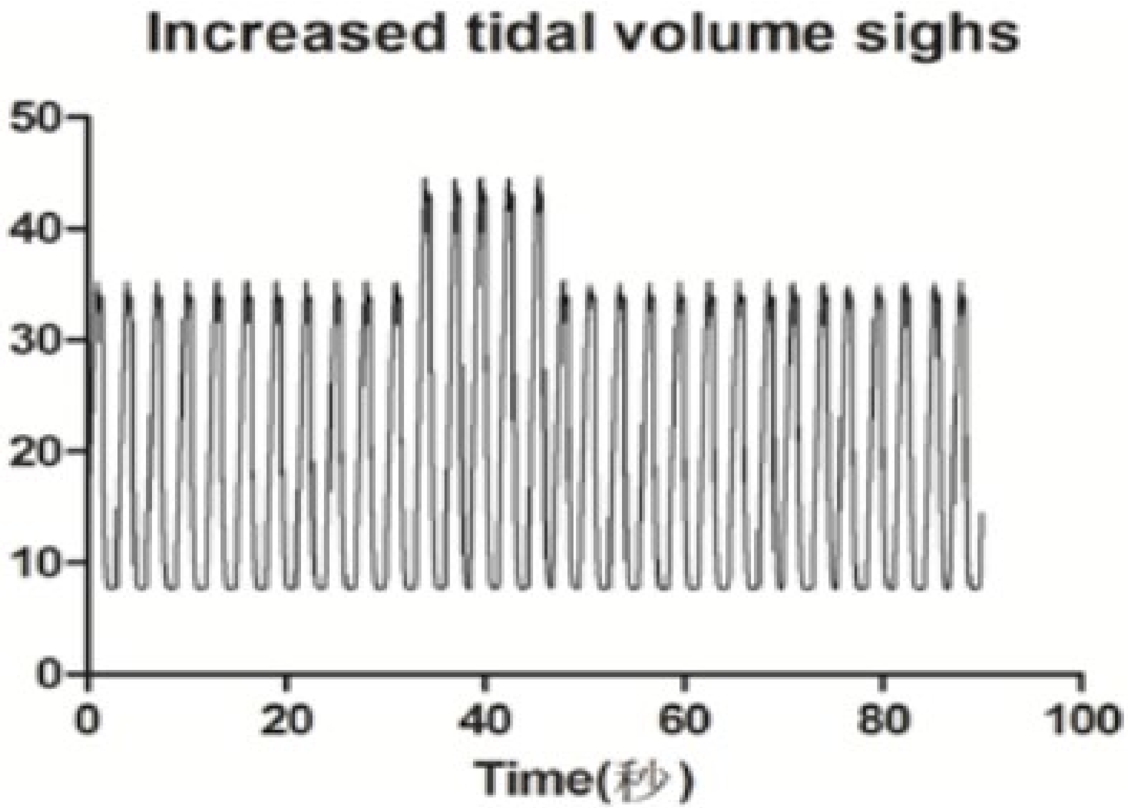
Sigh

- Elevated PEEP
- Increased tidal volume

Crit Care Med 2015;43:1823-1831



圖三：深呼吸的另一種模式(示意圖)：在一段呼吸間給
予較高吐氣末正壓(一般給予3次/每分鐘)。



圖二：深呼吸的一種(示意圖)：在一段呼吸間給予較高的潮氣容積(以高原壓力45 cmH_2O為上限之容積模式)。

Sigh vs Sustain Inflation

Figure 1

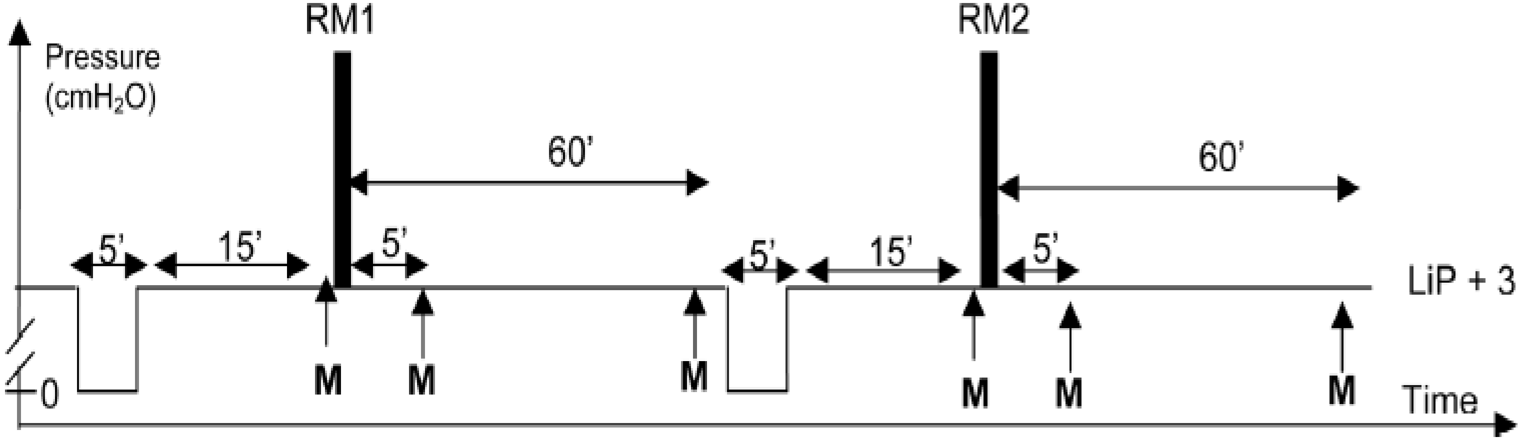
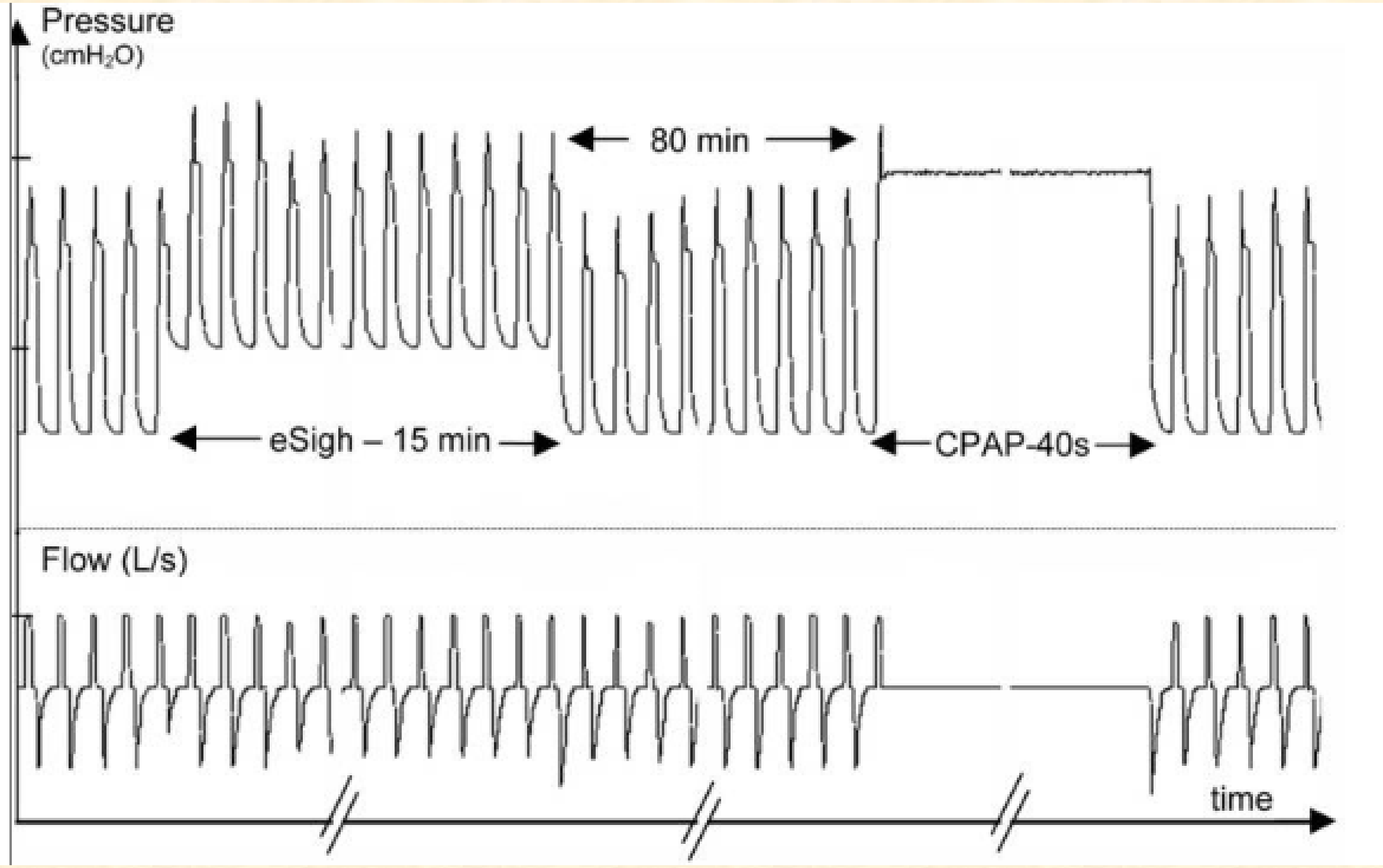


Illustration of the time course of the study. Nineteen patients ventilated with protective lung strategy first had a washout period of 5 minutes of zero end-expiratory pressure ventilation. After 15 minutes of stabilization in positive end-expiratory pressure (PEEP) ventilation, baseline measures (M) were obtained. Then, patients were randomly asssigned to benefit from one of the two recruitment maneuvers (RMs): RM1 or RM2 (that is, continuous positive airway pressure or extended sigh). At 5 and 60 minutes after RM, measurements were obtained. After this first part of the study, a second washout period was performed followed by 15 minutes of ventilation in PEEP and the second RM was performed. The same measurements were performed at baseline and at 5 and 60 minutes after RM. M indicates blood gas analysis, recruited volume by pressure-volume curve method, hemodynamics, and respiratory parameters. LIP, lower inflection point.

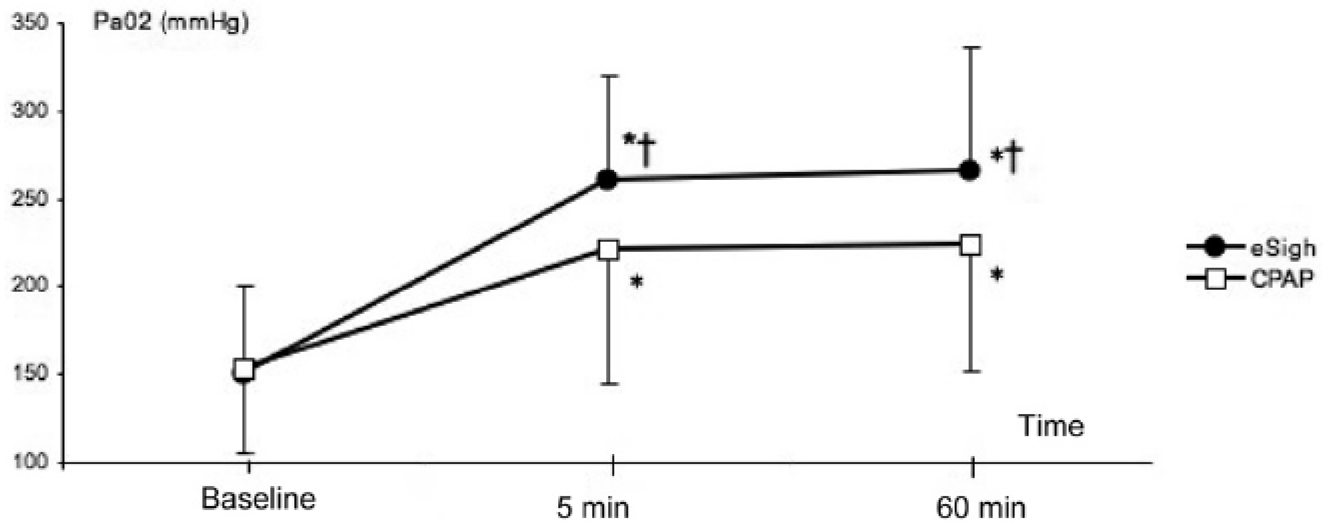
Sigh vs Sustain Inflation



Crit Care 2008;12:R50

Sigh vs Sustain Inflation

Figure 3



Both recruitment maneuvers increased oxygenation. Extended sigh (eSigh) induced a significantly higher increase in arterial partial pressure of oxygen (PaO_2) than continuous positive airway pressure (CPAP) at 5 and 60 minutes after the recruitment maneuver. * significant versus baseline, † significant versus CPAP.

Crit Care 2008;12:R50

Chest Wall Modification

- Decompression of the abdomen
- Drainage of pleural effusion
- Relaxation of the thoracic and abdominal muscle
- Using upright or prone position

Curr Opin Crit Care 2014;20:63-68

Prone Positioning

- Recruitment of non-aerated alveoli and make lung more homogenous.
- Shift in heart weight from lung beneath it onto the ventral chest wall.
- It producing regional PEEP-like effect that consolidates the dorsal recruitment associated position change.
- Prone position may reduce lung stress and strain in severe ARDS.
- Survival benefit for severe ARDS.

Curr Opin Crit Care 2014;20:63-68
Crit Care Med 2014;42:1252-1262

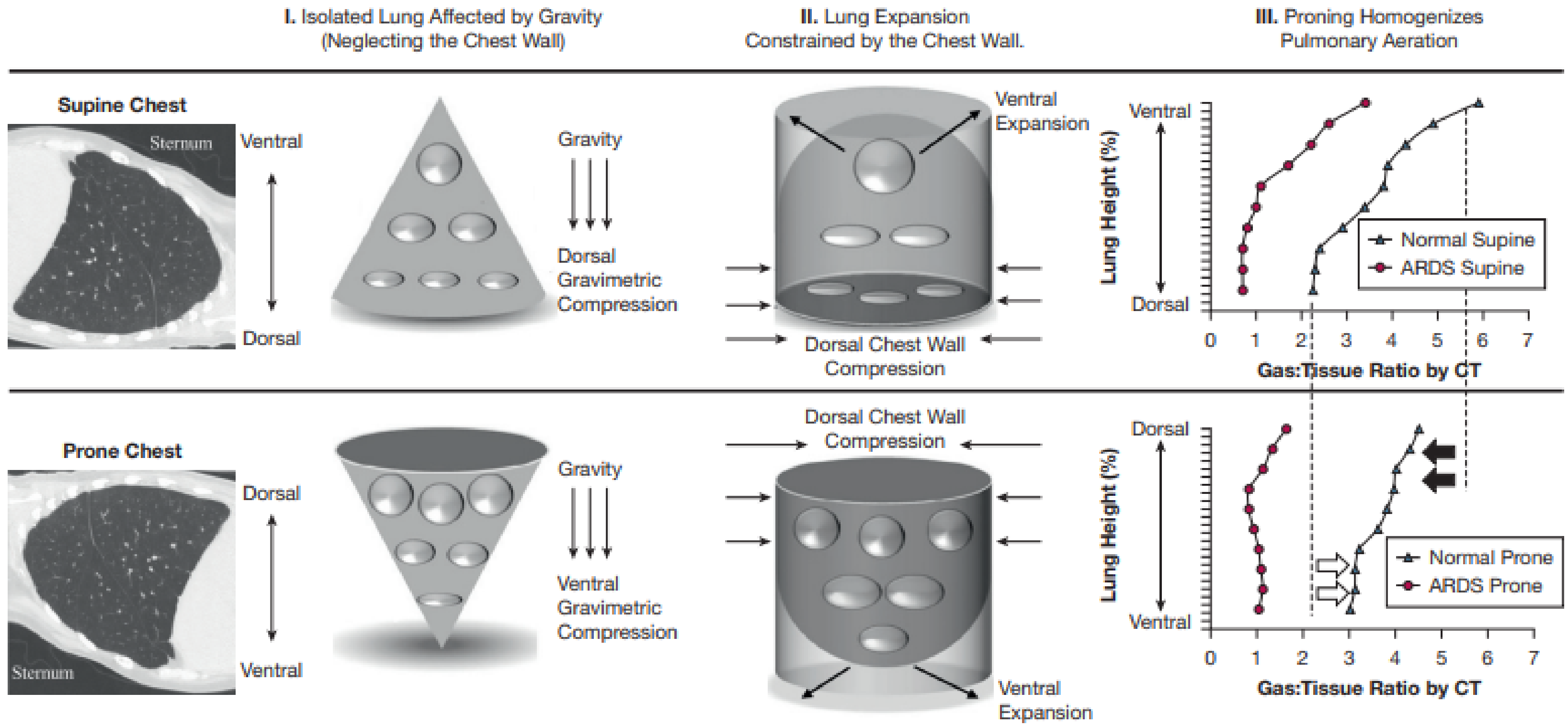


Figure 1 – *Column I shows an isolated lung (cone) and alveolar units (circles) removed from the chest wall. This illustrates how the unhindered lung contains more alveolar units in the dorsal regions than in the ventral regions and how a gravitational pleural pressure gradient leads to compression of dependent segments. When the patient is in a prone position, this results in a smaller fraction of compressed alveolar units than when the patient is supine. Column II illustrates the effects of compressing the native conical shape of the lungs into the rigid chest wall. While the patient is supine, the compressive effects of gravity are magnified by the chest wall, further compressing the dorsal segments while expanding the ventral segments. Conversely, when the patient is prone, the chest wall effects oppose gravimetric effects, leading to more homogeneous aeration. Column III displays experimental data supporting this model. The curves describe how pulmonary aeration (gas to tissue ratio on CT) varies as one moves along the lung's vertical axis in human patients with ARDS. Note the marked asymmetry in aeration (and thus ventilation) along the ventral/dorsal axis when supine and a much more uniform gas to tissue ratio when prone. The white arrows signify recruitment of dependent regions, and the black arrows signify reduced regional hyperinflation in well-aerated lung. (Adapted with permission from Gattinoni et al.[25])*

Eric L. Scholten, et al. Chest. 2017 Jan;151(1):215-224.

Study or Subgroup	Prone Events	Prone Total	Supine Events	Supine Total	Weight	Risk Ratio IV, Random, 95% CI
Moderate to Severe ARDS						
Mancebo *et al.* 2006	38	76	37	60	17.0%	0.81 [0.60, 1.10]
Chan *et al.* 2007	4	11	4	11	3.2%	1.00 [0.33, 3.02]
Fernandez *et al.* 2008	8	21	10	19	6.9%	0.72 [0.36, 1.45]
Taccone *et al.* 2009	52	168	57	174	16.6%	0.94 [0.69, 1.29]
Guerin *et al.* 2013	38	237	75	229	15.3%	0.49 [0.35, 0.69]
Subtotal (95% CI)		**513**		**493**	**59.1%**	**0.74 [0.56, 0.99]**
Total events	140		183			
Heterogeneity: $Tau^2 = 0.05$; $Chi^2 = 8.51$, df = 4 (P = 0.07); $I^2 = 53\%$						
Test for overall effect: Z = 2.06 (P = 0.04)						
All ARDS						
Gattinoni *et al.* 2001	70	152	67	152	19.1%	1.04 [0.82, 1.34]
Guerin *et al.* 2004	134	413	119	378	20.9%	1.03 [0.84, 1.26]
Voggenreiter *et al.* 2005	1	21	3	19	0.9%	0.30 [0.03, 2.66]
Subtotal (95% CI)		**586**		**549**	**40.9%**	**1.03 [0.88, 1.20]**
Total events	205		189			
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.24$, df = 2 (P = 0.54); $I^2 = 0\%$						
Test for overall effect: Z = 0.36 (P = 0.72)						
Total (95% CI)		**1099**		**1042**	**100.0%**	**0.84 [0.68, 1.04]**
Total events	345		372			
Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 16.94$, df = 7 (P = 0.02); $I^2 = 59\%$						
Test for overall effect: Z = 1.60 (P = 0.11)						
Test for subgroup differences: $Chi^2 = 3.93$, df = 1 (P = 0.05), $I^2 = 74.6\%$						

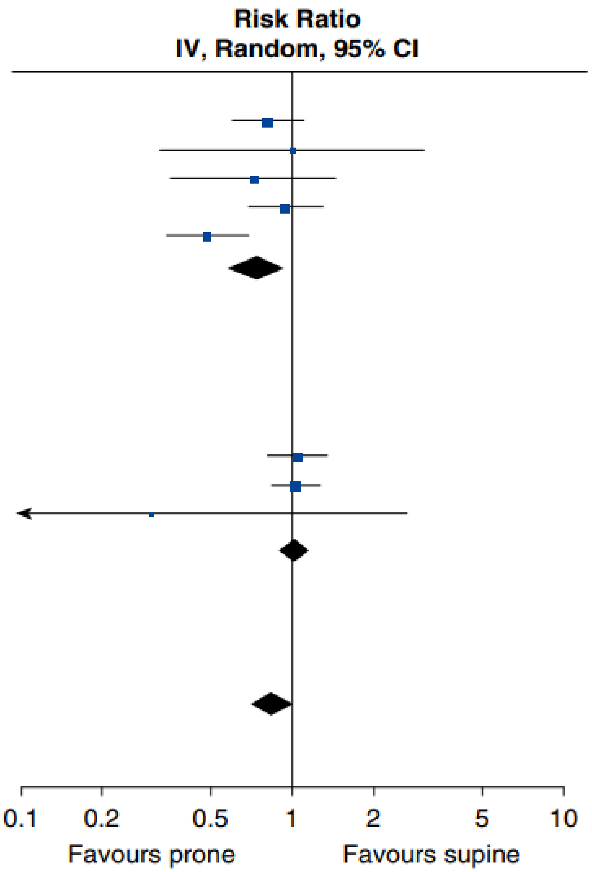
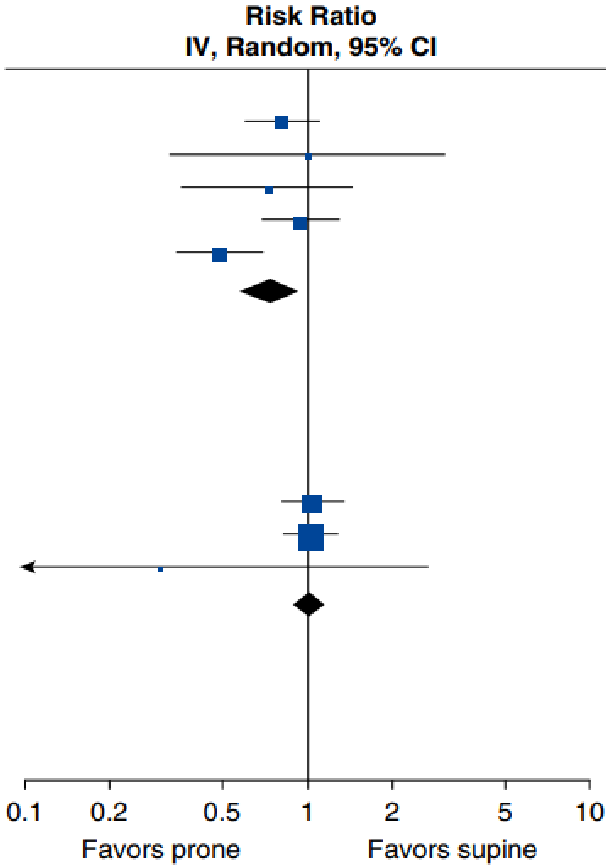


Figure 4. Primary outcome: mortality; subgroup analysis according to study entry criteria of moderate to severe acute respiratory distress syndrome (ARDS) versus all ARDS. Forest plot demonstrating pooled data of early mortality in studies of moderate to severe ARDS versus studies enrolling all types of ARDS using a random effects model. Early mortality was defined as 28-day mortality used for all studies where available; for Gattinoni and colleagues (4), 30-day mortality was used, for Voggenreiter and colleagues (6), 90-day mortality was used, for Fernandez and colleagues (22), 60-day mortality was used, and for Mancebo and colleagues (19), in-hospital mortality was used. The *arrowhead* indicates that the lower confidence interval is beyond the *x-axis* of the graph. CI = confidence interval; df = degrees of freedom; Events = number of deaths; I^2 = statistical heterogeneity; IV = inverse variance; Total = total number of patients.

Laveena Munshi, et al. Ann Am Thorac Soc. 2017 Oct;14(Supplement_4):S280-S288.

SYSTEMATIC REVIEW

Study or Subgroup	Prone Events	Prone Total	Supine Events	Supine Total	Weight	Risk Ratio IV, Random, 95% CI
≥12h Prone						
Mancebo *et al.* 2006	38	76	37	60	28.5%	0.81 [0.60, 1.10]
Chan *et al.* 2007	4	11	4	11	5.7%	1.00 [0.33, 3.02]
Fernandez *et al.* 2008	8	21	10	19	12.0%	0.72 [0.36, 1.45]
Taccone *et al.* 2009	52	166	57	172	27.9%	0.95 [0.69, 1.29]
Guerin *et al.* 2013	38	237	75	229	25.8%	0.49 [0.35, 0.69]
Subtotal (95% CI)		**511**		**491**	**100.0%**	**0.74 [0.56, 0.99]**
Total events	140		183			
Heterogeneity: $Tau^2 = 0.05$; $Chi^2 = 8.53$, df = 4 (P = 0.07); $I^2 = 53\%$						
Test for overall effect: Z = 2.06 (P = 0.04)						
<12h Prone						
Gattinoni *et al.* 2001	70	152	67	152	40.0%	1.04 [0.82, 1.34]
Guerin *et al.* 2004	134	413	119	378	59.5%	1.03 [0.84, 1.26]
Voggenreiter *et al.* 2005	1	21	3	19	0.5%	0.30 [0.03, 2.66]
Subtotal (95% CI)		**586**		**549**	**100.0%**	**1.03 [0.88, 1.20]**
Total events	205		189			
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.24$, df = 2 (P = 0.54); $I^2 = 0\%$						
Test for overall effect: Z = 0.36 (P = 0.72)						



Test for subgroup differences: $Chi^2 = 3.92$, df = 1 (P = 0.05), $I^2 = 74.5\%$

Figure 3. Primary outcome: mortality; subgroup analysis: duration of time prone. Forest plot demonstrating pooled data of early mortality in studies with a longer duration of time prone (≥12 h) versus a shorter time (<12 h) using a random effects model. Early mortality was defined as 28-day mortality used for all studies where available; for Gattinoni and colleagues (4), 30-day mortality was used, for Voggenreiter and colleagues (6), 90-day mortality was used, for Fernandez and colleagues (22), 60-day mortality was used, and for Mancebo and colleagues (19), in-hospital mortality was used. The *arrowhead* indicates that the lower confidence interval is beyond the *x-axis* of the graph. CI = confidence interval; df = degrees of freedom; Events = number of deaths; I^2 = statistical heterogeneity; IV = inverse variance; Total = total number of patients.

Laveena Munshi, et al. Ann Am Thorac Soc. 2017 Oct;14(Supplement_4):S280-S288.

Methods for Setting PEEP for ARDS

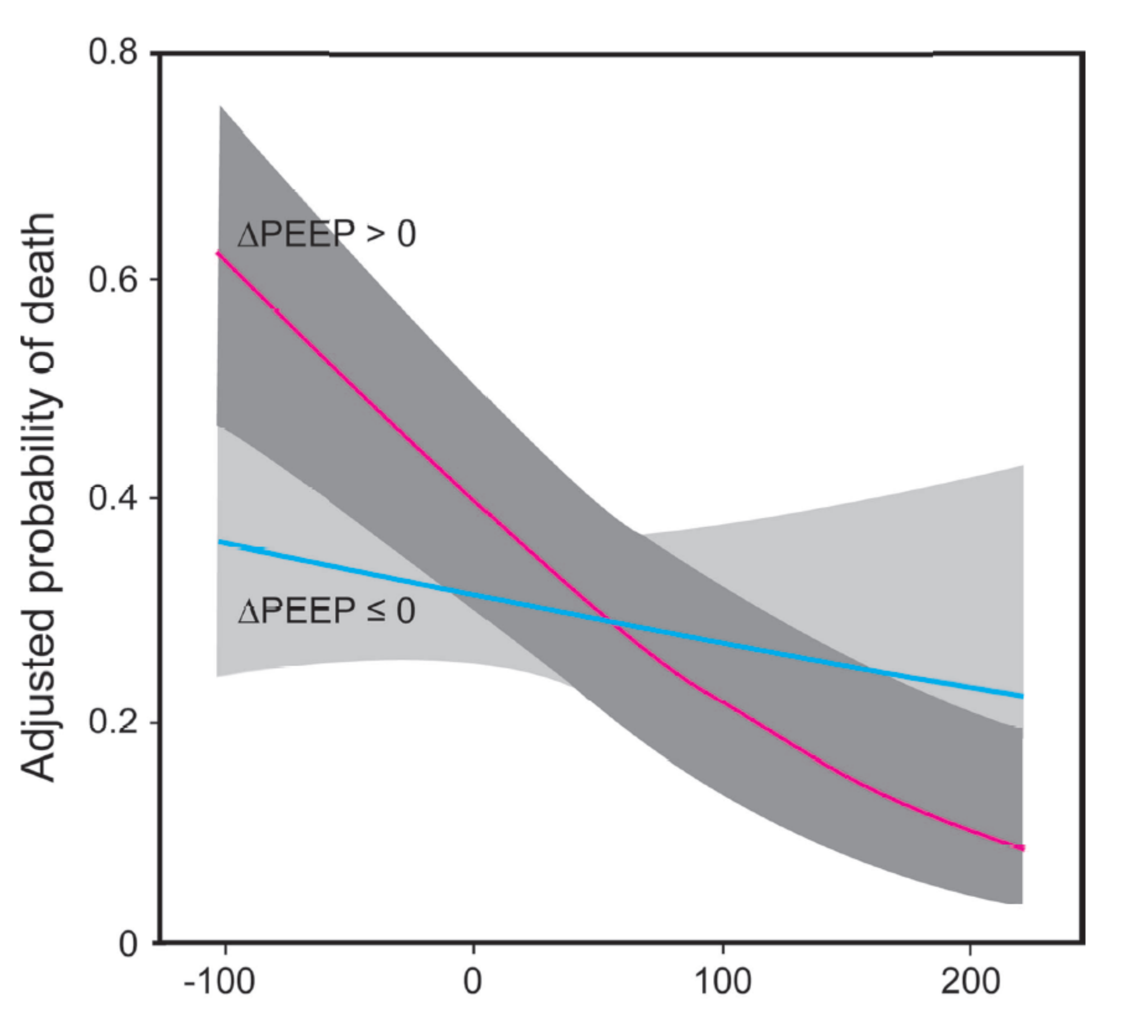
- Gas exchange
- Pressure volume curve
- Compliance
- Stress index
- Esophageal manometry
- Lung volume
- Imaging

Respir Care 2015;60:1688-1704

Gas Exchange

- A increased in PaO_2/FiO_2 when PEEP was increased was associated reduced mortality.
- A decreased in PaO_2/FiO_2 when PEEP was increased was associated increasing mortality.

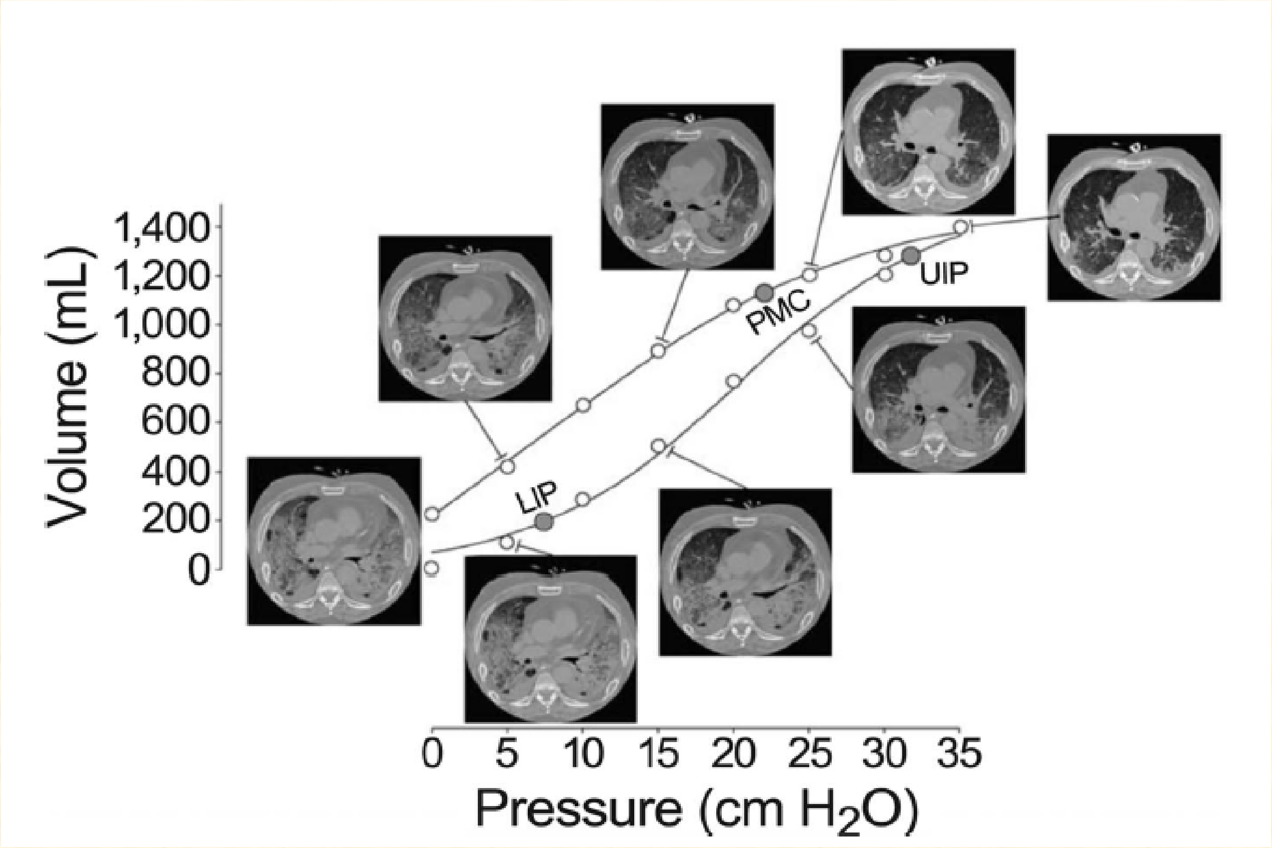
AJRCCM 2014;190:70-76



AJRCCM 2014;190:70-76

Pressure-volume Curve

Set PEEP to 2cmH_2O above lower inflection point.



Curr Opin Crit Care 2008;14:80-86

Compliance

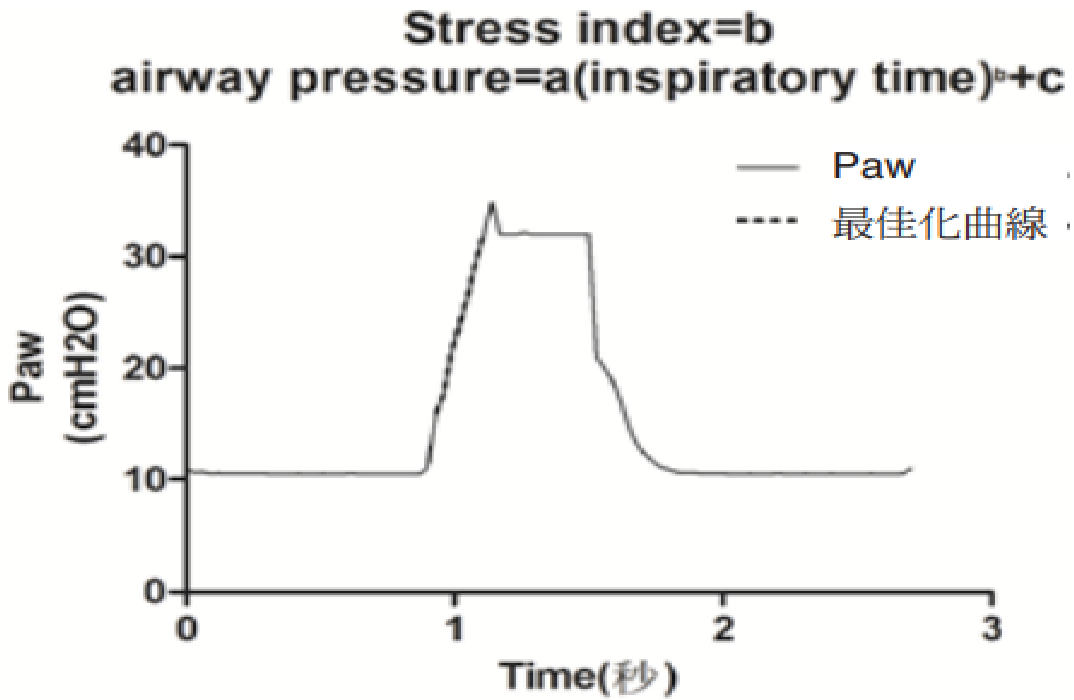
- Selecting the level of PEEP with the highest compliance.
- Compliance: Vt / (plateau pressure –PEEP)
- Increased mortality for driving pressure > 15 cmH_2O

Respir Care 2013;58:1416-1423
NEJM 2015;372:747-755

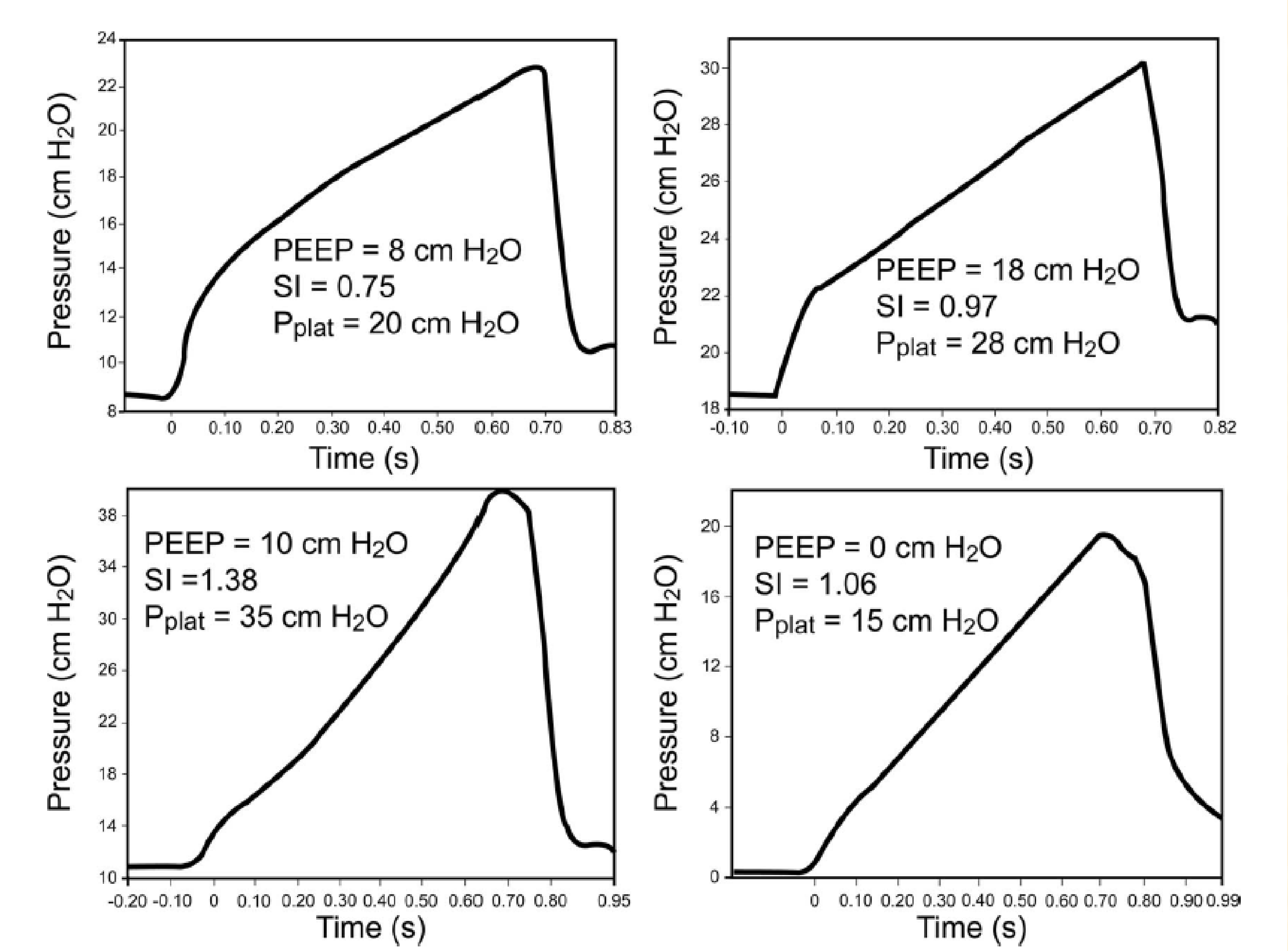
Stress Index

- A linear increase in pressure (stress index=1) suggests alveolar recruitment without over-distention.
- A decrease in compliance as lung are inflated (stress index > 1) suggest over-distention.
- A increase in compliance as lung inflated (stress index <1) suggest potential for additional recruitment.

Respir Care 2014:59:1773-1794



圖七：此圖是本院病人上實際紀錄的壓力時間曲線圖，在容積控制之固定流速模式下(volume controlled ventilation with constant flow)，在壓力時間曲線上取得對應固定流速的那段壓力時間曲線，可以找到一個方程式airway pressure=ax (inspiratory time)^b+c最接近所對應的那段曲線(圖中虛線)，其中方程式中的解b就是stress index。



Respir Care 2014;59:1773-1794
Respir Care 2011;56:1555-1572

Esophageal Manometry

- Chest wall compliance may be reduced in patients with ARDS which result in increased in pleural pressure.
- Pleural pressure higher than alveolar pressure, causing alveolar collapse.
- Set PEEP greater higher than end-expiratory pleural pressure.
- Use of esophageal balloon to estimate pleural pressure.
- Beneficial for morbid obesity or abdominal hypertension.

Respir Care 2010;55:162-167
J Appl Physiol 2010;183:515-522

Lung Volume

- End-expiratory lung volume (EELV) during mechanical ventilation by using helium dilution or nitrogen washout techniques.
- A PEEP induced increase in EELV might be the result of recruitment.
- EELV to assess PEEP response improved if it is combined with measurement of compliance.

Intensive Care Med 2011;37:1595-1604
Crit Care 2011;12:R150

Imaging

- CXR
- Sonogram
  - Can not detect overdistension
- CT
  - Gold standard
- Electrical impedance tomography (EIT)
  - Estimate regional alveolar collapse and overdistension

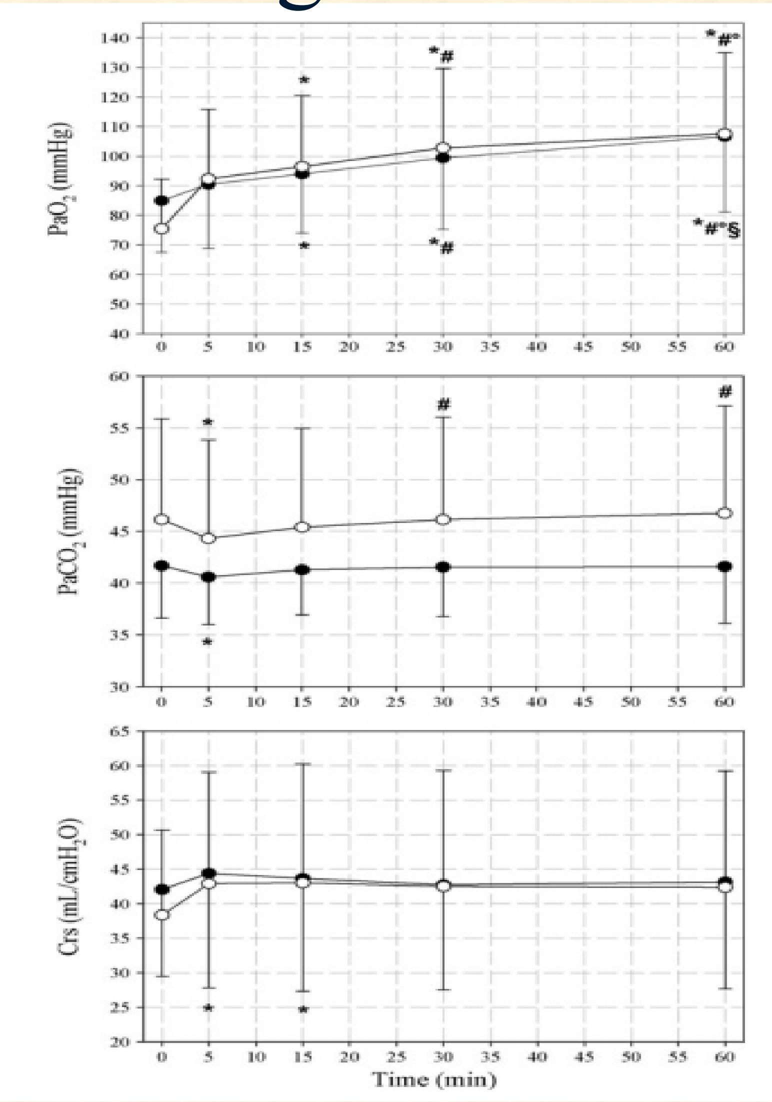
AJRCCM 2011;183:341-347
Respir care 2013;58:416-423
Anesthesiology 2015;122:437-447
Curr Opin Crit Care 2009;15:18-24

How long to wait between changes in PEEP

- The effect of change in PEEP will not be fully realized if too little time.
- Potentially injurious ventilation due to inappropriate PEEP if too much time.
- 5-minute might be used to judge the direction of change.

Intensive Care Med 2013;39:1377-1385

How long to wait between changes in PEEP



Intensive Care Med 2013;39:1377-1385

Higher PEEP vs Lower PEEP

Lower PEEP/Higher F_{IO_2}

F_{IO_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/Lower F_{IO_2}

F_{IO_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	0.9	1.0	1.0
PEEP	5	8	10	12	14	14	16	16	18	20	22	22	22	22	24

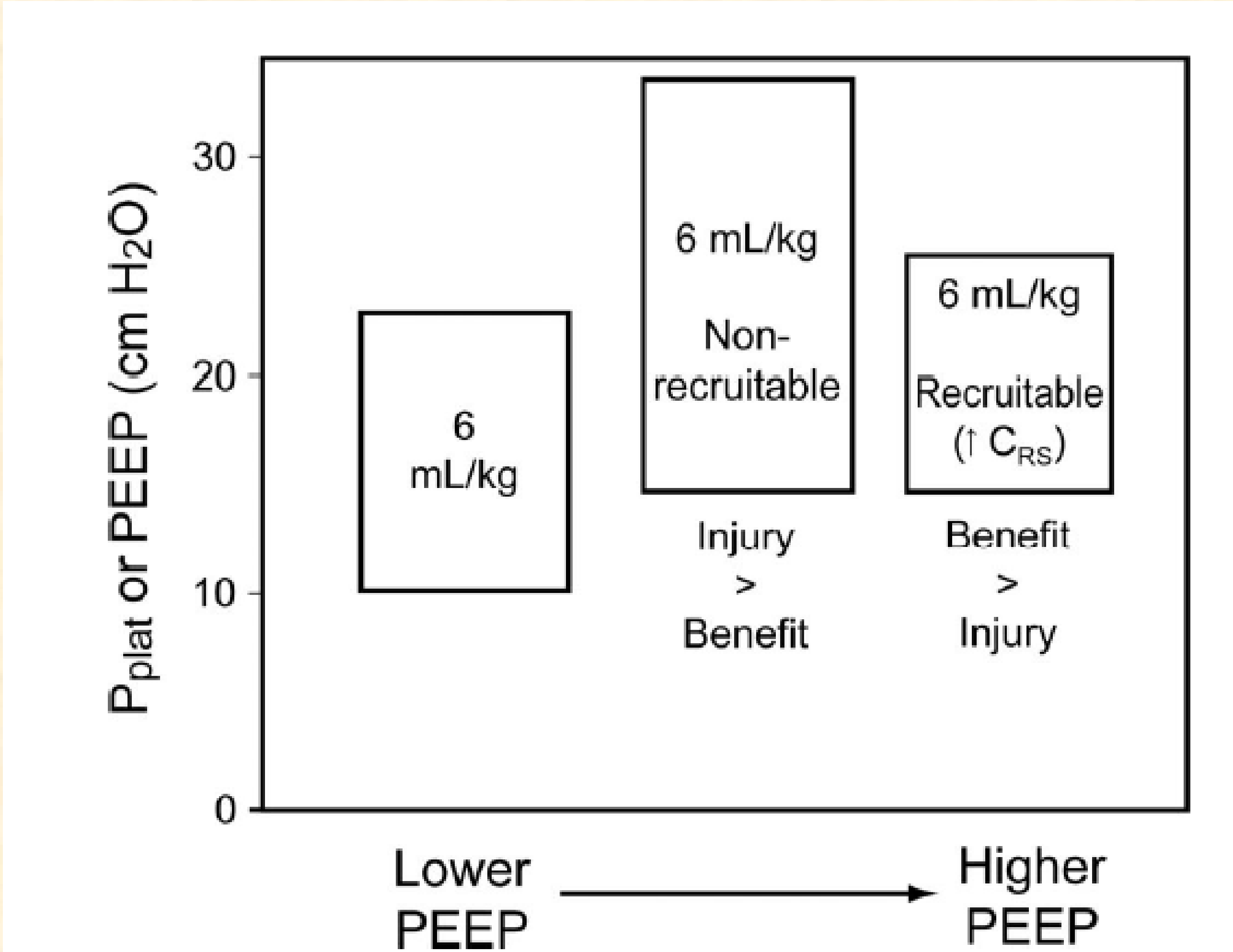
Fig. 4. Tables used to set combinations of F_{IO_2} and PEEP in the ARDS Network study. Data from Reference 59.

NEJM 2004;351:327-336

Higher PEEP vs Lower PEEP

- In moderate and severe ARDS, the mortality was 34.1% in the higher PEEP group 39.1% in the lower PEEP group (RR:0.9, 95%CI:0.81-1.00).
- In mild ARDS, mortality rate was 27.2% in the higher PEEP group 19.4% in the lower PEEP group (RR:1.37, 95%CI:0.98-1.92).

JAMA 2010;303:865-873



Respir Care 2011;56:1555-1572

Potential for Recruitment

- Severe ARDS
  - Lower PaO_2/FiO_2
  - Lower compliance
- Extra-pulmonary ARDS

Crit Care Med 2014;42:252-264
NEJM 2006;543:1775-1786
Intensive Care Med 2000;26:501-507

Contraindications

- Hemodynamic instability
- Pneumothorax or pneumomediastinum
- High risk for pneumothorax
  - Necrotizing pneumonia
  - Lung cysts

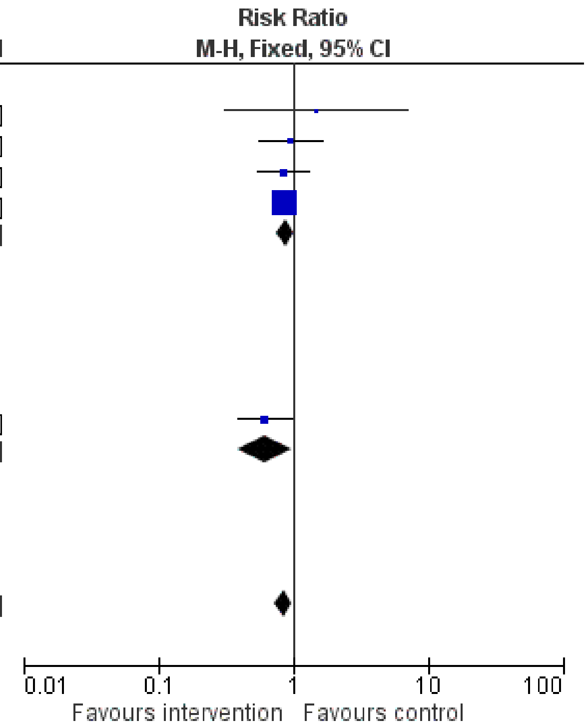
J Intensive Care Med 2011;26:41-49

Clinical Evidence of Recruitment Maneuvers

Primary Outcomes

ICU Mortality

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.2.1 Open lung ventilation including recruitment manoeuvres						
Hodgson 2011	3	10	2	10	0.8%	1.50 [0.32, 7.14]
Huh 2009	14	30	13	27	5.6%	0.97 [0.56, 1.68]
Kacmarek 2016	25	99	30	101	12.1%	0.85 [0.54, 1.34]
Meade 2008	145	475	178	508	69.8%	0.87 [0.73, 1.04]
Subtotal (95% CI)		**614**		**646**	**88.2%**	**0.88 [0.75, 1.03]**
Total events	187		223			
Heterogeneity: Chi² = 0.60, df = 3 (P = 0.90); I² = 0%						
Test for overall effect: Z = 1.57 (P = 0.12)						
1.2.2 Recruitment manoeuvres						
Xi 2010	18	55	29	55	11.8%	0.62 [0.39, 0.98]
Subtotal (95% CI)		**55**		**55**	**11.8%**	**0.62 [0.39, 0.98]**
Total events	18		29			
Heterogeneity: Not applicable						
Test for overall effect: Z = 2.06 (P = 0.04)						
Total (95% CI)		**669**		**701**	**100.0%**	**0.85 [0.73, 0.99]**
Total events	205		252			
Heterogeneity: Chi² = 2.64, df = 4 (P = 0.62); I² = 0%						
Test for overall effect: Z = 2.12 (P = 0.03)						
Test for subgroup differences: Chi² = 2.02, df = 1 (P = 0.15), I² = 50.6%						



Forest plot of comparison: 1 Recruitment manoeuvres versus no recruitment manoeuvres, outcome: 1.7 ICU mortality.

Cochrane database Syst Rev 2016;November:17

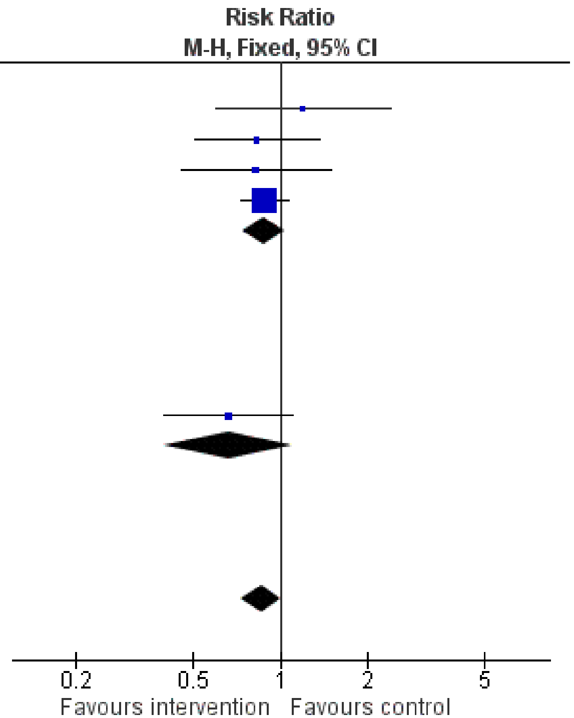
In-hospital Mortality

- Recruitment maneuvers did not reduce mortality in-hospital (RR 0.88, 95% CI 0.77 to 1.01, P = 0.07) (four studies; N = 1313, I^2 = 0%)

Cochrane database Syst Rev 2016;November:17

28-Day Mortality

Study or Subgroup	Intervention Events	Intervention Total	Control Events	Control Total	Weight	Risk Ratio M-H, Fixed, 95% CI
1.1.1 Open lung ventilation including recruitment manoeuvres						
Huh 2009	12	30	9	27	4.0%	1.20 [0.60, 2.39]
Kacmarek 2016	22	99	27	101	11.3%	0.83 [0.51, 1.36]
Liu 2011	14	50	17	50	7.2%	0.82 [0.46, 1.48]
Meade 2008	135	475	164	508	67.2%	0.88 [0.73, 1.06]
Subtotal (95% CI)		**654**		**686**	**89.8%**	**0.88 [0.75, 1.04]**
Total events	183		217			
Heterogeneity: Chi² = 0.87, df = 3 (P = 0.83); I² = 0%						
Test for overall effect: Z = 1.47 (P = 0.14)						
1.1.2 Recruitment manoeuvres						
Xi 2010	16	55	24	55	10.2%	0.67 [0.40, 1.11]
Subtotal (95% CI)		**55**		**55**	**10.2%**	**0.67 [0.40, 1.11]**
Total events	16		24			
Heterogeneity: Not applicable						
Test for overall effect: Z = 1.56 (P = 0.12)						
Total (95% CI)		**709**		**741**	**100.0%**	**0.86 [0.74, 1.01]**
Total events	199		241			
Heterogeneity: Chi² = 1.95, df = 4 (P = 0.75); I² = 0%						
Test for overall effect: Z = 1.86 (P = 0.06)						
Test for subgroup differences: Chi² = 1.06, df = 1 (P = 0.30), I² = 5.9%						



Forest plot of comparison: 1 Recruitment manoeuvres versus no recruitment manoeuvres, outcome: 1.1 28-Day mortality.

Cochrane database Syst Rev 2016;November:17

	LRMs		No LRMs			Risk Ratio	
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI	Year
Co-intervention with higher PEEP							
Amato 1998	11	29	17	24	8.9%	0.54 [0.31, 0.91]	1998
Meade 2008	145	475	178	508	59.3%	0.87 [0.73, 1.04]	2008
Huh 2009	14	30	13	27	8.4%	0.97 [0.56, 1.68]	2009
Hodgson 2011	3	10	2	10	1.1%	1.50 [0.32, 7.14]	2011
Kacmarek 2016	22	99	27	101	10.4%	0.83 [0.51, 1.36]	2016
Subtotal (95% CI)		**643**		**670**	**88.0%**	**0.84 [0.72, 0.98]**	
Total events	195		237				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.71$, df = 4 (P = 0.45); $I^2 = 0\%$							
Test for overall effect: Z = 2.16 (P = 0.03)							
No co-intervention with higher PEEP							
Xi 2010	18	55	29	55	12.0%	0.62 [0.39, 0.98]	2010
Subtotal (95% CI)		**55**		**55**	**12.0%**	**0.62 [0.39, 0.98]**	
Total events	18		29				
Heterogeneity: Not applicable							
Test for overall effect: Z = 2.06 (P = 0.04)							
Total (95% CI)		**698**		**725**	**100.0%**	**0.81 [0.69, 0.95]**	
Total events	213		266				
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 5.30$, df = 5 (P = 0.38); $I^2 = 6\%$							
Test for overall effect: Z = 2.57 (P = 0.01)							
Test for subgroup differences: $Chi^2 = 1.58$, df = 1 (P = 0.21), $I^2 = 36.7\%$							

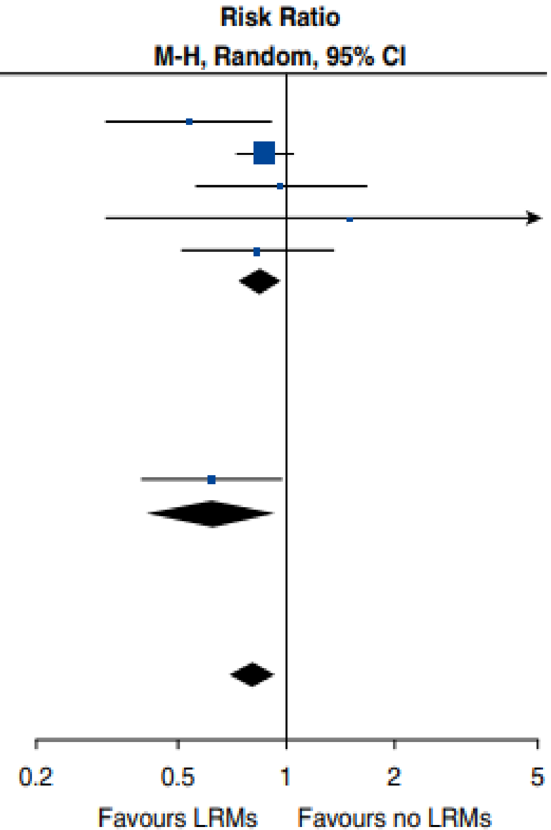


Figure 1. Effect of lung recruitment maneuvers (LRMs) on mortality in patients with acute respiratory distress syndrome. Although the overall pooled effect suggests a statistically significant reduction in mortality, the results are confounded by the concomitant use of a higher positive end-expiratory pressure (PEEP) ventilation strategy in the experimental arm in four of the five trials. Mortality effects of LRMs in trials with or without concomitant higher PEEP were similar (P = 0.27 for subgroup difference). “Events” columns show the number of deaths, and “Total” columns show the number of subjects in the group. Arrowhead indicates that the upper bound of the 95% confidence interval lies beyond the x-axis range. CI = confidence interval; df = degrees of freedom; I 2 = heterogeneity statistic; M-H = Mantel-Haenszel.

Ann Am Thorac Soc. 2017;14:S304-311

Traditional vs Incremental Recruitment

Quality assessment							Ne of patients		Effect		Quality	Importance
Ne of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerati ons	Recruitment maneuvers	control	Relative (95% CI)	Absolute (95% CI)	-	-
Mortality at 28-days												
8	Randomised trials	Not serious	Not serious	Not serious	none	none	490/1256 (39.0%)	509/1290 (39.5%)	RR 0.90 (0.74 to 1.09)	39 fewer per 1,000 (from 103 fewer to 36 more)	MODERATE	CRITICAL
Mortality at 28-days-Tradition Recruitment Maneuver												
4	Randomised trials	Not serious	Not serious	Not serious	serious	none	184/658 (28.0%)	232/688 (33.7%)	RR0.79 (0.64 to 0.96)	71 fewer per 1,000 (from 121 fewer to 13 fewer)	MODERATE	CRITICAL
Mortality at 28-days-Incremental PEEP Recruitment												
4	Randomised trials	Not serious	Not serious	Not serious	serious	none	277/602 (46.0%)	277/602 (46.0%)	RR 1.12 (1.00 to 0.25)	55 more per 1,000 (from 0 fewer to 115 mpre)	MODERATE	CRITICAL

2021 Surviving Sepsis Campaign, Crit Care Med 2021;49(11):e1063-e1143

Quality assessment							Ne of patients		Effect		Quality	Importance
Ne of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Recruitment maneuvers	control	Relative (95% CI)	Absolute (95% CI)	-	-
Hospital Mortality · Traditional Recruitment Maneuver												
4	Randomised trials	Not serious	Not serious	Not serious	serious	none	238/658 (36.2%)	288/687 (41.9%)	RR 0.85 (0.75 to 0.97)	63 fewer per 1,000 (from 105 fewer to 13 fewer)	MODERATE	CRITICAL
Hospital Mortality · Incremental PEEP Recruitment												
4	Randomised trials	Not serious	Not serious	Not serious	serious	none	350/597 (58.6%)	335/602 (55.6%)	RR 1.06 (0.97 to 1.17)	33 more per 1,000 (from 17 fewer to 95 more)	MODERATE	CRITICAL

2021 Surviving Sepsis Campaign, Crit Care Med 2021;49(11):e1063-e1143

2021 Sepsis Campaign Guideline

- For adults with sepsis-induced ARDS, we **recommend** using a low tidal volume ventilation strategy (6 mL/kg), over a high tidal volume strategy (> 10 mL/kg).
  Strong recommendation, high quality of evidence.
- For adults with sepsis-induced severe ARDS, we **recommend** using an upper limit goal for plateau pressures of 30 cm H_2O, over higher plateau pressures
  Strong recommendation, moderate quality of evidence.
- For adults with moderate to severe sepsis-induced ARDS, we **suggest** using higher PEEP over lower PEEP.
  Weak recommendation, moderate quality of evidence.
- For adults with sepsis-induced moderate-severe ARDS, we **suggest** using traditional recruitment maneuvers.
  Weak recommendation, moderate quality of evidence
- When using recruitment maneuvers, we **recommend against** using incremental PEEP titration/strategy.
  Strong recommendation, moderate quality of evidence.

2021 Surviving Sepsis Campaign, Crit Care Med 2021;49(11):e1063-e1143

Secondary Outcomes

Oxygenation

- Recruitment maneuvers improved oxygenation 24 to 48 hours after randomization compared with standard care.

Study or Subgroup	LRMs Mean [mm Hg]	LRMs SD [mm Hg]	LRMs Total	No LRMs Mean [mm Hg]	No LRMs SD [mm Hg]	No LRMs Total	Weight	Mean Difference IV, Random, 95% CI [mm Hg]	Year
Co-intervention with higher PEEP									
Amato 1998	220	38	29	135	29	24	18.9%	85.00 [66.95, 103.05]	1998
Meade 2008	187	69	464	149	61	498	21.1%	38.00 [29.75, 46.25]	2008
Huh 2009	160	82	30	140	47	27	14.2%	20.00 [−14.28, 54.28]	2009
Hodgson 2011	230	70	10	140	63	10	8.6%	90.00 [31.63, 148.37]	2011
Kacmarek 2016	199	79	94	136	44	104	18.9%	63.00 [44.93, 81.07]	2016
Subtotal (95% CI)			**627**			**663**	**81.7%**	**57.01 [32.72, 81.30]**	
Heterogeneity: $Tau^2 = 578.07$; $Chi^2 = 28.97$, df = 4 ($P < 0.00001$); $I^2 = 86\%$									
Test for overall effect: $Z = 4.60$ ($P < 0.00001$)									
No co-intervention with higher PEEP									
Xi 2010	142	61	55	125	46	55	18.3%	17.00 [−3.19, 37.19]	2010
Subtotal (95% CI)			**55**			**55**	**18.3%**	**17.00 [−3.19, 37.19]**	
Heterogeneity: Not applicable									
Test for overall effect: $Z = 1.65$ ($P = 0.10$)									
Total (95% CI)			**682**			**718**	**100.0%**	**49.67 [27.75, 71.59]**	
Heterogeneity: $Tau^2 = 575.99$; $Chi^2 = 37.15$, df = 5 ($P < 0.00001$); $I^2 = 87\%$									
Test for overall effect: $Z = 4.44$ ($P < 0.00001$)									
Test for subgroup differences: $Chi^2 = 6.16$, df = 1 ($P = 0.01$), $I^2 = 83.8\%$									

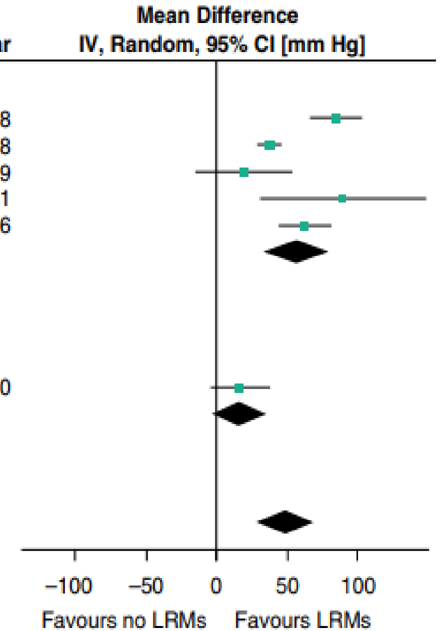


Figure 2. The effect of lung recruitment maneuvers (LRMs) on oxygenation (quantified by the PaO2 /FIO2 ratio) at 24 hours after randomization in patients with acute respiratory distress syndrome. CI = confidence interval; df = degrees of freedom; I 2 = heterogeneity statistic; IV = inverse variance; PEEP = positive end-expiratory pressure.

Ann Am Thorac Soc. 2017;14:S304-311

Barotrauma

- Recruitment maneuvers did not significantly affect the risk of barotrauma.

	LRMs		No LRMs			Risk Ratio	
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI	Year
Amato 1998	2	29	7	24	13.4%	0.24 [0.05, 1.03]	1998
Meade 2008	53	475	47	508	51.0%	1.21 [0.83, 1.75]	2008
Huh 2009	3	30	3	27	12.9%	0.90 [0.20, 4.09]	2009
Kacmarek 2016	6	99	8	101	22.7%	0.77 [0.28, 2.13]	2016
Total (95% CI)		**633**		**660**	**100.0%**	**0.84 [0.46, 1.55]**	
Total events	64		65				

Heterogeneity: $Tau^2 = 0.15$; $Chi^2 = 4.88$, df = 3 (P = 0.18); $I^2 = 38\%$

Test for overall effect: Z = 0.55 (P = 0.58)

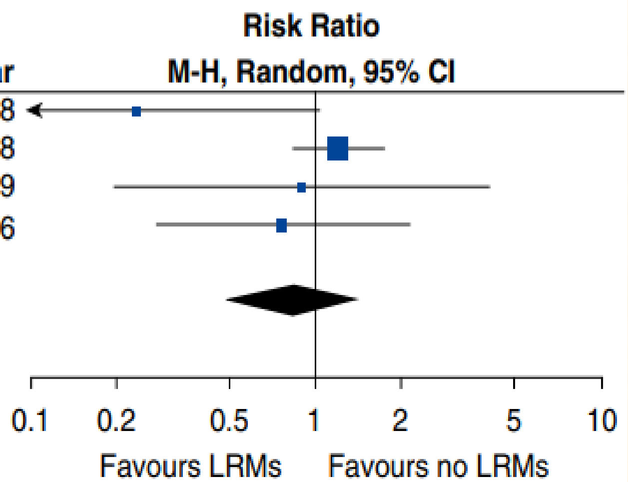


Figure 3. Lung recruitment maneuvers (LRMs) are not associated with a significant increase in barotrauma during mechanical ventilation for acute respiratory distress syndrome. Researchers in two additional trials reported no barotrauma events (16, 18). The median rate of barotrauma across all trials in which barotrauma was reported was 10%. “Events” columns show the number of deaths, and “Total” columns show the number of subjects in the group. Arrowhead indicates that the upper bound of the 95% confidence interval lies beyond the x-axis range. CI = confidence interval; df = degrees of freedom; I 2 = heterogeneity statistic; M-H = Mantel-Haenszel.

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Quality assessment							No. of patients		Effect		Quality	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Recruitment maneuvers	control	Relative (95% CI)	Absolute (95% CI)	-	-
P/F Ratio after 24 hours												
6	Randomised trials	Not serious	Serious	Not serious	Not serious	none	682	718	-	MD 49.67 higher (27.75 higher to 71.59 higher)	MODERATE	IMPORTANT
Barotrauma												
5	Randomised trials	Not serious	Serious	Not serious	serious	none	67/691 (9.7%)	71/716 (9.9%)	RR 0.79 (0.46 to 1.37)		LOW	IMPORTANT

2021 Surviving Sepsis Campaign, Crit Care Med 2021;49(11):e1063-e1143

Rescue Therapies

- An open lung ventilation strategy that included recruitment maneuvers had effect on the use of rescue therapies for participants with severe hypoxemia.

Study or Subgroup	LRMs Events	LRMs Total	No LRMs Events	No LRMs Total	Weight	Risk Ratio M-H, Random, 95% CI	Year
Meade 2008	37	475	61	508	98.3%	0.65 [0.44, 0.96]	2008
Hodgson 2011	0	10	2	10	1.7%	0.20 [0.01, 3.70]	2011
Total (95% CI)		**485**		**518**	**100.0%**	**0.64 [0.43, 0.93]**	
Total events	37		63				

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.61$, df = 1 (P = 0.43); $I^2 = 0\%$
Test for overall effect: Z = 2.31 (P = 0.02)

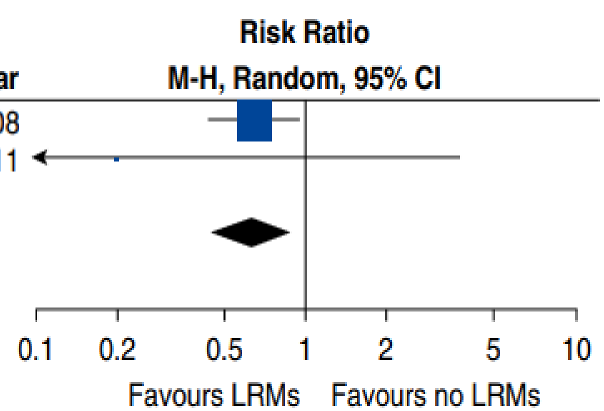

Figure 4. Rescue therapy was required less frequently in patients subjected to lung recruitment maneuvers (LRMs) during mechanical ventilation for acute respiratory distress syndrome. “Events” columns show the number of deaths, and “Total” columns show the number of subjects in the group. Arrowhead indicates that the upper bound of the 95% confidence interval lies beyond the x-axis range. CI = confidence interval; df = degrees of freedom; I 2 = heterogeneity statistic; M-H = Mantel-Haenszel.

Ann Am Thorac Soc. 2017;14:S304-311

Summary of Evidences

- Recruitment maneuvers in participants with ARDS reduced intensive care unit mortality without increasing the risk of barotrauma but had no effect on 28-day and hospital mortality.

- Meta-analysis have not found lasting improvement in clinical outcomes, possibly due to methodology and population heterogeneity.

Cochrane database Syst Rev 2016;November:17.
Am J Respir Crit Med 2008;178:1156-1163

Take Home Message

- Recruitment maneuvers are helpful in increasing aerated lung volume, which decreases strain and derecruitment.
- Patients with early, severe ARDS with diffuse changes on chest radiograph and low lung compliance are good candidate for recruitment maneuver.
- Post-recruitment application of adequate PEEP, appropriate position and management of fluid balance are critical for maintain recruitment maneuver-generated gains.

Take Home Message

- PEEP should be selected as a balance between alveolar recruitment and overdistension.
- PEEP of < 5 cmH_2O is probably harmful early in the course of ARDS.
- PEEP: 5-10 cmH_2O for mild ARDS, 10-15 cmH_2O in moderate ARDS, 15-20 cmH_2O in severe ARDS.
- Recruitment maneuvers should be used within lung protection and not just as a means of improving oxygenation.

Take Home Message

- Complications of recruitment maneuver are common but temporary, barotrauma appear to be rare.
- If a recruitment maneuver is effective, sufficient PEEP is necessary to maintain the recruitment, recommend against using incremental PEEP titration/strategy.
- Evidences show recruitment maneuvers improve patient outcome, especially improving ICU mortality or RM combination with higher PEEP.

The End

Thanks for Your Attention