# Recruitment maneuver in ARDS- Rationale, protocols and utility

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# Overview of the seminar

- Introduction
- Physiological considerations of ARDS and RMs
- Rationale of lung recruitment
- Different types of RMs
- Benefits and complications of RMs
- Assessment of lung recruitability

# Introduction

- In a normal homeostatic condition: Sigh reflex maintains lung compliance and decreases atelectasis. However, during mechanical ventilation, there is no sigh reflex
- One way to maintain oxygenation, FRC, and respiratory system elastance is the application of recruitment maneuvers (RMs), which have become a component of lung-protective ventilation strategies

Hartland BL, et al. Respir Care 2015; 60: 609-620

- Recruitment is the dynamic process of opening previously collapsed lung units by increasing transpulmonary pressure
- Lung units can be kept open by airway pressures that are lower than those required to open them, leading to the concept of recruitment using periodic higher pressure maneuvers with application of PEEP to maintain alveolar patency

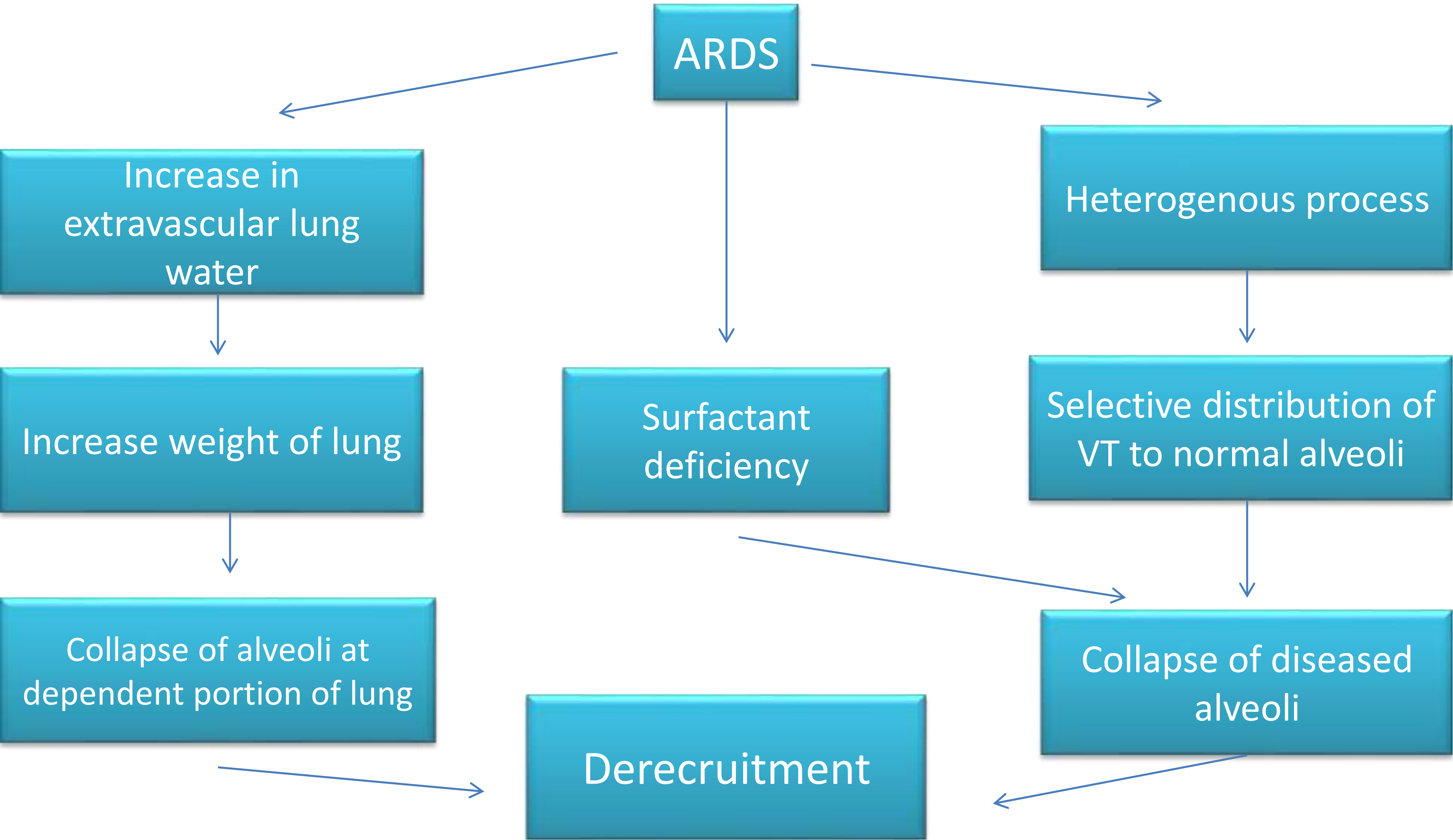
Lapinsky SE et al, Critical Care 2005; 9: 60-65
Crotti S et al, Am J Respir Crit Care Med 2001, 164: 131-140

# Definition

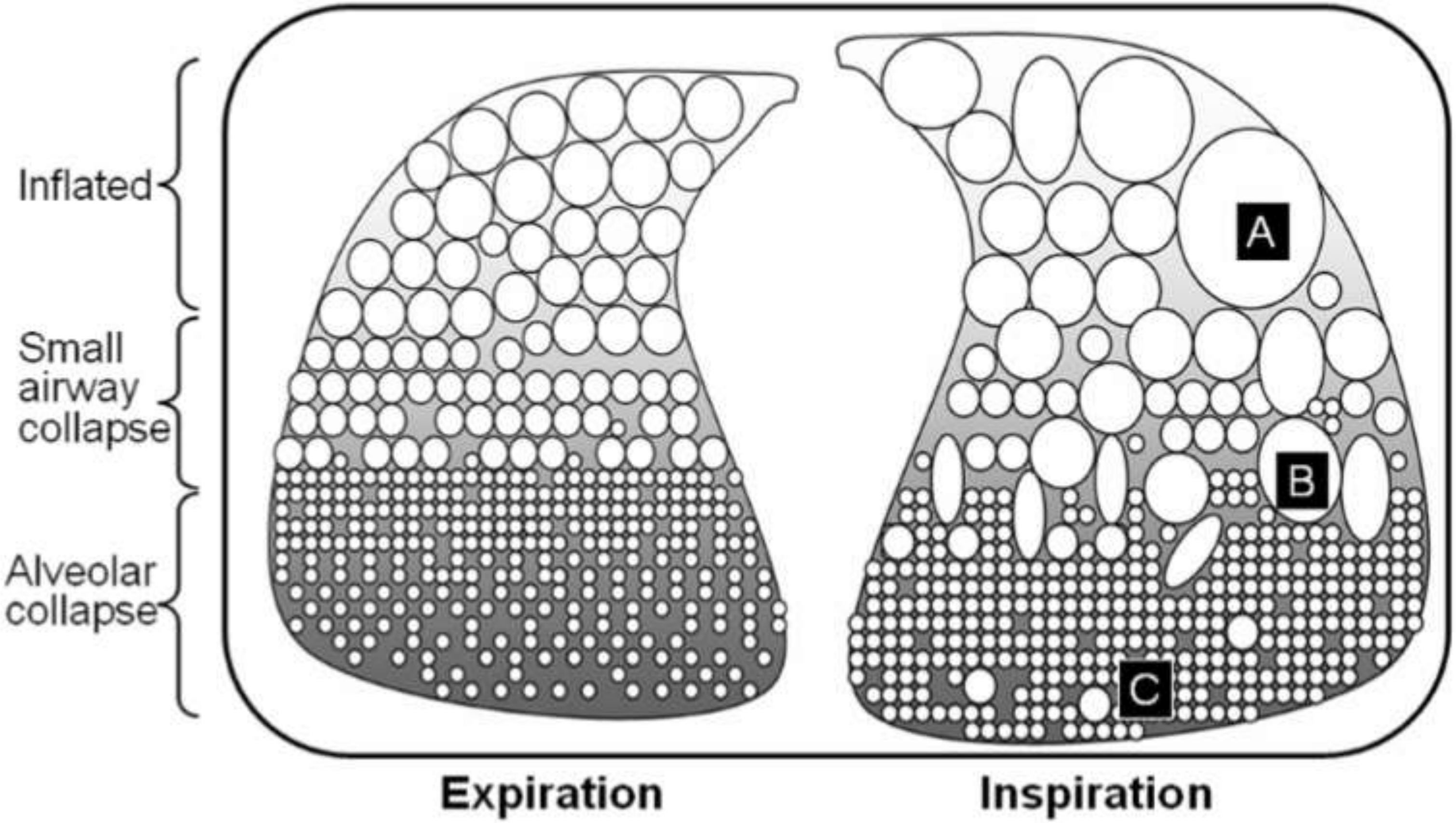
- Recruitment maneuvers can be defined as a voluntary strategy to increase the transpulmonary pressure transiently with the goal to reopen those alveolar units that are not aerated or poorly aerated but reopenable

Guerin C, et al. Annals of Intensive Care 2011; 1: 9

# Mechanisms of derecruitment in ARDS



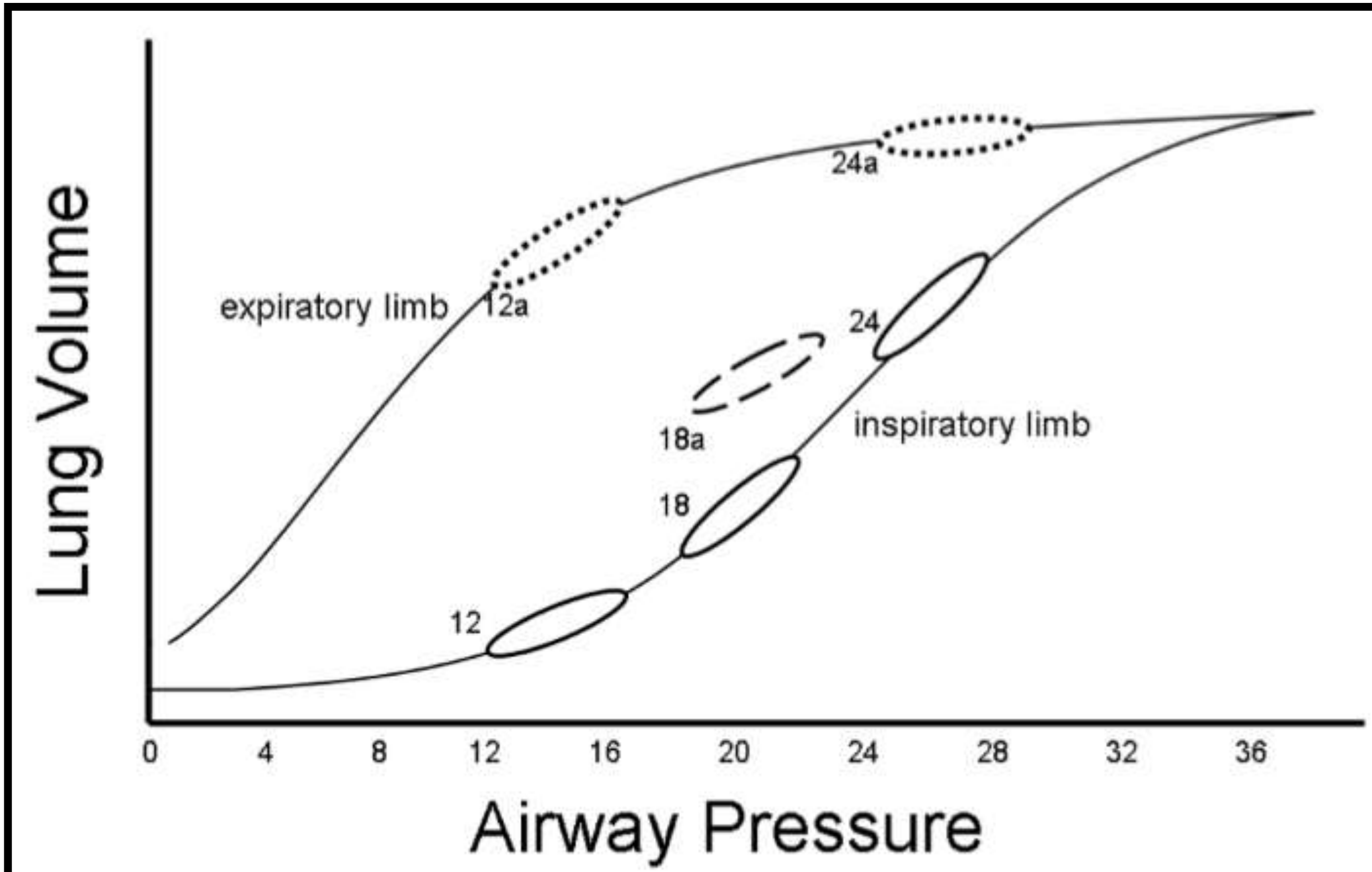
# Mechanisms of injury during tidal ventilation




A-At end-inspiration, patent alveoli may become over-stretched
B-Excessive stresses may be generated at the boundary between aerated and nonaerated lung
C-Dependent alveoli may be repetitively opened and closed producing tissue damage

Puybasset L, et al. Intensive Care Med 2000, 26: 857-869

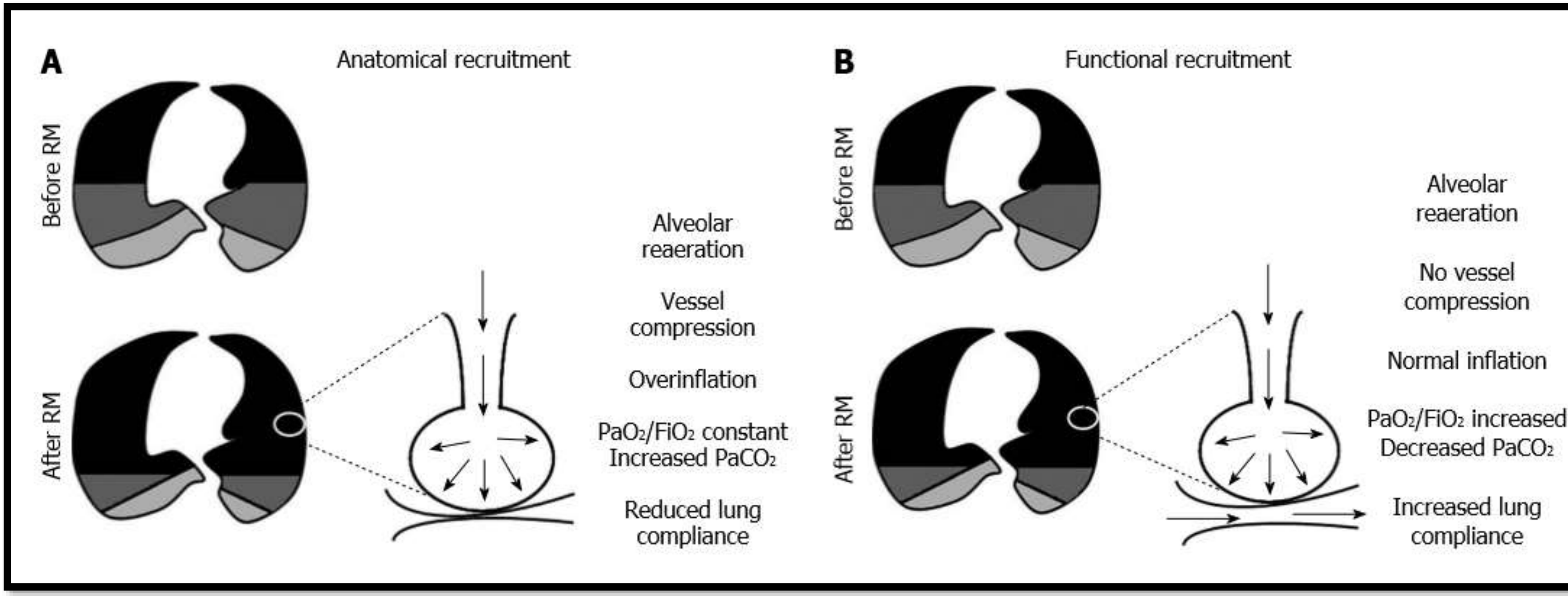
# Pressure–volume curve demonstrating tidal ventilation at various PEEP levels



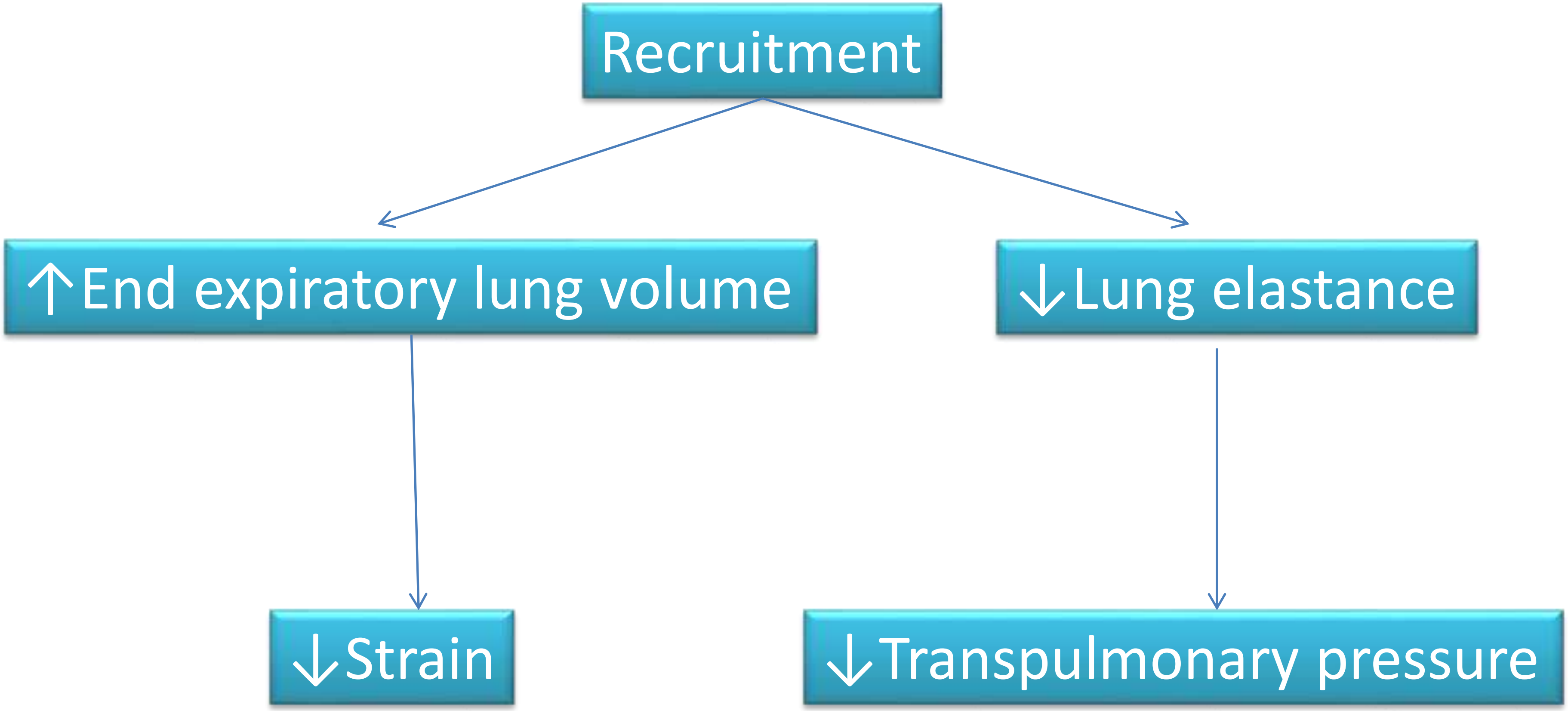

Tidal ventilation is shown at 12, 18 and 24 $cmH_2O$ with no recruitment effect (solid lines); at 18 $cmH_2O$ with partial recruitment (18a), and at 12 and 24 $cmH_2O$ following an effective recruitment manuever (12a, 24a)

Puybasset L, et al. Intensive Care Med 2000, 26: 857-869

# Physiological effects of RMs




Reperfusion is a landmark of functional recruitment


Recruitment
↑End expiratory lung volume
↓Lung elastance
↓Strain
↓Transpulmonary pressure

# Rationale of lung recruitment

**1.ARDS lung is derecruited and is recruitable**

- Atelectasis results from increased interstitial pressure and weight of the lung
- It can be enhanced by patient related factors- obesity, ↑intraabdominal pressure, high levels of inspired oxygen in unstable alveoli, patient disconnection from the ventilator, tracheal suctioning

- Lung in ARDS can be reaerated by increasing transpulmonary pressure
- Lung recruitability has been found to be quite low, averaging 9% of total lung mass, between 5 and 45 cm of $H_2O$
- Other investigators have found that all of the lung can be reopened in early ARDS if a sufficient amount of $P_L$ is generated to go over the critical opening pressure(COP) of the lung units

Gattinoni L, et al. N Eng J Med 2006; 354: 1775-86
Borges JB, et al. Am J Respir Crit Care Med 2006; 174: 268-78

## 2.Concept of COP of the lung units

- Closed terminal respiratory units should reopen once a minimal amount of regional $P_L$ to maintain patency of small airways and/or alveoli has been reached
- In humans, COP values have been found to follow a Gaussian distribution with a mode of approximately 25 cm of $H_2O$ or a bimodal distribution with a second mode close to 40 cm $H_2O$
- Full range of regional COP was as wide as 0 to 60 cm $H_2O$

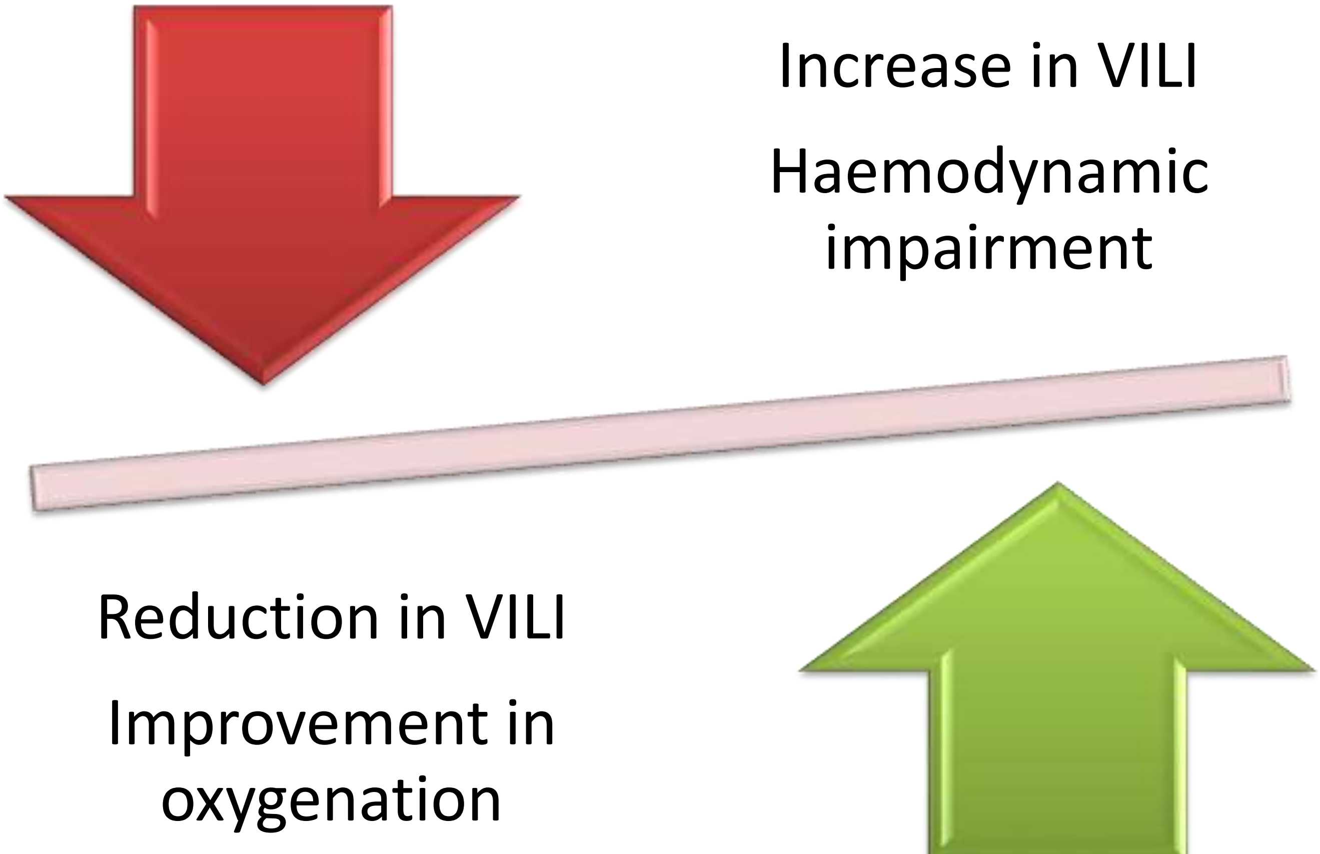
Crotti S, et al. Am J Respir Crit Care Med 2011; 164: 131-140
Borges JB, et al. N Eng J Med 2006; 355:319-320

**3. Lung recruitment is beneficial by reducing VILI**

- Recruiting the lung is a ventilatory strategy that can decrease VILI:
  - Increase in the aerated lung mass, which contributes to minimize the lung heterogeneity and to increase the size of baby lung
  - Prevention of repeated opening and closure of the terminal respiratory units

Dreyfuss D, et al. Am J Resp Crit Care Med 1998; 157: 294-323

# Global effect of RM



# How to recruit lung: Different types of recruitment maneuvers

1. The **sigh RM** in which higher tidal volume and inspiratory airway pressures are intermittently delivered
2. The **sustained inflation RM** in which a static increase in airway pressure (usually in CPAP mode) is transiently applied (20-40 s)
3. The **extended sigh RM**, where a stepwise PEEP increases is applied in order to increase airway pressure in volume or pressure controlled mode

Chiumello D, et al. Minerva anestesiologica 2016; 82: 210-20

# Sigh RM

- Mimic physiological breathing
- Consists of high VT in controlled mode or high PEEP up to a specific plateau pressure level, for a selected number of cycles
- Pelosi et al: 3 consecutive sighs/ minute at 45 cm $H_2O$ plateau pressure
- Improvement in oxygenation, lung elastance, and functional residual capacity compared to patients who did not receive sighs
- High sigh frequency (up to 180/h) was associated with hyperinflation and expression of type Ⅲ procollagen mRNA in lung tissue in experimental models

Pelosi P, et al. Am J Respir Crit Care Med 1999; 159: 872-880
Steimback PW, et al. Intensive Care Med 2009; 35: 1120-1128

# Clinical studies evaluating sigh maneuvers

| Author,year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Pelosi (1999) | 10 | ARDS | Observational | VT :6-8 ml/kg PEEP 14±2.2 $cmH_2O$ | $PaO_2$ significantly increased; reduction of $PaCO_2$ | N=5(50%) | No data |
| Pelosi (2003) | 10 | ARDS(early) | Observational | VT 7 ml/kg IBW; PEEP 14±3 $cmH_2O$ | $PaO_2$ significantly increased in both supine and prone | N=4(40%) | No major complications |
| Villagrà (2002) | 17 | ARDS (early: 8 patient were also studied in late phase) | Observational | VT<8 ml/kg PEEP 14±1 $cmH_2O$ | $PaO_2$ not increased during rM. $PaCO_2$ increased and pH decreased significantly. Values returned to baseline 15 min after rM in early but remained altered in late ARDs group | No data | No major complications |

# Sustained inflation RM

- Most widely described RM
- Oczenski, Grasso: 40 cm $H_2O$ for 40 seconds
- Reported to improve oxygenation and lung function and minimize atelectasis in experimental and clinical scenarios
- Has also been associated with risk of hypotension and barotrauma

Riva DR, et al. Crit Care Med 2008; 36: 1900-1908
Meade MO, et al. JAMA 2008; 299: 637-645

# Procedure of sustained inflation recruitment

- Done after ensuring SBP between 100-200 mmHg and HR between 70-140/min
- Ensure patient is sedated and paralyzed. If $FiO_2$ <1.00, $FiO_2$ to be raised to 1.00 for 5 minutes
- Ventilation mode to be changed to CPAP= most recent PEEP level
- CPAP to be increased over 10 seconds to 40 cm $H_2O$ (or 45 if measured BW is > 150% PBW).CPAP to be maintained at 40(or 45) cm$H_2O$ for 45 seconds

- The RM to be terminated immediately and CPAP returned to the most recent PEEP level if any of the following signs of distress occurs:
  - A. SBP decreases to 90 mmHg or by > 30 mmHg
  - B. HR increases to >140/min or by >20/min
  - C. SpO2 decreases by 5% and is <90%
- After 45 seconds at CPAP=40(or 45)cm $H_2O$,CPAP to be decreased over 5 seconds to the pre-RM level
- Most recent ventilation settings will be resumed upon completion or early termination of RM
- If 2 RMs require early termination within a single 24 hour interval, no additional recruitment maneuvers to be attempted for atleast 12 hours

# Clinical studies evaluating sustained inflation maneuvers

| Author, year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Oczenski (2004) | 30 | ARDS (early) | Randomized | VT 6 ml/kg IBW. PEEP:rM group 15.1±1.2 $cmH_2O$, no-rM group: 14.5±1.3 $cmH_2O$ | $PaO_2$ significantly increased at 3 min after rM, baseline values were reached again within 30 min | No data | No major complication |
| Xi (2010) | 110 | ARDS | Randomized | VT, rM group 6.6±0.9 ml/kg, no-rM group 6.8±1.1 ml/kg PEEP, rM-group 10.5±3.2 $cmH_2O$, no-rM group 9.7±2.4 $cmH_2O$ | No differences in $PaO_2$ between two groups | No differences in hospital and 28-day mortality. ICU mortality significantly lower in rM group | Hypotension: in one instance rM was terminated early |
| Brower (2003) | 96 | ALI/ ARDS | Cross-over study | VT 6.0±0.8 ml/kg PBW PEEP 13.8±3.0 $cmH_2O$ | $SpO_2$ were greater within 10 and 60 mins after rMs than after sham rMs; no significant differences at the other time points | No data | Hypotension and low SpO2: in 3 instances rMs were terminated early. Barotrauma after one rM and after one sham rM |

# Clinical studies evaluating sustained inflation maneuvers

| Author, year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Grasso (2002) | 22 | ARDS | Observational | VT, rM-responding group 6.1±0.1 ml/kg, rM-non responding group 6.0±0.2 ml/kg PEEP, rM responding group 9.4±2.2 $cmH_2O$, rM-non-responding group 9.1±2.7 $cmH_2O$ | $PaO_2$ significantly increased in rM responding group than in non-responding; 20 min after values of $PaO_2$ tended to return toward baseline values in both groups | No data | Hypotension (transitory) in PEEP non responding group |
| Meade (2008) | 125 | ALI/ARDS | Observational | VT 8.4±3.0 ml/kg PEEP 10±4 $cmH_2O$ | $PaO_2$ not significantly increased following the first or subsequent rMs. Augmenting the inflation pressure or duration had no significant effect | No data | Barotrauma: 4(3.2%), ventilator asynchrony: 5 (4%), appeared uncomfortable: 3 (2.4%), experienced transient hypotension: 2 (1.6%) |

# Clinical studies evaluating sustained inflation maneuvers

| Author, year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Meade (2008) | 983 | ALI/ARDS | Randomized | VT, LOV group 6.8±1.4 ml/kg, control group 6.8±1.3 ml/kg PEEP, LOV group 14.6±3.4 $cmH_2O$, control group 9.8±2.7 $cmH_2O$ | LOV group had lower rates of refractory hypoxemia and lower mortality rates with refractory hypoxemia; no difference in $PaCO_2$ | Hospital mortality: 36.4% in LOV group and 40.4% in the control group | Hypotension 4.5%, desaturation: 4.2%, bradycardia or tachycardia: 1.8%, barotrauma: LOV 53 (11.2%) control 47 (9.1%) |
| Amato (1998) | 53 | ARDS(early) | Randomized | VT, protective ventilation 6 ml/kg, Control group 12 ml/kg. PEEP, protective ventilation 16.4 ±0.4 $cmH_2O$,control group 6.2±0.5 $cmH_2O$ | $PaO_2$ significantly increased in protective ventilation group;$PaCO_2$ higher in protective group | 28 days mortality:11(38%) in protective group vs. 17(71%)in control group | Barotrauma: 2 (7%) in protective ventilation vs. 10 (42%) in control group |

# Optimal duration of a sustained inflation recruitment maneuver

50 ARDS patients,within 24 hours of meeting ARDS criteria

↓

A 40 $cmH_2O$ sustained inflation RM maintained for 30 s after sedation

↓

Volume increase during the RM was measured by integration of the flow required to maintain the pressure at 40 $cmH_2O$

↓

In early-onset ARDS patients, most of the recruitment occurs during the first 10 s of a sustained inflation RM. However, hemodynamic impairment is significant after the tenth second of RM

Arnal JM, et al. Intensive Care Med 2011; 37: 1588-94

# Stepwise RM

- Hodgson: PEEP was increased from baseline (range 10-18) to 20, 30 and 40 cm $H_2O$ every 2 minutes to achieve maximum alveolar pressure of 55 ± 3 cm $H_2O$, then decreased at 3-minute intervals to 25, 22.5, 20, 17.5, and 15 cm $H_2O$ until a decrease of 1% to 2% oxygen saturation from maximum was detected
- Since stepwise RMs recruit lung units as effectively as sustained inflation with a lower mean airway pressure, they may lead to less hemodynamic compromise and hyperinflation

Hodgson CL, et al. J Intensive Care Med. 2011; 26: 41-9

- In experimental endotoxin-induced mild ARDS, stepwise RM, compared to sustained inflation, was associated with reduced type Ⅱ epithelial cell damage and decreased expression of markers associated with fibrosis and endothelial cell damage

Silva PL, et al. Crit Care Med 2013; 41: e256-e265

# Clinical studies evaluating extended sigh maneuvers

| Author, year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Foti (2000) | 15 | ARDS(only PEEP responders) | Observational | VT 7.9 ml/kg PEEP 13.3±27.7 $cmH_2O$ | $PaO_2$ and $SaO_2$ significantly increased after rMs, no difference in $PaCO_2$ | No data | No major complication |
| Johannigman (2003) | 12 | ARDS (early) | Observational | VT 6.3 ml/kg IBW PEEP 12.3±3.2 $cmH_2O$ | $PaO_2$ significantly increased 3 mins after rM. 2 hours after the rM, oxygenation fell below 30-min values but remained greater than pre-rM values | No data | No major complication |
| Borges (2006) | 26 | ALI/ARDS (early) | Observational | VT 6 ml/kg PBW PEEP 5-10 $cmH_2O$ | PaO2 significantly increased | Overall ICU mortality: 11(42.3%), hospital death 14 (57.7%) | No major complication |

# Clinical studies evaluating extended sigh maneuvers

| Author, year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Moràn (2011) | 13 | ALI/ARDS(early) | Observational | VT 7.8 ml/kg IBW PEEP 15±4 $cmH_2O$ | $PaO_2$ significantly increased and remained greater than pre-rM values | No data | Transitory hypotension |
| Lim (2003) | 47 | ARDS(early) | Randomized | VT 8 ml/kg PEEP of 10 $cmH_2O$ | PaO2 significantly increased in rM+PEEP group. $PaO_2$ in rM-only and in PEEP-only group did not differ. Patients with extrapulmonary ARDS showed greater increase in $PaO_2$ after rM | rM+PEEP 10 (50%); rM 10 (52.6%); PEEP-only group 7 (87.5%) | No major complication |

# Clinical studies evaluating extended sigh maneuvers

| Author, year | n | Diagnosis | Study type | Ventilation strategy | Gas exchange | Mortality | Complications |
|---|---|---|---|---|---|---|---|
| Hogdson (2011) | 20 | ARDS | Randomized | VT 6 ml/kg in both groups. PEEP, experimental group 15±1 $cmH_2O$, control group 10±0.5 $cmH_2O$ | PaO2 significantly increased in experimental group than control group over the first 24 hours and over 7 days | No data | Desaturation in 3 instances at maximum PEEP of 40 $cmH_2O$ (no lasting adverse effects) |
| Huh (2009) | 57 | ARDS | Randomized | VT,Experimental group 7.9±1.9 ml/kg,Control group 8.0±1.4 ml/kg. PEEP,Experimental group 8.4±3.1$cmH_2O$,control gproup 7.0±3.7 $cmH_2O$ | $PaO_2$ significantly increased and $PaCO_2$ was higher in decremental PEEP titration group than in control group. PaO2 and $PaCO_2$ levels were not different between 2 groups during follow up | Overall mortality 37%. 28 and 60 day mortality did not differ between 2 groups | Barotrauma:3 (11%) in experimental vs 3 (11%) in control group |

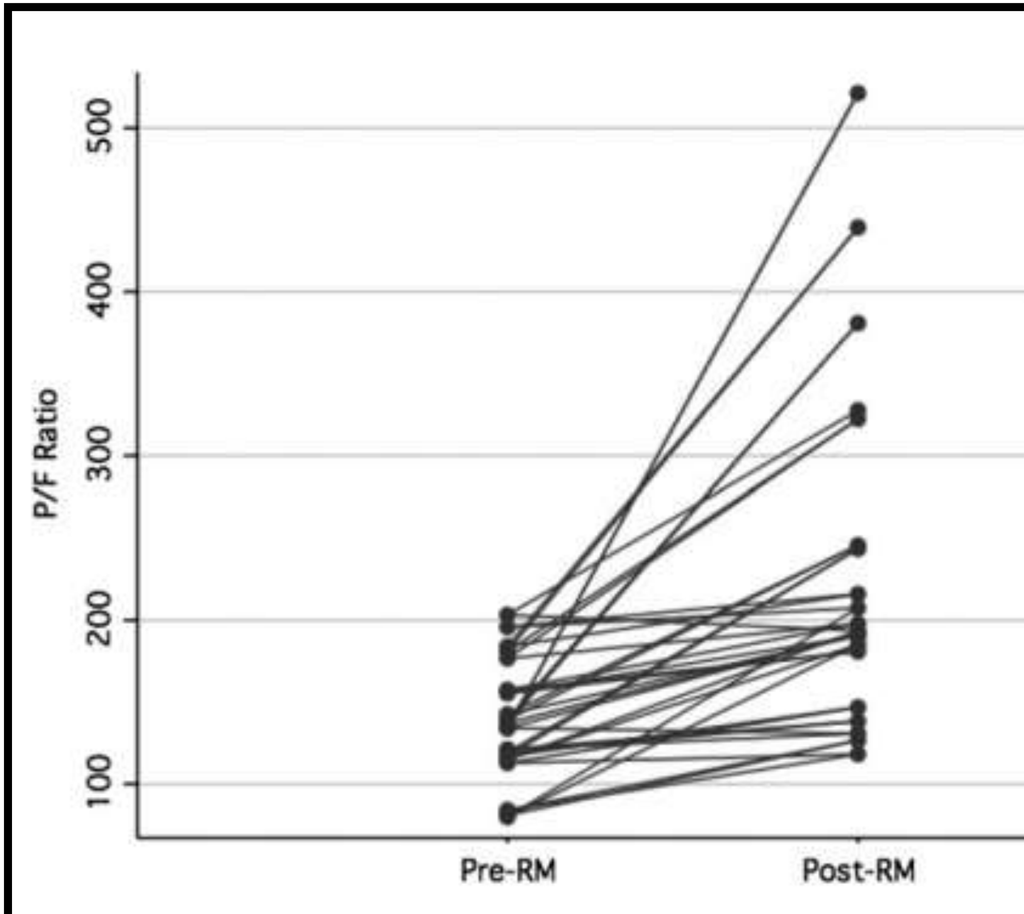
# Open lung tool


Real time monitoring option that looks at the changes in lung mechanics during the clinical application of a recruitment strategy.

3 graph windows.

# Lung recruitment using OLT

# Effect on oxygenation




20 studies
Oxygenation was significantly increased after a RM ($PaO_2$ / $FiO_2$ ratio: 251 vs 139 mm Hg; $P < 0.001$)

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

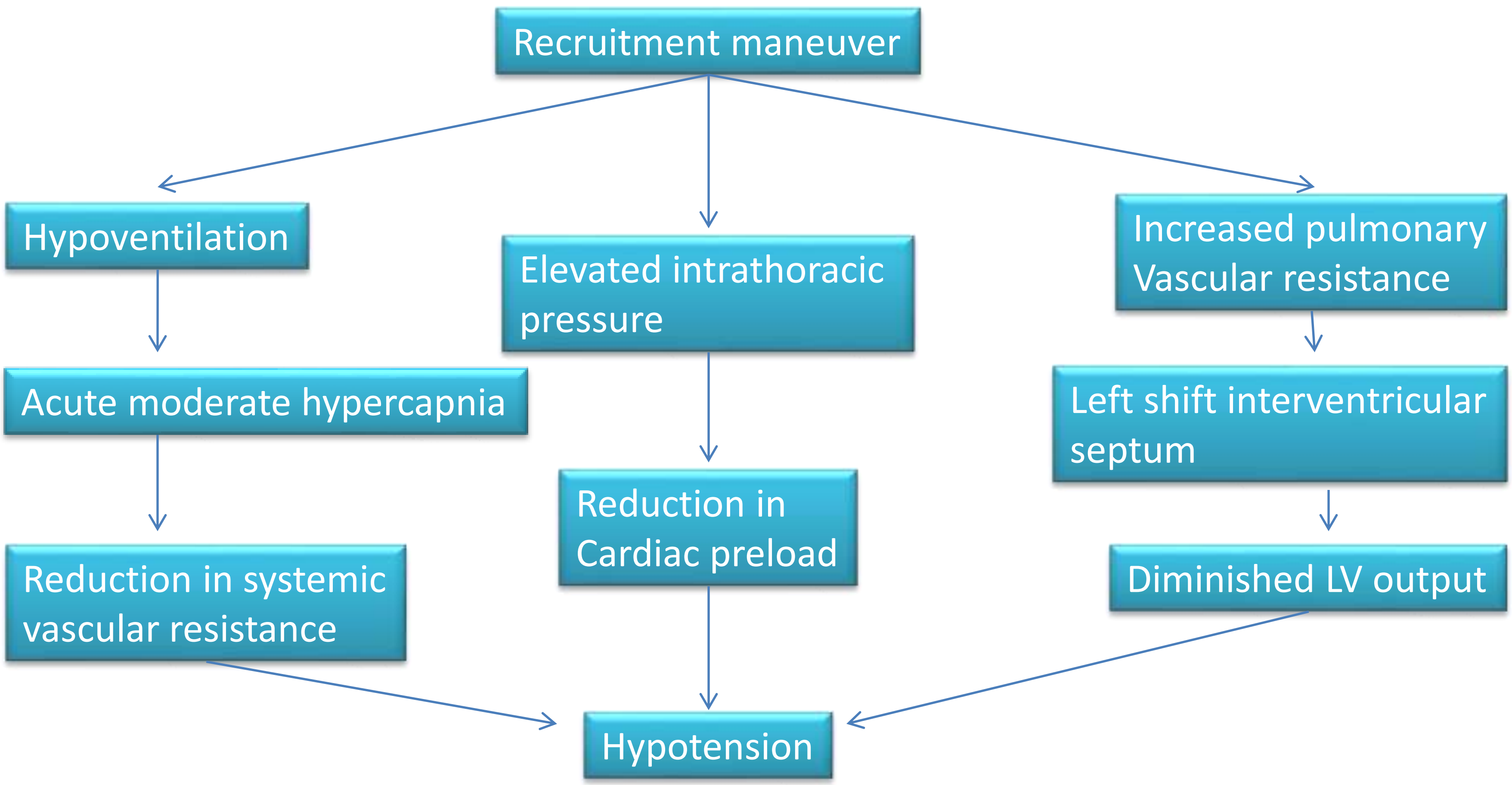
- Improvements in oxygenation after RM have been demonstrated in many studies. However, many studies report a rapid decline in these oxygenation gains over the subsequent 24 hours, some within 15 to 20 minutes of the RM
- Type of RM used and post RM PEEP applied may affect the sustainability of the effect

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

# Complications of RMs

- Hemodynamic compromise
- Barotrauma
- Desaturation

# Hemodynamic effects of RM- Mechanism



# SI vs PCV-RM: Hemodynamic effects

| Author | Pre-RM SI group | Post-SI RM group | Pre-PCV RM Group | Post-PCV RM |
|---|---|---|---|---|
| $PaO_2$ (mmHg) | 86.3±23.7 | 105.2±31.5 | 88.2±20.2 | 157.6± 61.5* |
| P/F (mmHg) | 141.8±40.7 | 165.7±44.4 | 155±30.8 | 238.8±86.5* |
| $PaCO_2$ (mmHg) | 58.0±3.2 | 62.0±1.3 | 55.0±2.1 | 55.0±3.4 |
| $C_{RS}$ | 32.0±11.1 | 48.0±5.1 | 30.0±9.4 | 62.0±12.5* |
| Qs/Qt (%) | 28.4±5.8 | 23.5± 3.2 | | |
| C.I. (L/min) | 3.3±0.9 | 2.0±0.8* | 3.2±0.5 | 3.4±0.8 |
| PAOP (mmHg) | 21.4±2.5 | 28.4±2.70* | 20.4±2.3 | 19.7±2.0* |
| MPAP (mmHg) | 40.4±7.8 | 49.6± 2.8 | 40.2±5.7 | 30.2±3.5* |
| PVRI (dyne · sec · $m^2/cm^5$) | 460.5±64.0 | 848.6±12.4 | 505.0±20.1 | 247.0±15.2 |
| RVSWI (g · $m/m^2$) | 12.0±1.4 | 9.4±0.5 | 10.6±0.7 | 5.7±0.9* |
| CVP (mmHg) | 17.4±2.5 | 20.4±2.7 | 18.1±1.8 | 19.7±2 |
| Sys/Dia (mmHg) | 108.5±14.3/53.5±12.4 | 89±6.5*; 49.5±9.2 | 105.5±15.5/58.2±10.4 | 106.5±13.1; 55.7±10.3 |
| HR (bpm) | 85.1±15.4 | 84.3±14.3 | 86.0±10.5 | 84.5±13.1 |

N=40 patients of ARDS

SI was achieved by raising peak inspiratory pressure to 45 $cmH_2O$ and sustaining it for 40s.

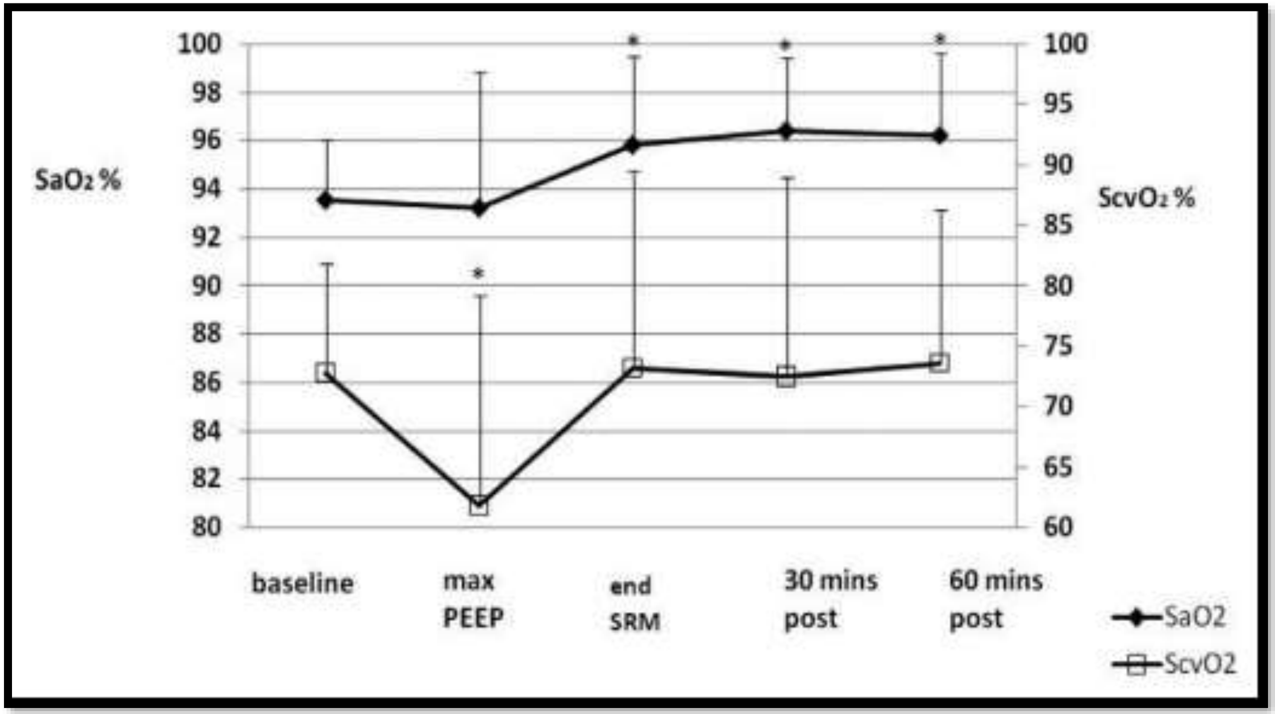
The PCV was set to obtain a 45 $cmH_2O$ peak inspiratory pressure for 2m I:E 1:2 PEEP 16 RR 8.

Iannuzzi M, et al, Minerva_Anestesiol 2010;76: 692-8

N= 20 patients of ARDS

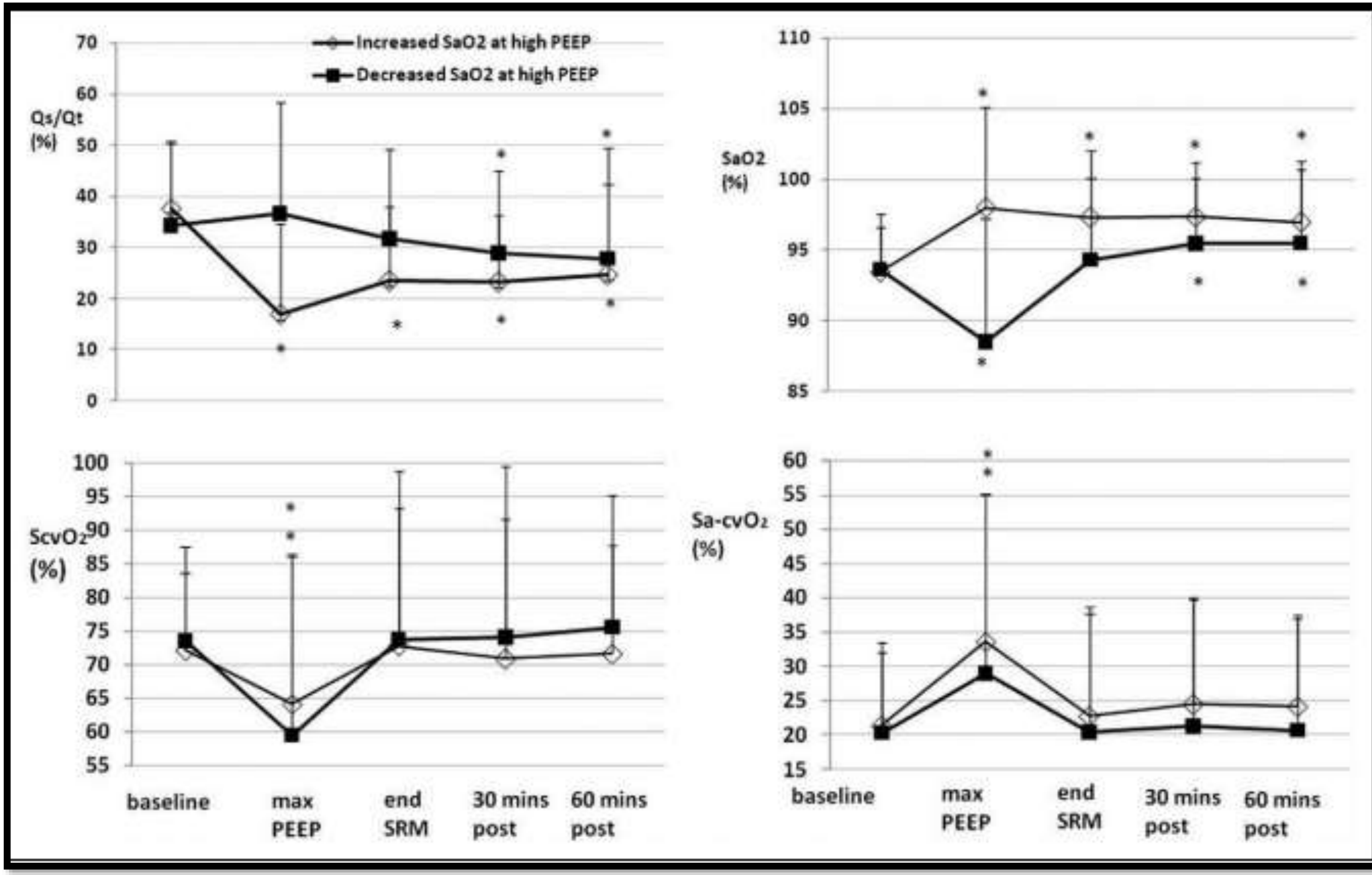
15± 3 cm $H_2O$ pressure-controlled ventilation

PEEP was ↑ from baseline (range 10-18) to 20,30,and 40 cm $H_2O$ every 2 min to achieve maximum alveolar pressure of 55 + 3 cm $H_2O$, then ↓ at 3-min intervals to 25, 22.5,20,17.5, and 15 cm $H_2O$ until a decrease of 1% to 2% oxygen saturation from maximum was detected




8 of 20 patients desaturated and exhibited transient circulatory depression during RMs

Hodgson CL, et al. J Intensive Care Med 2011; 26: 41-9




A comparison of changes between saturators and desaturators in arterial and venous oxygen saturation, shunt fraction, and central arterial-venous oxygenation difference

Hodgson CL, et al. J Intensive Care Med 2011; 26: 41-9

| Outcomes | No. (%) Lung Open Ventilation (n = 475) | Control Ventilation (n = 508) | Relative Risk (95% Confidence Interval) | *P* Value |
|---|---|---|---|---|
| Death in hospital | 173 (36.4) | 205 (40.4) | 0.90 (0.77-1.05) | .19 |
| Death in intensive care unit | 145 (30.5) | 178 (35.0) | 0.87 (0.73-1.04) | .13 |
| Death during mechanical ventilation | 136 (28.6) | 168 (33.1) | 0.87 (0.72-1.04) | .13 |
| Death during first 28 d | 135 (28.4) | 164 (32.3) | 0.88 (0.73-1.07) | .20 |
| Barotrauma[b] | 53 (11.2) | 47 (9.1) | 1.21 (0.83-1.75) | .33 |
| Refractory hypoxemia | 22 (4.6) | 52 (10.2) | 0.54 (0.34-0.86) | .01 |
| Death with refractory hypoxemia | 20 (4.2) | 45 (8.9) | 0.56 (0.34-0.93) | .03 |
| Refractory acidosis | 29 (6.1) | 42 (8.3) | 0.81 (0.51-1.31) | .39 |
| Death with refractory acidosis | 27 (5.7) | 38 (7.5) | 0.85 (0.51-1.40) | .52 |
| Refractory barotrauma | 14 (3.0) | 12 (2.4) | 1.10 (0.54-2.26) | .80 |
| Death with refractory barotrauma | 8 (1.7) | 8 (1.6) | 1.00 (0.41-2.40) | .99 |

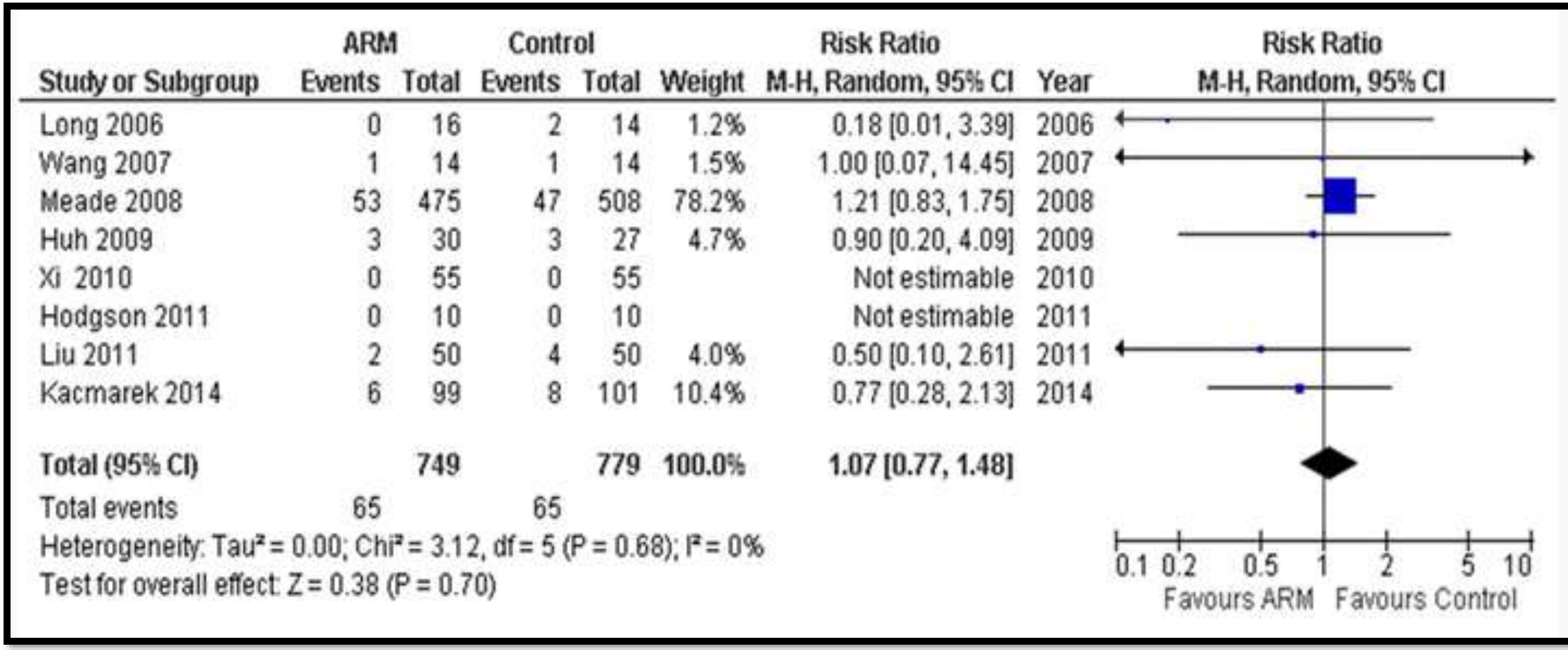
No evidence of significant harm or increased risk of barotrauma despite the use of higher PEEP and recruitment maneuvers.

Meade MO, et al. JAMA 2008; 299: 637-45

- Among patients in the experimental group, 366 received at least 1 recruitment maneuver following the initial recruitment maneuver at study initiation
- 81 patients (22.1%) developed a complication associated with a recruitment maneuver
  - 61 (4.5%) resulted in a MAP< 60 mm Hg
  - 58 (4.2%) were associated with $SpO_2$ < 85%
  - 24 (1.8%) were associated with bradycardia or tachycardia
  - 4 (0.3%) were associated with cardiac arrhythmia
  - 4 (0.3%) were associated with a new air leak through an existing thoracostomy tube
- In 3 patients, clinicians detected new barotrauma immediately following a recruitment maneuver

Meade MO, et al. JAMA 2008; 299: 637-45

# Meta-analysis: Effect on barotrauma



| Study or Subgroup | ARM Events | ARM Total | Control Events | Control Total | Weight | Risk Ratio M-H, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|
| Long 2006 | 0 | 16 | 2 | 14 | 1.2% | 0.18 [0.01, 3.39] | 2006 |
| Wang 2007 | 1 | 14 | 1 | 14 | 1.5% | 1.00 [0.07, 14.45] | 2007 |
| Meade 2008 | 53 | 475 | 47 | 508 | 78.2% | 1.21 [0.83, 1.75] | 2008 |
| Huh 2009 | 3 | 30 | 3 | 27 | 4.7% | 0.90 [0.20, 4.09] | 2009 |
| Xi 2010 | 0 | 55 | 0 | 55 | | Not estimable | 2010 |
| Hodgson 2011 | 0 | 10 | 0 | 10 | | Not estimable | 2011 |
| Liu 2011 | 2 | 50 | 4 | 50 | 4.0% | 0.50 [0.10, 2.61] | 2011 |
| Kacmarek 2014 | 6 | 99 | 8 | 101 | 10.4% | 0.77 [0.28, 2.13] | 2014 |
| **Total (95% CI)** | | **749** | | **779** | **100.0%** | **1.07 [0.77, 1.48]** | |
| Total events | 65 | | 65 | | | | |

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 3.12$, df = 5 (P = 0.68); $I^2 = 0\%$

Test for overall effect: Z = 0.38 (P = 0.70)

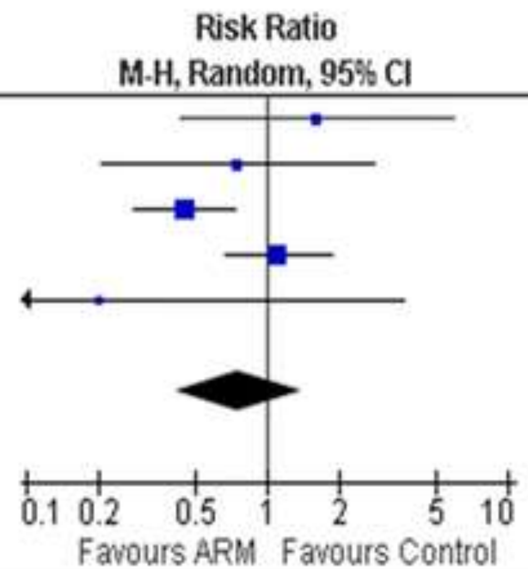


Suzumura EA, et al. Intensive Care Med 2014; 40: 1227-40

# Effect on severe hypoxemia requiring rescue therapies

| Study or Subgroup | ARM Events | ARM Total | Control Events | Control Total | Weight | Risk Ratio M-H, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|
| Lim 2003 | 8 | 20 | 2 | 8 | 14.4% | 1.60 [0.43, 5.96] | 2003 |
| Wang 2007 | 3 | 14 | 4 | 14 | 14.6% | 0.75 [0.20, 2.75] | 2007 |
| Meade 2008 | 22 | 475 | 52 | 508 | 33.9% | 0.45 [0.28, 0.73] | 2008 |
| Huh 2009 | 16 | 30 | 13 | 27 | 33.0% | 1.11 [0.66, 1.85] | 2009 |
| Hodgson 2011 | 0 | 10 | 2 | 10 | 4.0% | 0.20 [0.01, 3.70] | 2011 |
| **Total (95% CI)** | | **549** | | **567** | **100.0%** | **0.76 [0.41, 1.40]** | |
| Total events | 49 | | 73 | | | | |

Heterogeneity: Tau² = 0.23; Chi² = 9.06, df = 4 (P = 0.06); I² = 56%
Test for overall effect: Z = 0.88 (P = 0.38)



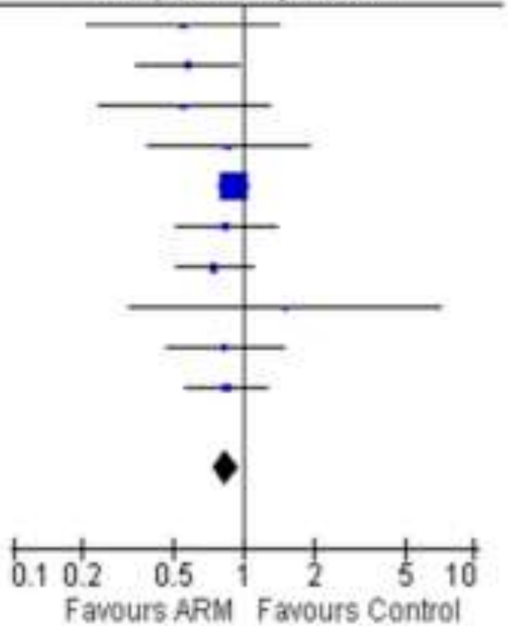

Suzumura EA, et al. Intensive Care Med 2014; 40: 1227-40

# Effect on in-hospital mortality

| | ARM | | Control | | | Risk Ratio | | Risk Ratio |
|---|---|---|---|---|---|---|---|---|
| Study or Subgroup | Events | Total | Events | Total | Weight | M-H, Random, 95% CI | Year | M-H, Random, 95% CI |
| Park 2003 | 4 | 11 | 4 | 6 | 1.6% | 0.55 [0.21, 1.43] | 2003 | |
| Lim 2003 | 10 | 20 | 7 | 8 | 5.7% | 0.57 [0.34, 0.95] | 2003 | |
| Long 2006 | 5 | 16 | 8 | 14 | 2.0% | 0.55 [0.23, 1.29] | 2006 | |
| Wang 2007 | 6 | 14 | 7 | 14 | 2.3% | 0.86 [0.39, 1.91] | 2007 | |
| Meade 2008 | 173 | 475 | 205 | 508 | 58.9% | 0.90 [0.77, 1.06] | 2008 | |
| Huh 2009 | 14 | 30 | 15 | 27 | 5.7% | 0.84 [0.50, 1.40] | 2009 | |
| Xi 2010 | 23 | 55 | 31 | 55 | 9.8% | 0.74 [0.50, 1.09] | 2010 | |
| Hodgson 2011 | 3 | 10 | 2 | 10 | 0.6% | 1.50 [0.32, 7.14] | 2011 | |
| Liu 2011 | 14 | 50 | 17 | 50 | 4.3% | 0.82 [0.46, 1.48] | 2011 | |
| Kacmarek 2014 | 29 | 99 | 35 | 101 | 9.0% | 0.85 [0.56, 1.27] | 2014 | |
| **Total (95% CI)** | | **780** | | **793** | **100.0%** | **0.84 [0.74, 0.95]** | | |
| Total events | 281 | | 331 | | | | | |

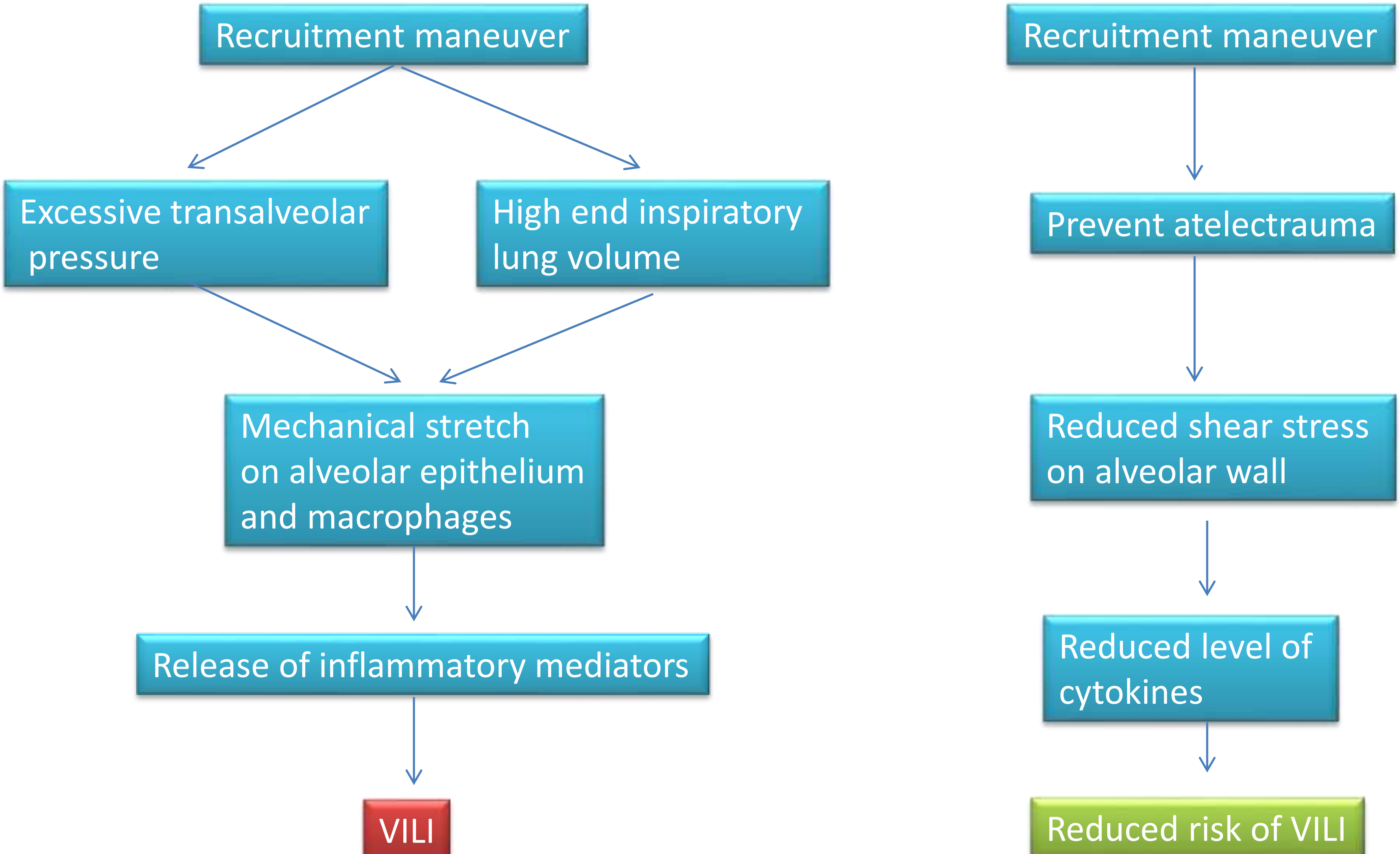
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 5.71$, $df = 9$ ($P = 0.77$); $I^2 = 0\%$

Test for overall effect: $Z = 2.86$ ($P = 0.004$)




Suzumura EA, et al. Intensive Care Med 2014; 40: 1227-40

# What is the impact of RM on VILI?



# How to assess lung recruitability?

- Recruitment maneuvers (RM) are not without risks. To reduce the number of patients unnecessarily exposed can prevent potential complications
- Lung recruitability could provide valuable information before RM application to prevent possible deleterious effects

# Factors potentially involved in the variability of response to RM in ARDS

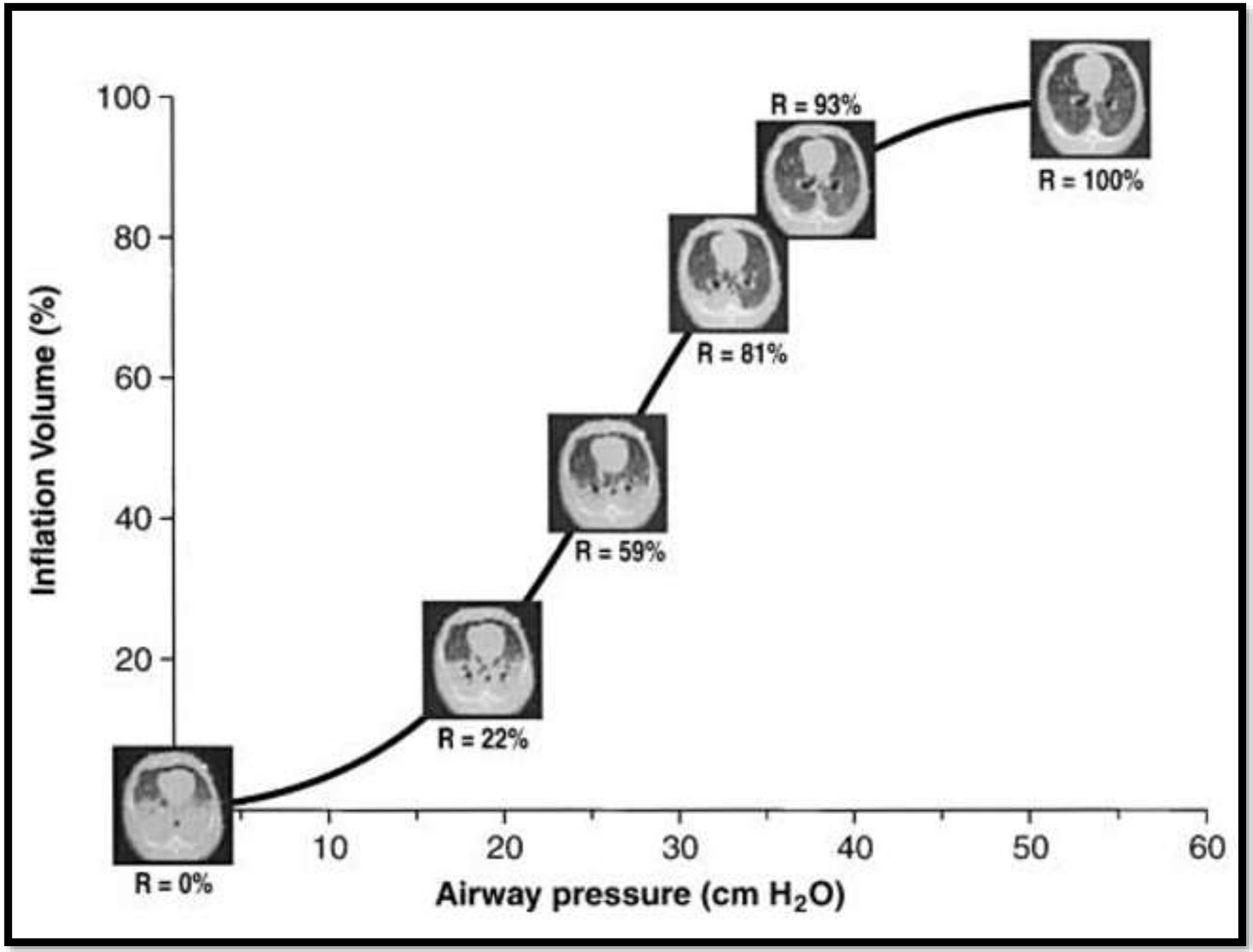
| | |
|---|---|
| **ARDS related** | Focal vs nonfocal<br>Early vs late<br>Severe vs moderate<br>Associated vasoactive drugs |
| **RM-Related** | Type of RMs<br>Distribution of lung perfusion<br>Transpulmonary pressure<br>Timing of application<br>Patient positioning |
| **Post-RM strategy** | Post-RM PEEP |

Guerin ,et al. Annals of Intensive Care 2011, 1:9

- The earlier or exudative phase of ARDS has better chance of RM success compared with a later or fibrotic phase
- Patients with extrapulmonary etiology of ARDS have better response to recruitment
- Those with diffuse changes on imaging studies have better chance of RM success than those with focal changes
- Patients with severe ARDS respond better to RM and the high respiratory system elastance is associated with better response to recruitment in clinical trials

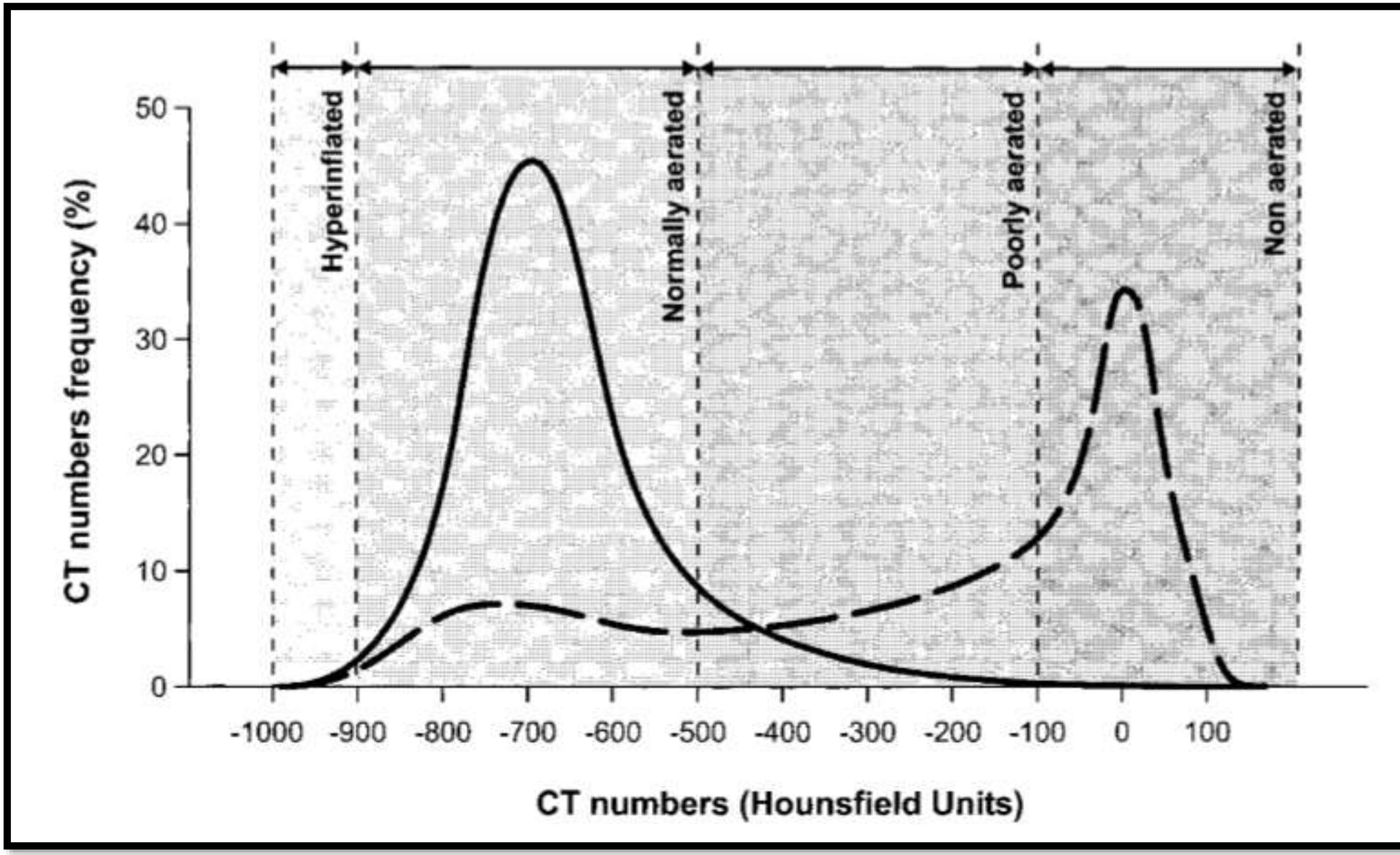
Santos CL, et al. Rev Col Bras Cir 2015; 42: 125-129

# CT SCAN




Recruitment occurs along the entire volume–pressure curve well above the lower inflection point and even above the upper inflection point, with a definite spatial distribution (ventral to dorsal and cephalad to caudal)

Gattinoni L, et al. Am J Respir Crit Care Med 2001;164:1701–11




CT scan provides morphological (focal and nonfocal distribution of lung injury) and functional information, allows the estimation of potentially recruitable lung (i.e., the amount of lung tissue in which aeration can be restored) and to differentiate between recruitment (an increase in gas volume in previously poorly aerated and nonaerated lung regions) and inflation

Gattinoni L, et al. Am J Respir Crit Care Med 2001;164:1701–11

- The advantages of CT must be balanced against potential risks of transporting critically ill patients, additional cost and additional radiation dose
- Best reserved for solving clinical dilemmas and for clinical research than for routine use

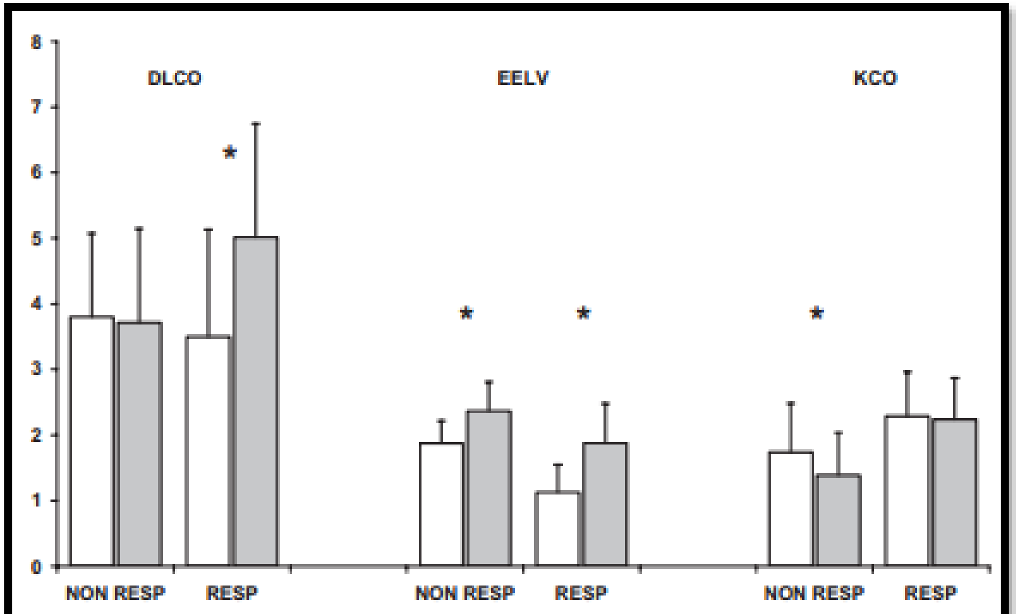
# Oxygenation

- Improvement in oxygenation is usually associated with the reexpansion of nonaerated lung areas and has been used in several studies to discriminate between responders and nonresponders to recruitment
- Absence of change in $PaO_2$ does not necessarily mean absence of anatomical recruitment
- Changes in oxygenation alone may not directly reflect recruitment because oxygenation may be influenced by other factors affected by RMs, such as cardiac output

Godet T, et al. Curr Opin Crit Care 2015, 21: 253–258

# DLCO

Prospective study of 16 mechanically ventilated patients with ARDS
Measurement of DLCO, using a bag-in-box system between the circuit Y-piece and the ET tube that allows a rebreathing maneuver without patient disconnection




DLCO measurement supplies information about functional lung recruitment, which is influenced by, but does not coincide with, mechanical recruitment and cannot be entirely predicted by changes in $PaO_2/FIO_2$ or in mechanical lung properties

Marco FD, et al. Crit Care Med 2010; 38:127–132

# Lung complianace

- Patients with ARDS who have higher % of potentially recruitable lung have poorer oxygenation and lung compliance in addition to higher levels of dead space
- Increase in static lung compliance after recruitment maneuver application could be reflective of improved lung aeration
- This parameter lacks sensitivity and specificity to precisely assess lung status and should therefore be used in conjunction with other parameters

Gattinoni L, et al.  N Engl J Med 2006; 354:1775-1786

# Alveolar recruitment and dead space

- Tusman et al found that $VD_{alv}$ and $VD_{alv}/VT_{alv}$ were closely correlated with atelectatic lung areas on CT scan and had a high specificity and sensitivity [$VD_{alv}$ (0.89 and 0.90), $VD_{alv}/VT_{alv}$ (0.82 and 1.00)] for detecting early lung collapse during a PEEP trial following a recruitment maneuver
- As lung closing and opening is not easy to evaluate at the bedside, monitoring of dead space may be useful for detecting lung collapse and for establishing open-lung PEEP after a recruitment maneuver (PEEP associated with the lowest dead space value during the descending limb of the recruitment maneuver)

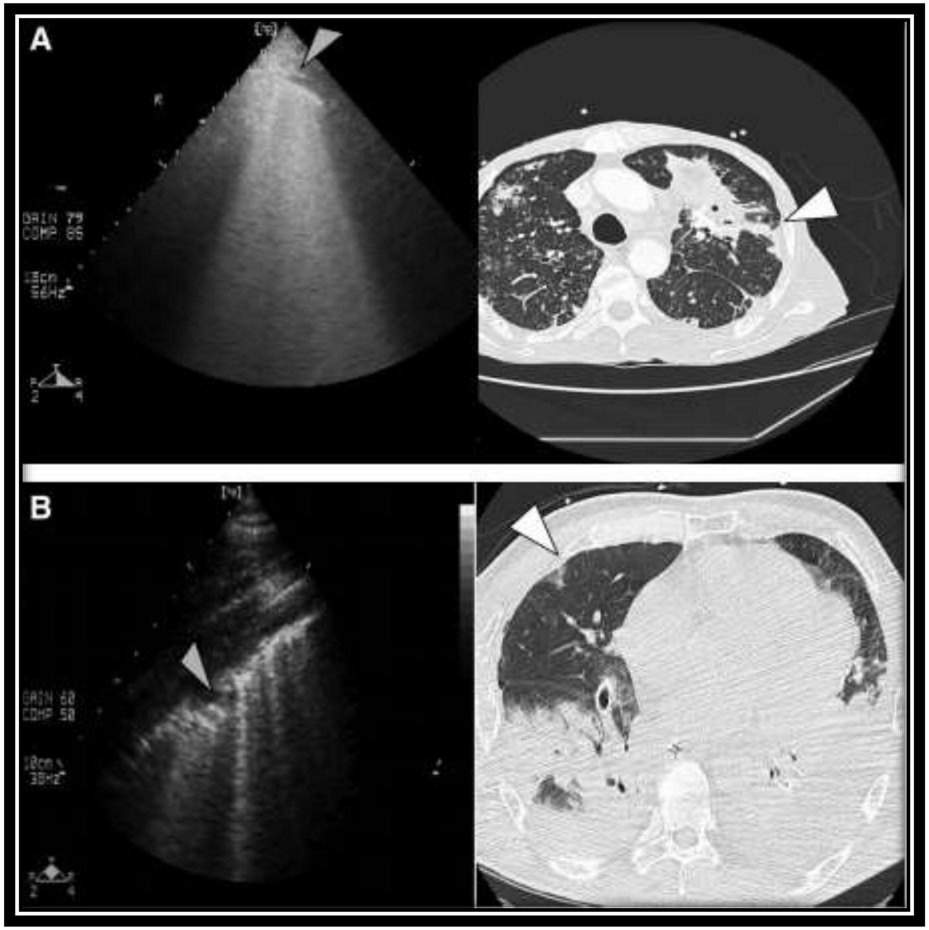
Tusman G, et al. Intensive Care Med 2006; 32: 1863–1871

# Monitoring changes in lung volume at the bedside

- EELV measurement using an automatized system based on the nitrogen washout/ washin technique that is incorporated into a ventilator is an acceptable surrogate of gas volume computed from lung density measures by CT
- Changes in EELV analyzed solely should however be interpreted with caution as EELV does not permit one to differentiate the volume caused by recruitment of previously nonaerated lung units and the volume as a result of the inflation of already open alveoli

Chiumello D, et al. Crit Care 2008; 12:R150

# Lung ultrasonography and alveolar recruitment



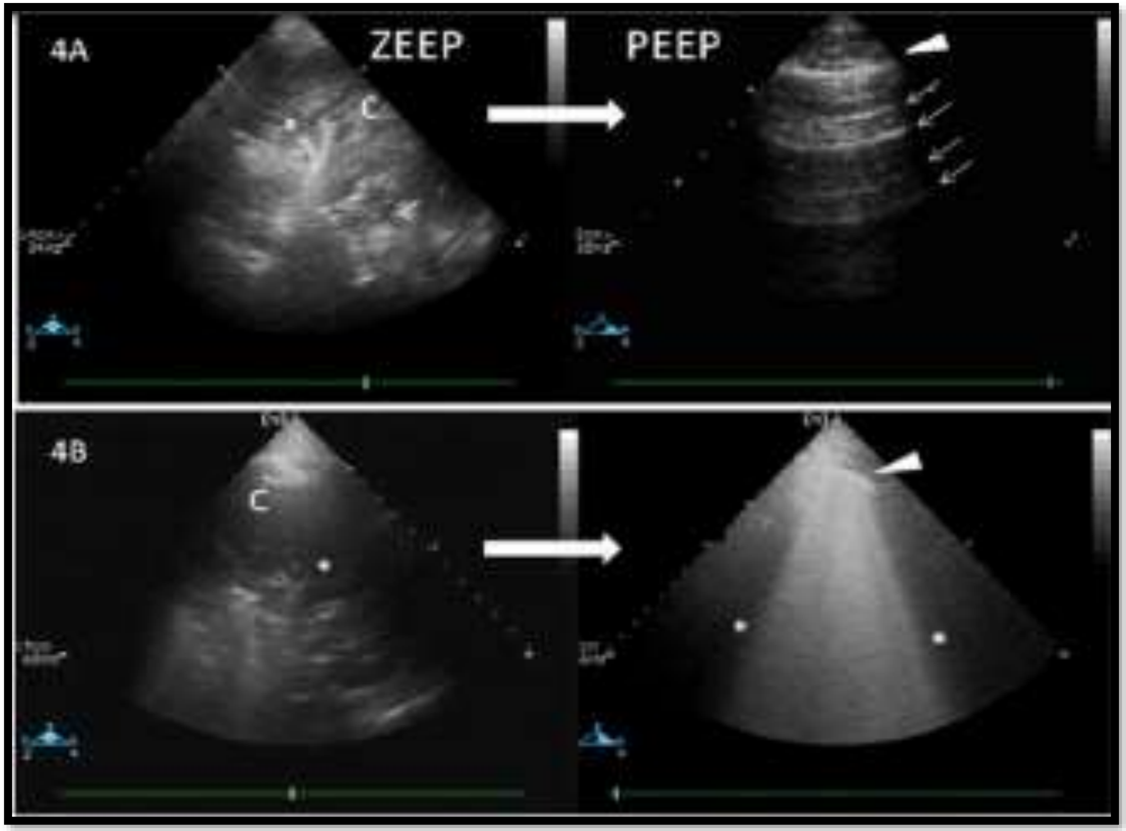

Abutting ultrasound lung comets arising from the pleural line

Irregularly spaced and abutting ultrasound lung comets arising from a subpleural consolidation

Bouhemad B, et al. Crit Care Med 2010; 38: 84–92

# Lung ultrasonography and alveolar recruitment

Illustration of PEEP- induced lung recruitment detected by ultrasound

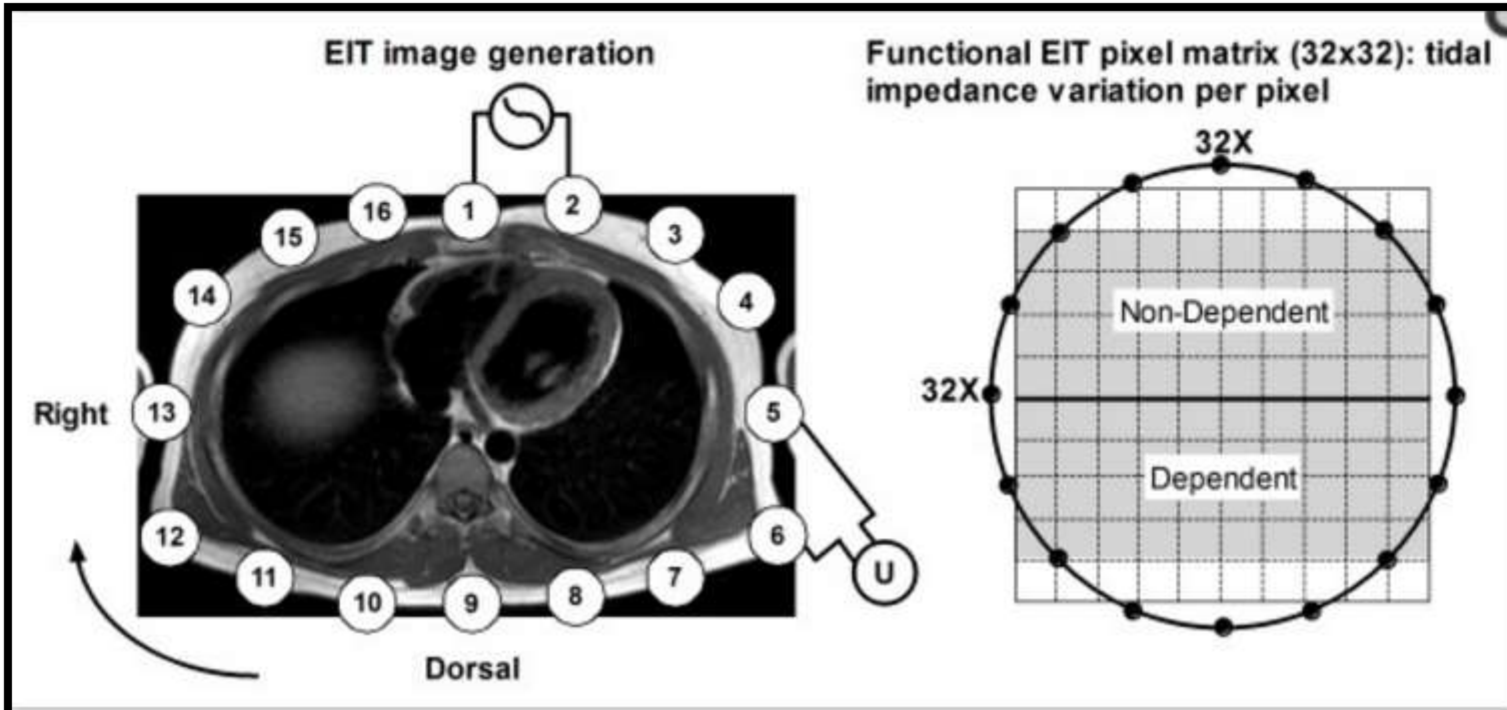



Bouhemad B, et al. Am J Respir Crit Care Med 2011; 183: 341–347

- A statistically significant correlation was found between PEEP-induced lung recruitment, evaluated by the P-V curves method, and the ultrasound reaeration score calculated from changes in the ultrasound pattern of each of the 12 lung regions (Rho= 0.88; $P < 0.0001$)
- Although LUS is an easily repeatable technique, it nevertheless remains time-consuming, unsuitable for continuous monitoring and inappropriate to detect lung hyperinflation

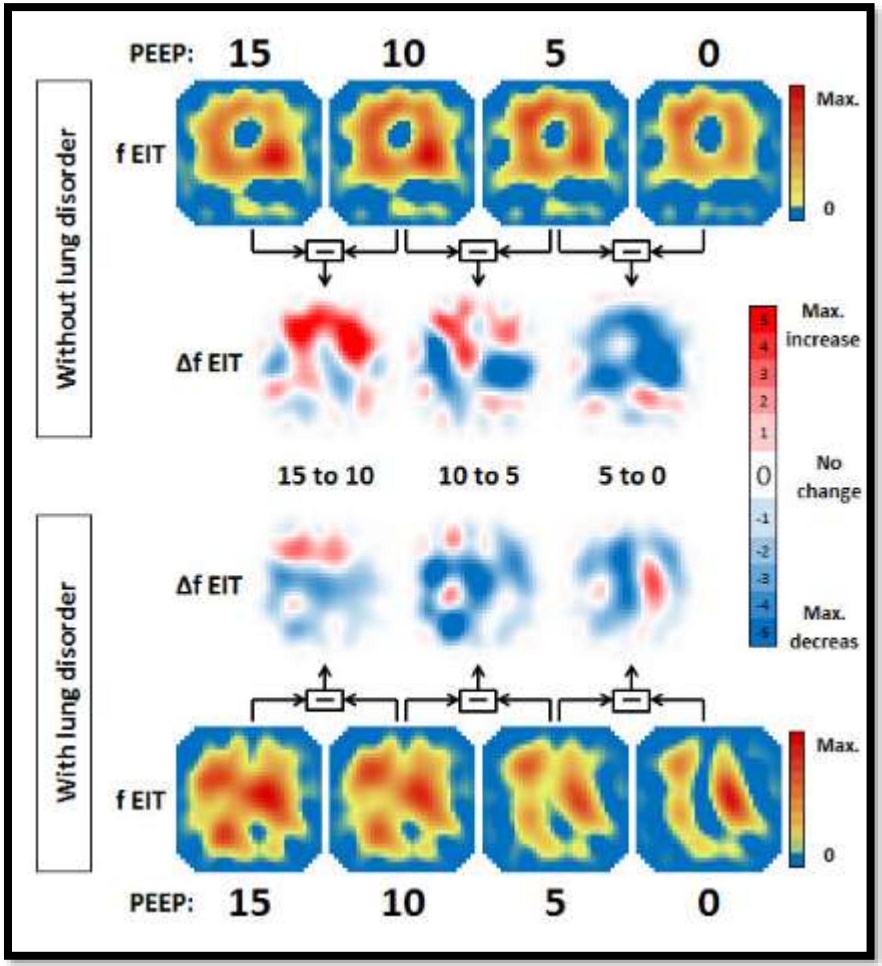
Bouhemad B, et al. Am J Respir Crit Care Med 2011; 183: 341–347

# Electrical impedence tomography




**Principle of electrical impedance tomography (EIT) and the functional EIT image (fEIT)**. Electrical excitation currents are applied between pairs of adjacent surface electrodes (1 to 16); the resulting voltages are measured between the other electrodes (U). In the fEIT image, impedance variation induced by the tidal volume is divided into a 32 × 32 matrix. Each pixel contains the individual tidal impedance variation, creating an image of ventilation distribution

# Regional ventilation changes by EIT




The increase or decrease in regional ventilation between PEEP (ΔfEIT) steps is displayed in a color-coded matrix. Electrical impedance tomography (EIT) can provide a good estimate of the amount of tidal recruitment and may be useful to individualize ventilatory settings

Bikker IG et al, Crit Care. 2010; 14: R100

# Future directions

- Thus far, no RCT has aimed to show whether the presence or absence of RM among the constituent elements of a protective ventilator strategy bundle makes a difference
- A RCT designed to answer this question with sufficient statistical power, the alveolar recruitment for ARDS trial, is ongoing

# Take home message

- RMs in ARDS improve oxygenation in majority of patients
- Routine use of RMs cannot be recommended or discouraged; it should be considered for use on an individualized basis in patients with ARDS who have life threatening hypoxemia
- Should be considered if $SpO_2$ decreases by ≥ 5% or $PaO_2$ drops by ≥ 15 mmHg within 5 minutes of disconnection during suction or coughing or agitation and the same lasts for ≥ 10 minutes
- If a recruitment maneuver is conducted, a decremental PEEP trial must be done to determine the minimum PEEP that sustains the benefits of the recruitment maneuver

# THANK YOU