# PEEP setting in ARDS

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# Disclosure of Conflict of Interest

No disclosure of COI

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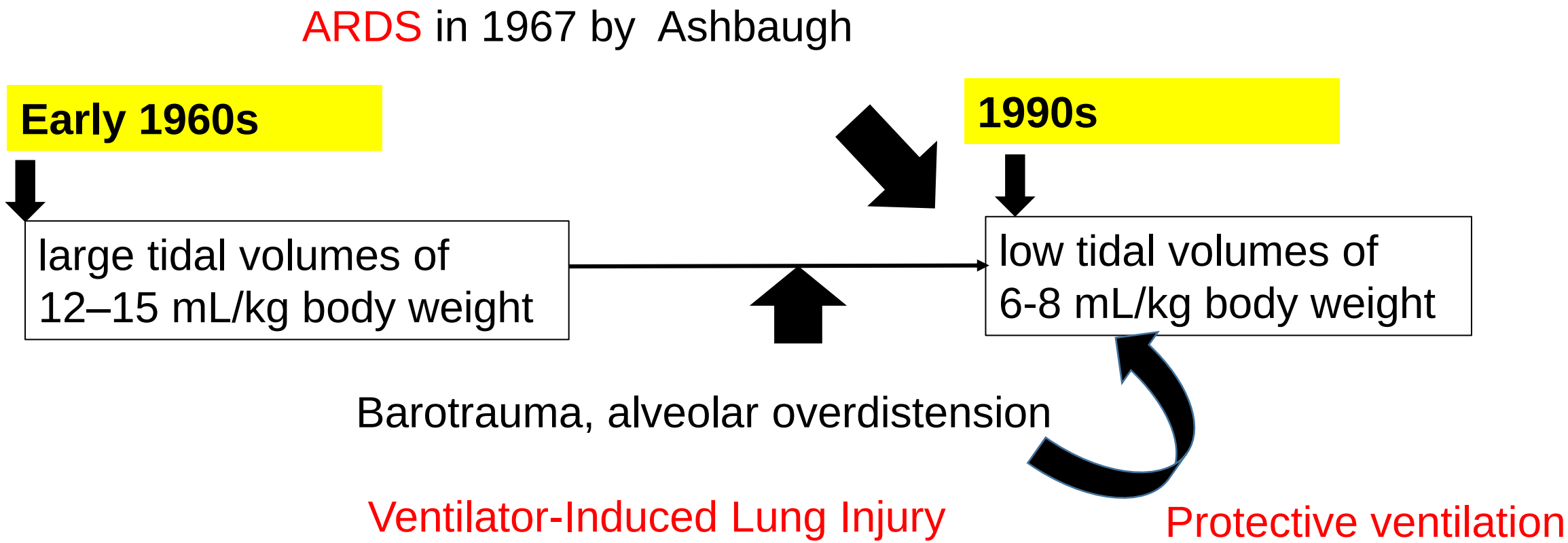
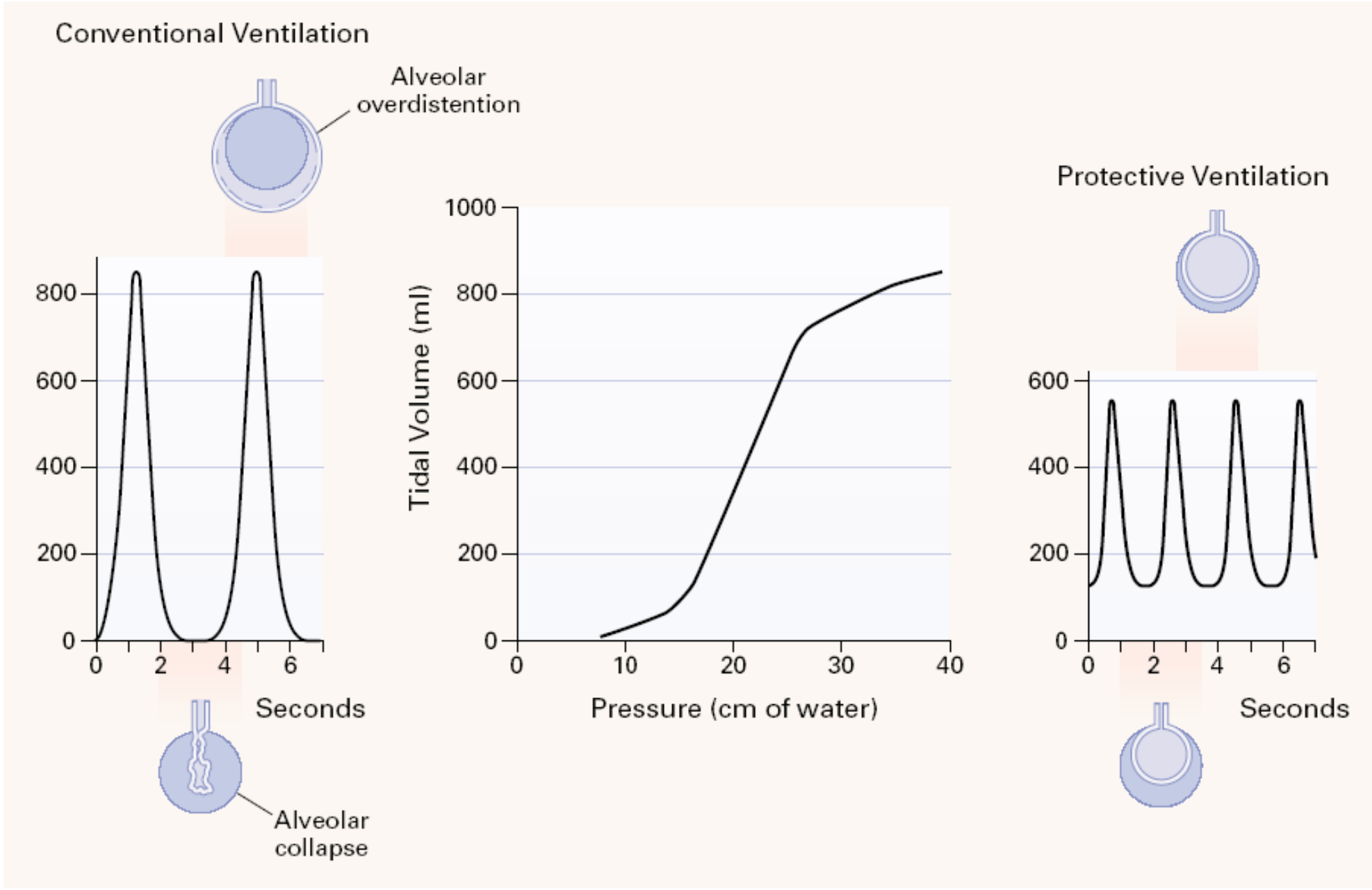
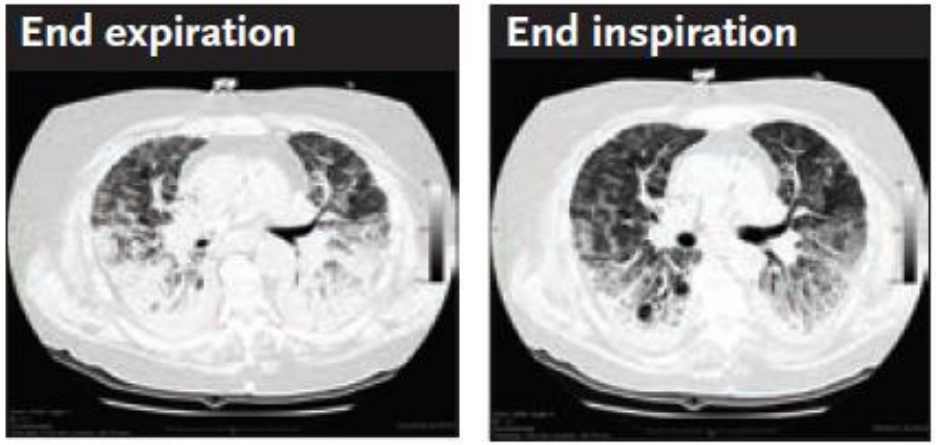
# History


ARDS in 1967 by Ashbaugh
Early 1960s
1990s
large tidal volumes of
12–15 mL/kg body weight
low tidal volumes of
6-8 mL/kg body weight
Barotrauma, alveolar overdistension
Ventilator-Induced Lung Injury
Protective ventilation




barotrauma, volutrauma, atelectrauma, and biotrauma.

A Ventilation at low lung volume




Atelectrauma

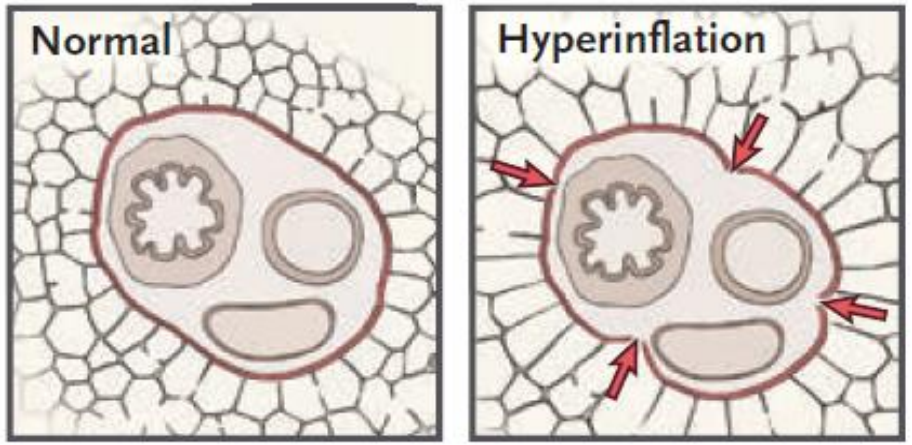
***Opening and closing***

Lung inhomogeneity

Positive end-expiratory pressure (PEEP)

***Opening and Keeping***

B Ventilation at high lung volume




Air leaks

Overdistention

Small $V_T$

Slutsky A et al. NEJM 2013:369;22

# Mechanical Ventilation in Patients with ARDS

- **low Vt** ventilation strategies with appropriate levels of **PEEP**

  to limit lung distention and atelectrauma

➡ **Open lung strategy**

# ESICM guidelines on acute respiratory distress syndrome: definition, phenotyping and respiratory support strategies

**Recommendation 5.1**

We **recommend** the use of low tidal volume ventilation strategies (i.e., 4–8 ml/kg PBW), compared to larger tidal volumes (traditionally used to normalize blood gases), to reduce mortality in patients with ARDS not due to COVID-19.
*Strong recommendation based on expert opinion despite lack of statistical significance; high level of evidence.*

This recommendation applies also to ARDS from COVID-19.
*Strong recommendation; moderate level of evidence for indirectness.*

*Intensive Care Med (2023) 49:727–759*

## Recommendation 6.1

We are **unable to make a recommendation** for or against routine PEEP titration with a higher PEEP/$FiO_2$ strategy versus a lower PEEP/$FiO_2$ strategy to reduce mortality in patients with ARDS.
*No recommendation; high level of evidence of no effect.*

## Recommendation 6.2

We are **unable to make a recommendation** for or against PEEP titration guided principally by respiratory mechanics, compared to PEEP titration based principally on PEEP/$FiO_2$ strategy, to reduce mortality in patients with ARDS.
*No recommendation; high level of evidence of no effect.*

## Recommendation 6.3

We **recommend against** use of prolonged high-pressure recruitment maneuvers (defined as airway pressure maintained $\geq$ 35 $cmH_2O$ for at least one minute) to reduce mortality of patients with ARDS.
*Strong recommendation; moderate level of evidence against.*

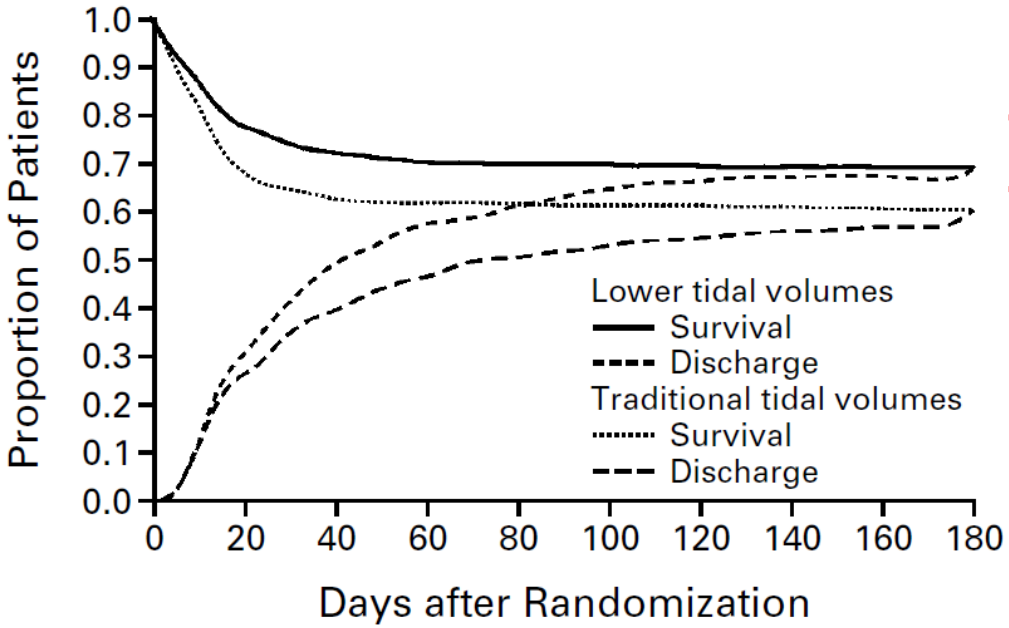
## Recommendation 6.4

We **suggest against** *routine* use of brief high-pressure recruitment maneuvers (defined as airway pressure maintained $\geq$ 35 $cmH_2O$ for less than one minute) to reduce mortality in patients with ARDS.
*Weak recommendation; high level of evidence of no effect.*

*Intensive Care Med (2023) 49:727–759*

# VENTILATION WITH LOWER TIDAL VOLUMES AS COMPARED WITH TRADITIONAL TIDAL VOLUMES FOR ACUTE LUNG INJURY AND THE ACUTE RESPIRATORY DISTRESS SYNDROME

THE ACUTE RESPIRATORY DISTRESS SYNDROME NETWORK*




| VARIABLE | GROUP RECEIVING TRADITIONAL TIDAL VOLUMES | GROUP RECEIVING LOWER TIDAL VOLUMES |
|---|---|---|
| Ventilator mode | Volume assist–control | Volume assist–control |
| Initial tidal volume (ml/kg of predicted body weight)† | 12 | 6 |
| Plateau pressure (cm of water) | ≤50 | ≤30 |
| Ventilator rate setting needed to achieve a pH goal of 7.3 to 7.45 (breaths/min) | 6–35 | 6–35 |
| Ratio of the duration of inspiration to the duration of expiration | 1:1–1:3 | 1:1–1:3 |
| Oxygenation goal | $PaO_2$, 55–80 mm Hg, or $SpO_2$, 88–95% | $PaO_2$, 55–80 mm Hg, or $SpO_2$, 88–95% |
| Allowable combinations of $FiO_2$ and PEEP (cm of water)‡ | 0.3 and 5<br>0.4 and 5<br>0.4 and 8<br>0.5 and 8<br>0.5 and 10<br>0.6 and 10<br>0.7 and 10<br>0.7 and 12<br>0.7 and 14<br>0.8 and 14<br>0.9 and 14<br>0.9 and 16<br>0.9 and 18<br>1.0 and 18<br>1.0 and 20<br>1.0 and 22<br>1.0 and 24 | 0.3 and 5<br>0.4 and 5<br>0.4 and 8<br>0.5 and 8<br>0.5 and 10<br>0.6 and 10<br>0.7 and 10<br>0.7 and 12<br>0.7 and 14<br>0.8 and 14<br>0.9 and 14<br>0.9 and 16<br>0.9 and 18<br>1.0 and 18<br>1.0 and 20<br>1.0 and 22<br>1.0 and 24 |
| Weaning | By pressure support; required by protocol when $FiO_2 \leq 0.4$ | By pressure support; required by protocol when $FiO_2 \leq 0.4$ |

ARDS network, N Engl J Med 2000;342:1301-1308

# Higher versus Lower Positive End-Expiratory Pressures in Patients with the Acute Respiratory Distress Syndrome

**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 |

ALVEOLI

ARDS network, N Engl J Med 2004;351:327-36

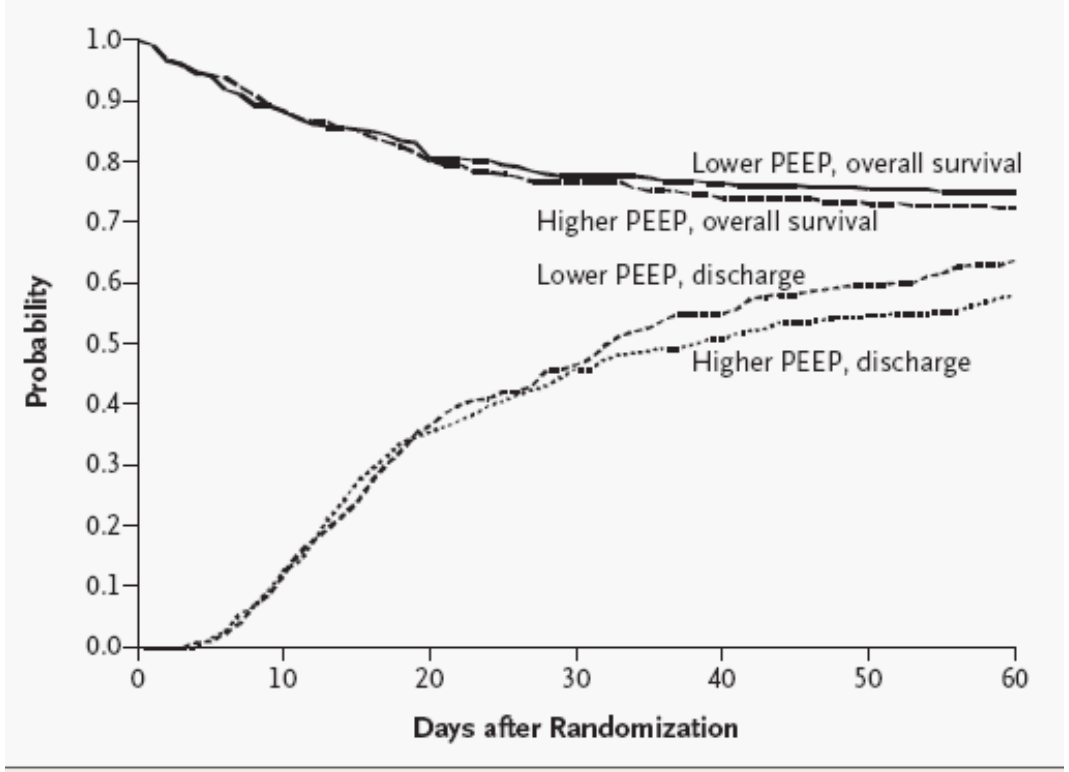



**Figure 1.** **Probabilities of Survival and of Discharge Home While Breathing without Assistance, from the Day of Randomization (Day 0) to Day 60 among Patients with Acute Lung Injury and ARDS, According to Whether Patients Received Lower or Higher Levels of PEEP.**

**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 |

# Ventilation Strategy Using Low Tidal Volumes, Recruitment Maneuvers, and High Positive End-Expiratory Pressure for Acute Lung Injury and Acute Respiratory Distress Syndrome

A Randomized Controlled Trial

LOVS

| Component Variables | Control Ventilation Strategy | Lung Open Ventilation Strategy |
|---|---|---|
| Ventilator mode | Volume-assist control | Pressure control |
| Tidal volume target, mL/kg predicted body weight | 6 | 6 |
| Tidal volume range, mL/kg predicted body weight | 4-8 | 4-8 |
| Plateau airway pressure, cm $H_2O$ | ≤30 | ≤40 |
| Positive end-expiratory pressure, cm $H_2O$ | See Table 2 | See Table 2 |
| Partial pressure of oxygen, arterial, mm Hg | 55-80 | 55-80 |
| Oxygen saturation as measured by pulse oximetry, % | 88-93 | 88-93 |
| pH | ≥7.30 | ≥7.30 |
| Ventilator rate, breaths/min | ≤35 | ≤35 |
| Inspiration:expiration time | 1:1-1:3 | 1:1-1:3 |
| Recruitment maneuvers | Not permitted | After ventilator disconnects |

Meade et al. JAMA 2008;299:637-645

| | Fraction of Inspired Oxygen ($FIO_2$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
| Control PEEP ranges, cm $H_2O$ | 5 | 5-8 | 8-10 | 10 | 10-14 | 14 | 14-18 | 18-24 |
| Lung open ventilation PEEP ranges, cm $H_2O$ | | | | | | | | |
| Before protocol change | 5-10 | 10-14 | 14-20 | 20 | 20 | 20 | 20 | 20-24 |
| After protocol change | 5-10 | 10-18 | 18-20 | 20 | 20 | 20-22 | 22 | 22-24 |

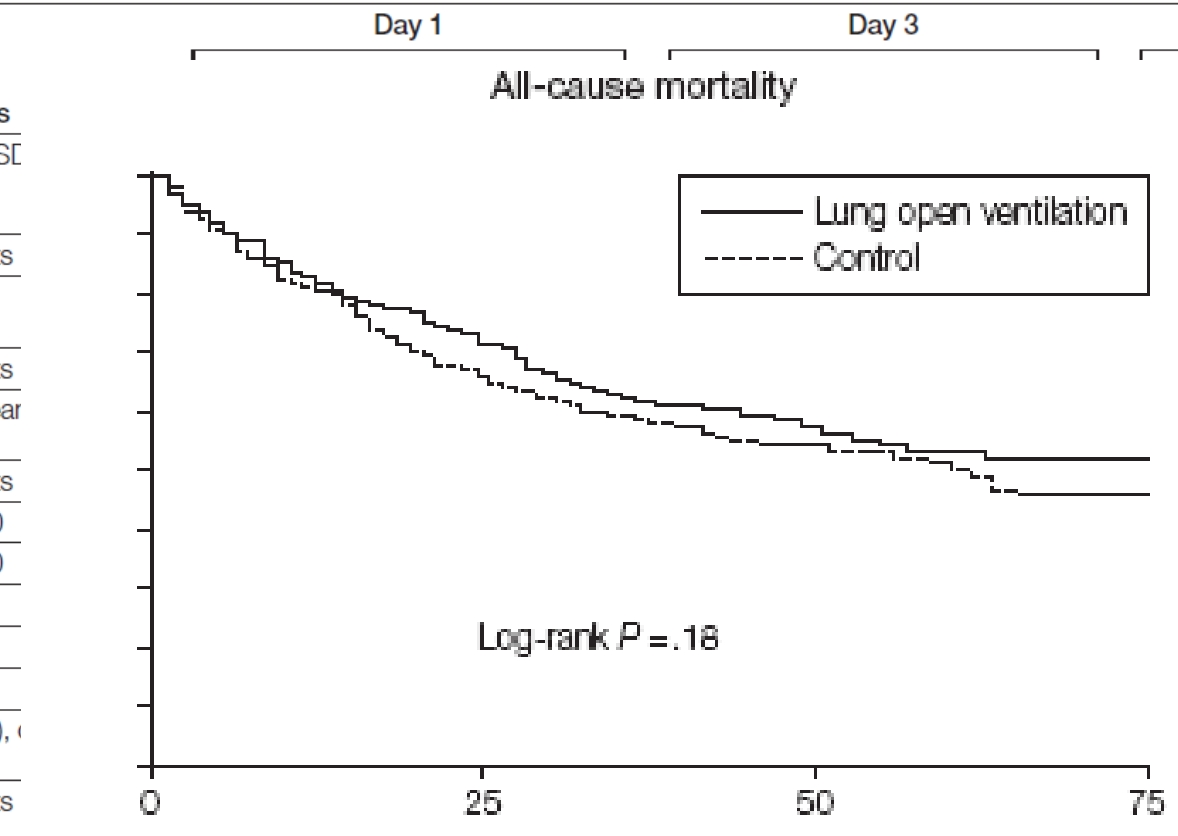
Abbreviation: PEEP, positive end-expiratory pressure.
[a] Both ventilation strategies included a protocol for reducing PEEP when plateau pressure exceeded the assigned plateau pressure limit or when mean arterial pressure decreased to less than 60 mm Hg, whether or not this occurred in the setting of an increase in PEEP.

starting with PEEP at 20 cm H2O

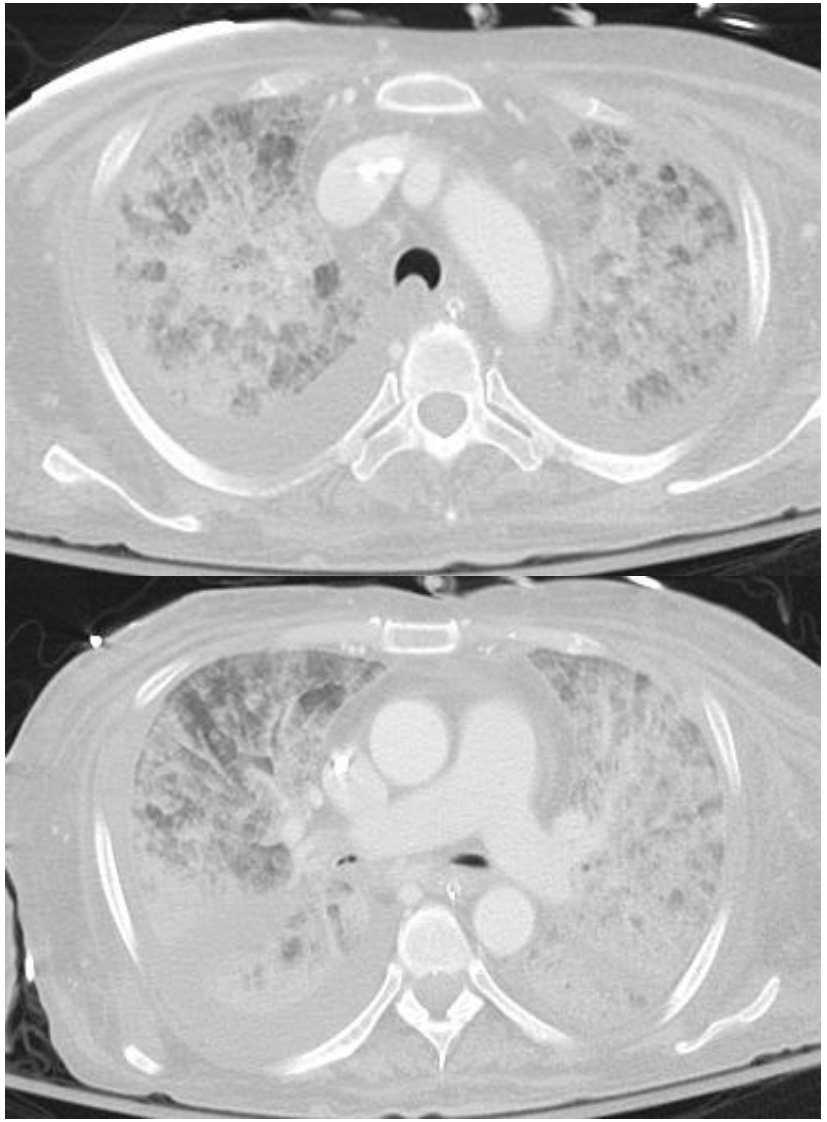
Recruitment Maneuver ;

40 sec breath-hold at 40 cm H2O airway pressure, FiO2 of 1.0

Meade et al. JAMA 2008;299:637-645



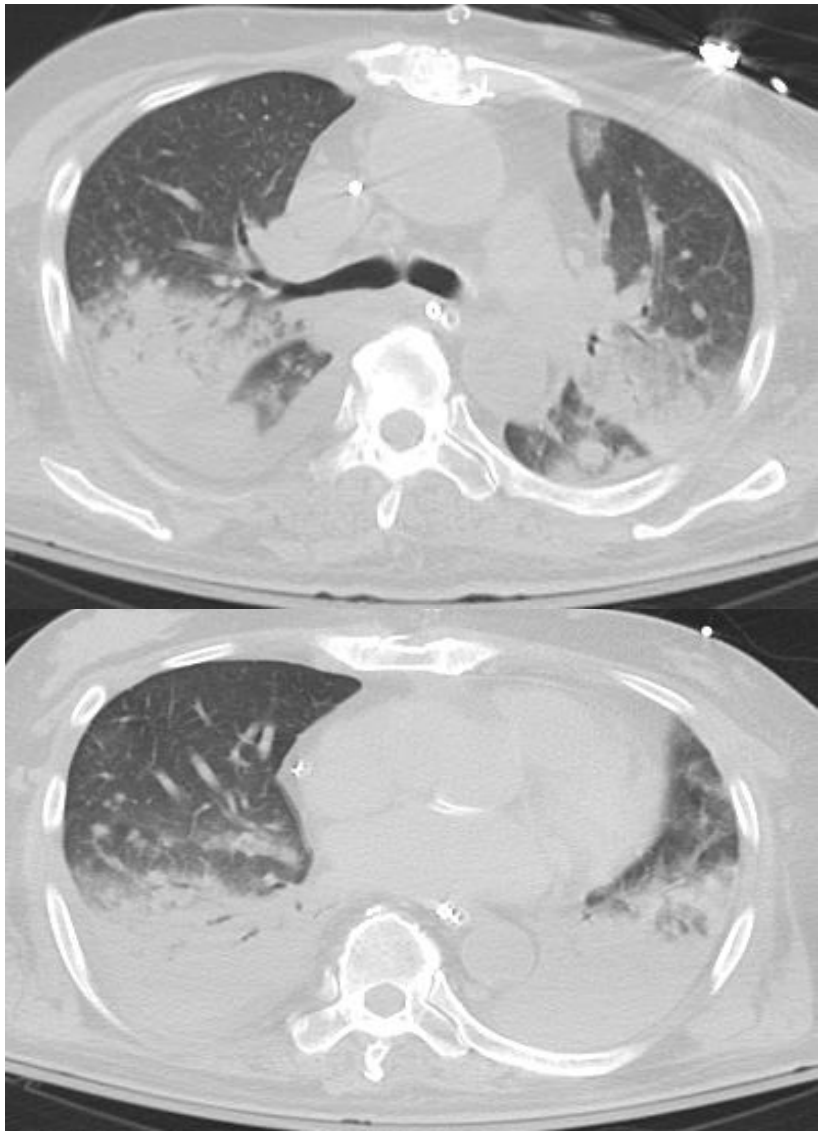

| Variables | | | | | | | | Control | *P* Value |
|---|---|---|---|---|---|---|---|---|---|
| Tidal volume, mean (SD), mL/kg predicted body weight | | | | | | | | 7.0 (1.6) | .53 |
| No. of patients | | | | | | | | 243 | |
| Total respiratory rate, mean (SD), /min | | | | | | | | 26.1 (7.6) | .26 |
| No. of patients | | | | | | | | 351 | |
| Plateau pressure, mean, cm $H_2O$ | | | | | | | | 25.1 (6.8) | <.001 |
| No. of patients | | | | | | | | 232 | |
| 30.1-35.0 | | | | | | | | 27 | |
| 35.1-40.0 | | | | | | | | 13 | |
| >40.0 | | | | | | | | 4 | |
| $FIO_2$, mean (SD) | | | | | | | | 0.48 (0.17) | <.001 |
| No. of patients | | | | | | | | 356 | |
| Set PEEP, mean (SD), All patients | | | | | | | | 8.0 (3.1) | <.001 |
| No. of patients | | | | | | | | 348 | |
| $PaO_2/FIO_2$, mean (SD) | | | | | | | | 180.8 (73.0) | <.001 |
| No. of patients | | | | | | | | 342 | |
| $PaO_2$, mean (SD), mm H | | | | | | | | 77.0 (17.1) | .56 |
| No. of patients | | | | | | | | 342 | |
| $PaCO_2$, mean (SD), mm Hg | | 45.5 (12.0) | 44.6 (10.9) | .22 | 44.8 (9.5) | 45.3 (9.8) | .41 | 46.6 (11.7) | .04 |
| No. of patients | | 464 | 498 | | 444 | 472 | | 342 | |
| pH, mean (SD) | | 7.33 (0.10) | 7.35 (0.09) | .17 | 7.38 (0.07) | 7.37 (0.08) | .11 | 7.39 (0.08) | .03 |
| No. of patients | | 464 | 498 | | 444 | 472 | | 342 | |



if same $FiO_2$

same PEEP ?

same
Recruitability ?



# Positive End-Expiratory Pressure Setting in Adults With Acute Lung Injury and Acute Respiratory Distress Syndrome

## A Randomized Controlled Trial

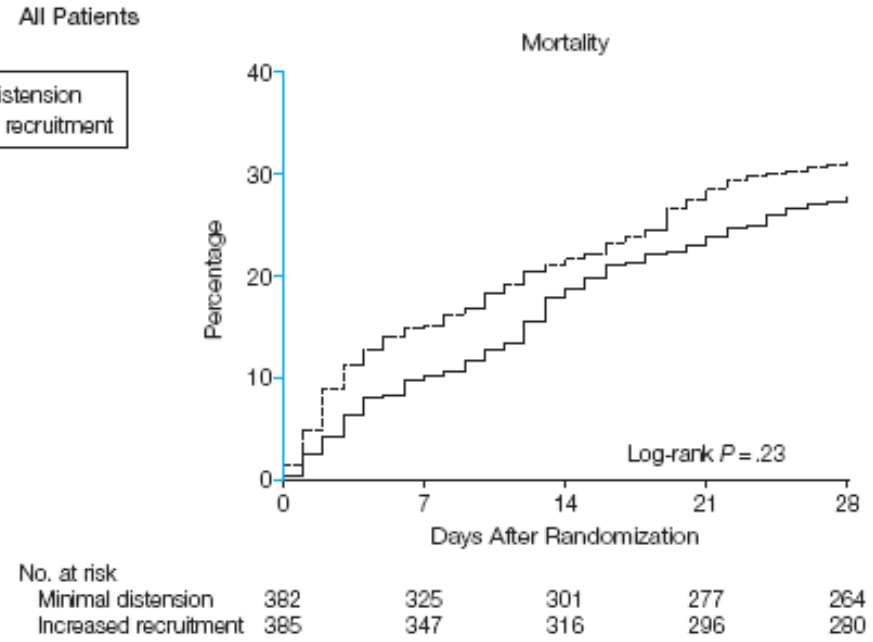
EXPRESS

| Ventilator Mode | Volume-Assist Control |
|---|---|
| Tidal volume goal | 6 mL/kg of predicted body weight[a] |
| Plateau pressure limit | ≤30 cm $H_2O$ |
| Ventilation rate and pH goals | ≤35; adjusted for a pH between 7.30 and 7.45 |
| Oxygenation goals | |
| $Pa_{O_2}$ | 55-80 mm Hg |
| $Sp_{O_2}$ | 88%-95% |
| PEEP[b] | |
| Minimal distension group[c] | Total PEEP between 5 and 9 cm $H_2O$ |
| Increased recruitment group[d] | Plateau pressure between 28 and 30 cm $H_2O$ |
| Recruitment maneuvers | Allowed but not recommended |
| Adjunctive therapies (prone position or inhaled nitric oxide or almitrine bismesylate) | Allowed when the oxygenation goal was not met despite $F_{IO_2}$ ≥0.8 |
| PEEP weaning test | |
| In patients with $Pa_{O_2}$:$F_{IO_2}$ >150 mm Hg with $F_{IO_2}$ ≤0.6 daily from day 4 onward; $F_{IO_2}$ of 0.5 and PEEP of 5 cm $H_2O$ for 20-30 min | Successful if $Pa_{O_2}$ ≥100 mm Hg; subsequent ventilation with PEEP of 5 cm $H_2O$, tidal volume <10 mL/kg predicted body weight, and plateau pressure <30 cm $H_2O$ |

*Mercat et al. JAMA 2008;299:646-655*

| Variable | Day 1 | | | Day 3 | | | Day 7 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Minimal Distension | Increased Recruitment | *P* Value | Minimal Distension | Increased Recruitment | *P* Value | Minimal Distension | Increased Recruitment | *P* Value |
| Tidal volume, mL/kg of predicted body weight | 6.1 (0.4) | 6.1 (0.3) | .57 | 6.2 (0.6) | 6.2 (0.5) | .83 | 6.4 (0.9) | 6.8 (1.3) | .001 |
| No. of patients | 372 | 379 | | 322 | 332 | | 210 | 192 | |
| Plateau pressure, cm $H_2O$ | 21.1 (4.7) | 27.5 (2.4) | <.001 | 20.7 (5.0) | 26.5 (4.2) | <.001 | 21.1 (5.6) | 24.3 (5.8) | <.001 |
| No. of patients | 365 | 378 | | 314 | 329 | | 173 | 163 | |
| Respiratory rate, cycles/min | 27.8 (5.4) | 28.2 (5.4) | .32 | 27.8 (5.7) | 28.2 (6.1) | .39 | 27.4 (6.4) | 26.5 (7.1) | .13 |
| No. of patients | 371 | 377 | | 331 | 346 | | 250 | 242 | |
| Minute ventilation, L/min | 11.2 (2.8) | 11.3 (2.7) | .39 | 11.3 (2.8) | 11.5 (2.7) | .36 | 12.0 (3.0) | 12.2 (3.0) | .55 |
| No. of patients | 369 | 376 | | 331 | 348 | | 245 | 233 | |
| $FIO_2$ | 0.66 (0.21) | 0.55 (0.19) | <.001 | 0.58 (0.20) | 0.46 (0.17) | <.001 | 0.54 (0.20) | 0.49 (0.17) | .001 |
| No. of patients | 372 | 380 | | 333 | 351 | | 266 | 252 | |
| PEEP, cm $H_2O$ | 7.1 (1.8) | 14.6 (3.2) | <.001 | 6.7 (1.8) | | | | | |
| No. of patients | 372 | 380 | | 333 | | | | | |

| Outcome | Minimal Distension (n = 382) | Increased Recruitment (n = 385) | *P* Value |
|---|---|---|---|
| | No. (%) | | |
| Death in the first 28 d[a] | 119 (31.2) | 107 (27.8) | .31 |
| Death before hospital discharge | 149 (39.0) | 136 (35.4) | .30 |
| Death in the first 60 d | 151 (39.5) | 138 (35.9) | .31 |
| Pneumothorax between day 1 and day 28[b] | 22 (5.8) | 26 (6.8) | .57 |
| | Median (IQR) | | |
| No. of days between day 1 and day 28 | | | |
| Ventilator-free[c] | 3 (0-17) | 7 (0-19) | .04 |
| Organ failure–free[d] | 2 (0-16) | 6 (0-18) | .04 |
| Cardiovascular failure–free[d] | 21 (4-26) | 23 (10-26) | .09 |
| Renal failure–free[d] | 27.5 (8.0-28.0) | 28.0 (11.0-28.0) | .23 |




*Mercat et al. JAMA 2008;299:646-655*

## Recommendation 6.1

We are **unable to make a recommendation** for or against routine PEEP titration with a higher PEEP/$FiO_2$ strategy versus a lower PEEP/$FiO_2$ strategy to reduce mortality in patients with ARDS.
*No recommendation; high level of evidence of no effect.*

## Recommendation 6.2

We are **unable to make a recommendation** for or against PEEP titration guided principally by respiratory mechanics, compared to PEEP titration based principally on PEEP/$FiO_2$ strategy to reduce mortality in patients with ARDS.
*No recommendation; high level of evidence of no effect.*

## Recommendation 6.3

We **recommend against** use of prolonged high-pressure recruitment maneuvers (defined as airway pressure maintained $\geq$ 35 $cmH_2O$ for at least one minute) to reduce mortality of patients with ARDS.
*Strong recommendation; moderate level of evidence against.*

## Recommendation 6.4

We **suggest against** *routine* use of brief high-pressure recruitment maneuvers (defined as airway pressure maintained $\geq$ 35 $cmH_2O$ for less than one minute) to reduce mortality in patients with ARDS.
*Weak recommendation; high level of evidence of no effect.*

*Intensive Care Med (2023) 49:727–759*

# Mechanical Ventilation Guided by Esophageal Pressure in Acute Lung Injury

**EPVent**

Recruitment Maneuver ;

30 sec breath-hold at 40 cm H2O airway pressure

**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 |

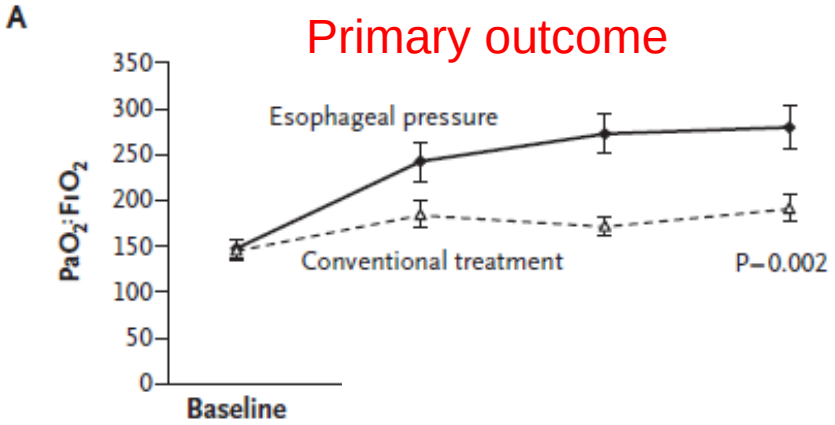
**transpulmonary pressure** = airway pressure-esophageal pressure

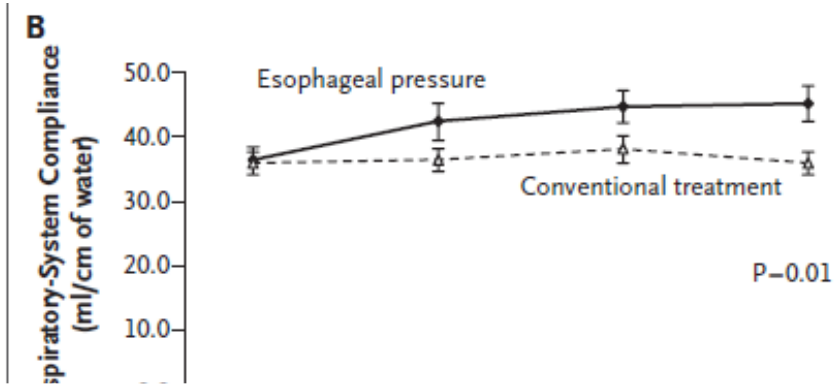
**Control Group**

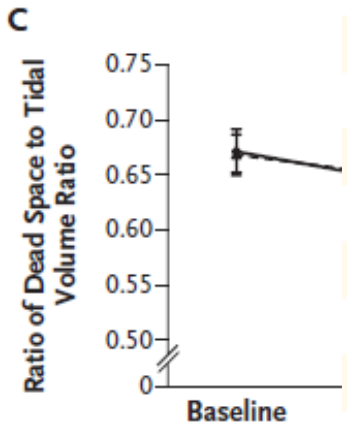
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $FIO_2$ | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 | 0.9 | 0.9 | 0.9 | 1.0 |
| PEEP | 5 | 5 | 8 | 8 | 10 | 10 | 10 | 12 | 14 | 14 | 14 | 16 | 18 | 20–24 |

Talmor D et al. N Engl J Med 2008;359:2095– 2104

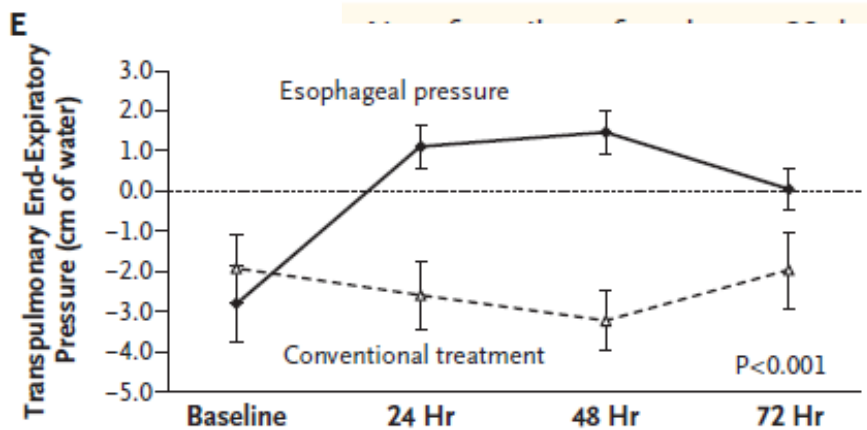
## Primary outcome

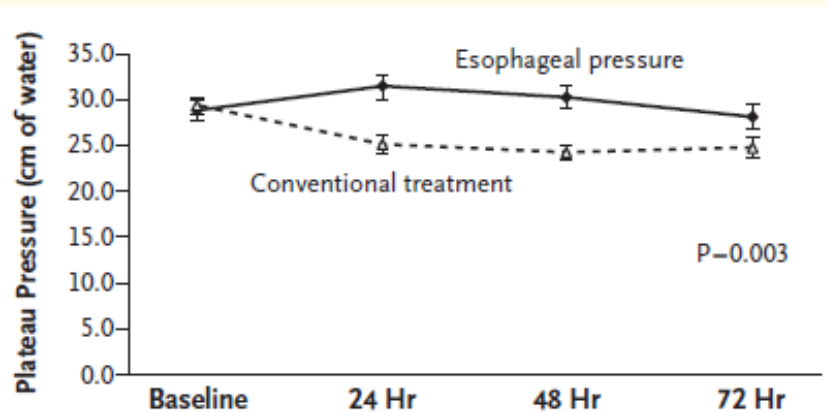



| Outcome | Esophageal-Pressure–Guided (N=30) | Conventional Treatment (N=31) | P Value |
|---|---|---|---|
| 28-Day mortality — no. (%) | 5 (17) | 12 (39) | 0.055 |
| 180-Day mortality — no. (%) | 8 (27) | 14 (45) | 0.13 |
| Length of ICU stay — days | | | 0.16 |
| Median | 15.5 | 13.0 | |
| Interquartile 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 | |



| Protocol Variable | $P_{ES}$-Guided PEEP | | Empirical PEEP-$FIO_2$ | |
|---|---|---|---|---|
| Ventilator mode | Volume or pressure assist control | | Volume or pressure assist control | |
| Tidal volume, mL/kg PBW | 6 (range, 4-8) | | 6 (range, 4-8) | |
| End-inspiratory pressure limit, cm $H_2O$ | $P_L \leq 20$ | | $P_{PLAT} \leq 35$ | |
| Respiratory rate set to attain target pH 7.30-7.45, breaths/min | 6-35 | | 6-35 | |
| Inspiratory to expiratory time ratio | 1.1-1.3 | | 1.1-1.3 | |
| Goal oxygenation | $PaO_2$: 55-80 mm Hg or $SpO_2$: 88%-93% | | $PaO_2$: 55-80 mm Hg or $SpO_2$: 88%-93% | |
| Allowable combinations of $FIO_2$ and either end-expiratory $P_L$ or PEEP to attain goal oxygenation[a] | $FIO_2$ | $P_L$, cm $H_2O$ | $FIO_2$ | PEEP, cm $H_2O$ |
| | 0.3 | 0 | 0.3 | 5 |
| | 0.4 | 0 | 0.3 | 8 |
| | 0.5 | 0 | 0.3 | 10 |
| | 0.5 | 2 | 0.4 | 10 |
| | 0.6 | 2 | 0.4 | 12 |
| | 0.6 | 3 | 0.4 | 14 |
| | 0.7 | 3 | 0.4 | 16 |
| | 0.7 | 4 | 0.4 | 18 |

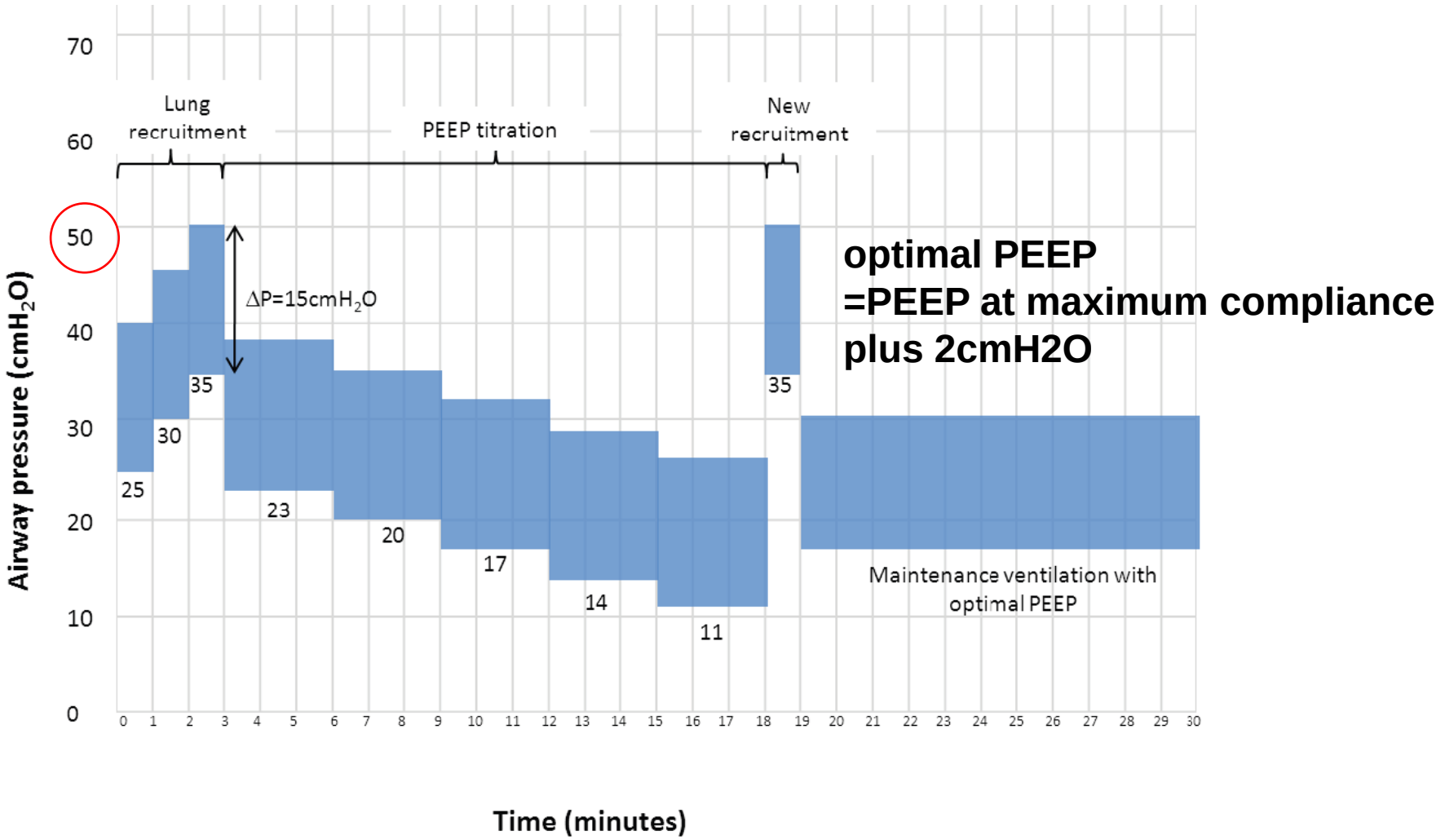
| Variable | $P_{ES}$-Guided PEEP (n = 102) | Empirical PEEP-$FIO_2$ (n = 98) | Absolute Difference, % (95% CI)[b] | *P* Value[c] |
|---|---|---|---|---|
| **Primary End Point** | | | | |
| Probability of more favorable outcome, a ranked composite incorporating death and days free from mechanical ventilation among survivors, % (95% CI)[d] | 49.6 (41.7 to 57.5) | 50.4 (42.5 to 58.3) | NR[e] | .92 |
| **Secondary Clinical End Points** | | | | |
| Mortality through day 28, No. (%) | 33 (32.4) | 30 (30.6) | 1.7 (−11.1 to 14.6) | .88 |
| Days free from mechanical ventilation among survivors through day 28, median (IQR) | 22 (15 to 24) | 21 (16.5 to 24) | 0 (−1 to 2) | .85 |
| Mortality through day 60, No./total No. (%) | 38/101 (37.6) | 37/98 (37.8) | −0.1 (−13.6 to 13.3) | >.99 |
| Mortality through 1 y, No./total No. (%) | 44/100 (44.0) | 44/96 (45.8) | −1.8 (−15.8 to 12.1) | .89 |
| Ventilator-free days through day 28, median (IQR)[f] | 15.5 (0 to 23) | 17.5 (0 to 23) | 0 (0 to 0) | .93 |
| ICU length of stay through day 28, median (IQR), d | 10 (6 to 17) | 9.5 (5 to 14) | 1 (−1 to 3) | .24 |
| Hospital length of stay through day 28, median (IQR), d | 16 (9 to 26) | 15 (8 to 24) | 0 (−1 to 3) | .58 |
| Hospital length of stay through day 60, median (IQR), d | 16 (9 to 26) | 15 (8 to 24) | 1 (−2 to 4) | .47 |

*Beitler JR, et al. JAMA*. 2019;321(9):846-857

# Effect of Lung Recruitment and Titrated Positive End-Expiratory Pressure (PEEP) vs Low PEEP on Mortality in Patients With Acute Respiratory Distress Syndrome ART

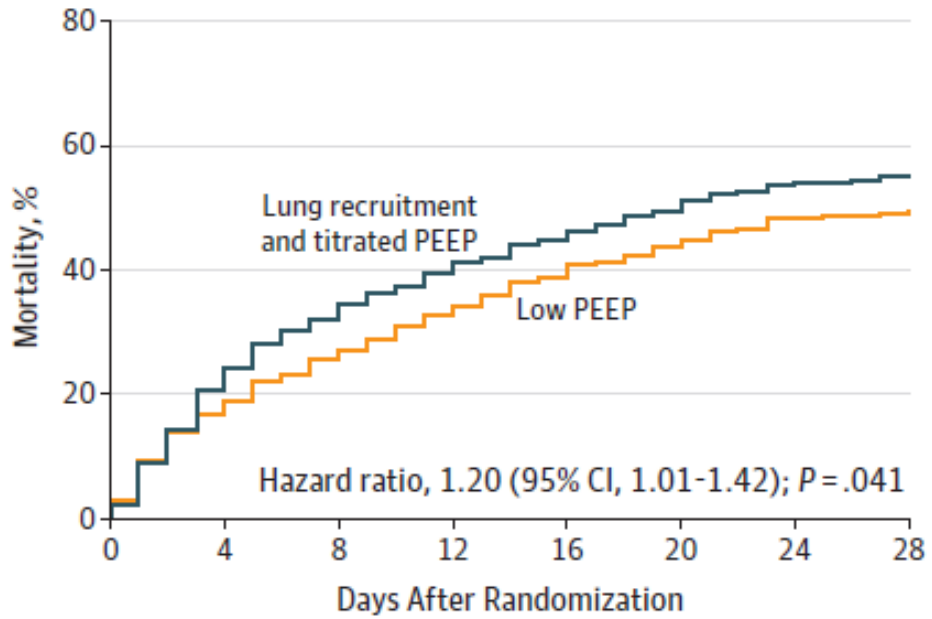
| Procedure | ART Strategy - Maximum alveolar recruitment maneuver associated with PEEP titration | ARDSNet strategy |
|---|---|---|
| **Alveolar recruitment maneuver** | Yes (see figure 1) | No |
| **Ventilation mode** | Controlled volume | Controlled volume |
| **Target plateau pressure and driving pressure** | Plateau ≤30cm$H_2O$ | Plateau ≤30cm$H_2O$ |
| **Target tidal volume** | 4 to 6mL/kg of predicted body weight | 4 to 6mL/kg of predicted body weight |
| **Respiratory rate and pH goal** | 6-35/min, adjusted for pH ≥ 7.30 if possible | 6-35/min, adjusted for pH ≥ 7.30 if possible |
| **I:E ratio** | 1:1 to 1:2; Flow 60L/min; Inspiratory pause 0.5sec | 1:1 to 1:2; Flow 60L/min; Inspiratory pause 0.5sec |
| **Oxygenation goals** | | |
| **$PaO_2$** | 60-80mmHg | 55 – 80mmHg |
| **$SpO_2$** | 90-95% | 88 – 95% |
| **PEEP and $FiO_2$ adjustment** | PEEP titration 2cm$H_2O$ above PEEP value associated with maximum compliance. $FiO_2$ titration adjusted according to oxygenation goals | According to PEEP/$FiO_2$ combination table |
| **Weaning** | After 24 hours with $PaO_2/FiO_2$ (same or ascending of anterior day) start weaning from PEEP 2cm$H_2O$ every 8 hours. Consider pressure support ventilation after PEEP≤14 cm$H_2O$. Spontaneous ventilation test in PS = 5cm$H_2O$ and PEEP = 5cm$H_2O$. Prophylactic use of NIV immediately after extubation is encouraged. | Weaning from PEEP according to table of PEEP and $FiO_2$ combinations. Consider pressure support ventilation after PEEP≤14 cm$H_2O$. Spontaneous ventilation test in PS = 5cm$H_2O$ and PEEP = 5cm$H_2O$. Prophylactic use of NIV immediately after extubation is encouraged. |

*JAMA*. 2017;318(14):1335-1345




**optimal PEEP**
**=PEEP at maximum compliance**
**plus 2cmH2O**

ART Strategy - Maximum alveolar recruitment maneuver associated with PEEP titration




| No. at risk | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Lung recruitment and titrated PEEP | 501 | 397 | 340 | 303 | 276 | 254 | 233 | 225 |
| Low PEEP | 509 | 423 | 378 | 343 | 312 | 286 | 264 | 260 |

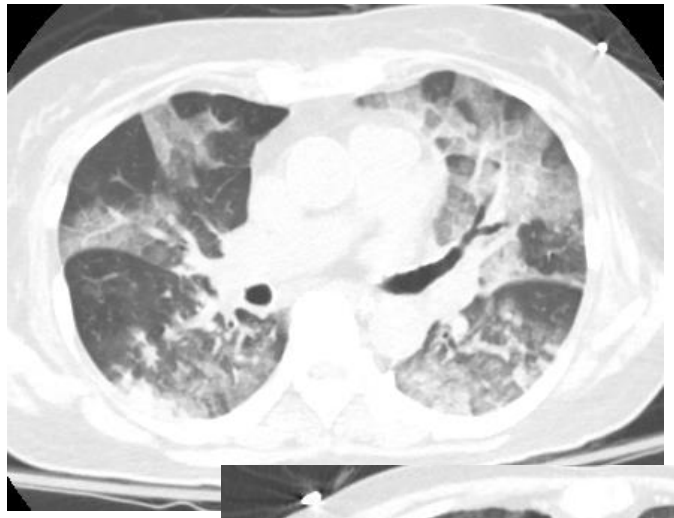
| Outcome | Lung Recruitment Maneuver With PEEP Titration Group (n = 501) | Low-PEEP Group (n = 509) | Type of Effect Estimate | Effect Estimate (95% CI) | *P* Value |
|---|---|---|---|---|---|
| Pneumothorax requiring drainage ≤7 d, No./total No. (%) | 16/501 (3.2) | 6/509 (1.2) | RD | 2.0 (0.2 to 3.8) | .03 |
| Barotrauma ≤7 d, No./total No. (%) | 28/501 (5.6) | 8/509 (1.6) | RD | 4.0 (1.5 to 6.5) | .001 |

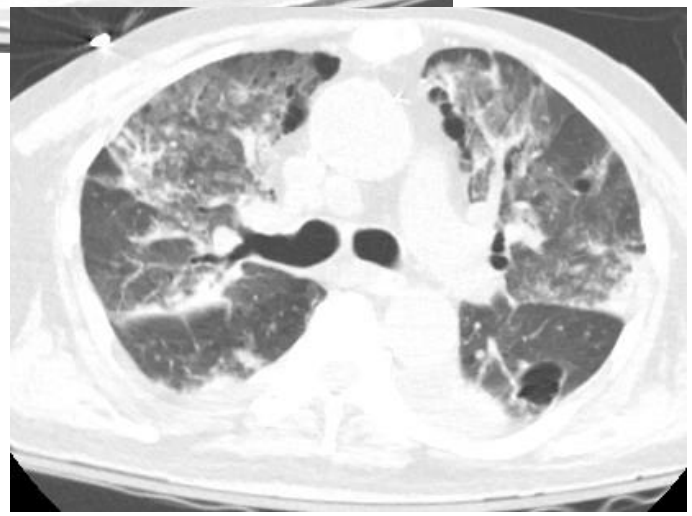
# In ARDS patients

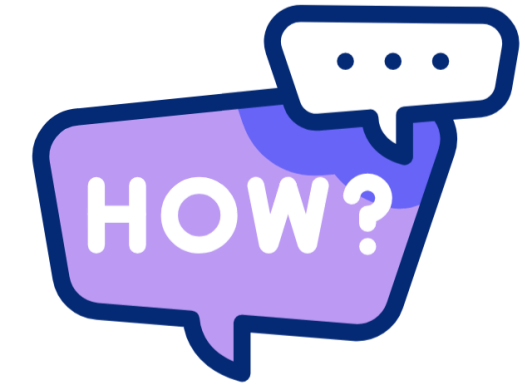
Tidal volume 6.2 ml/ Kg PBW

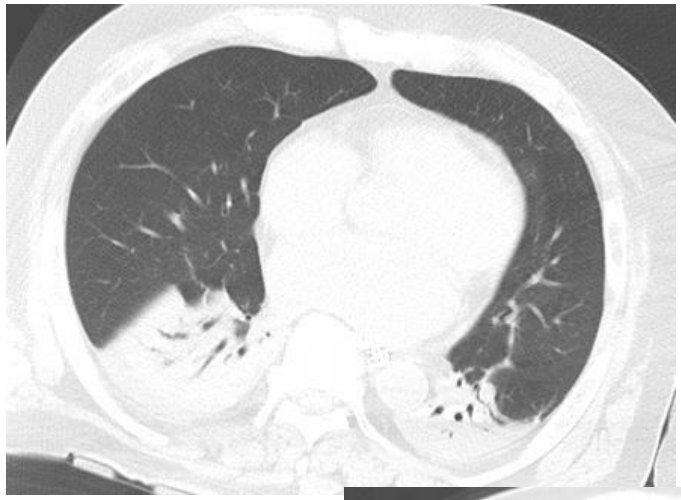
Plateau pressure = 24 cm $H_2O$, PEEP = 12 $cmH_2O$

FiO2 80% ABGA pH 7.35, $PaCO_2$ 48 $cmH_2O$, PaO2 60 $cmH_2O$





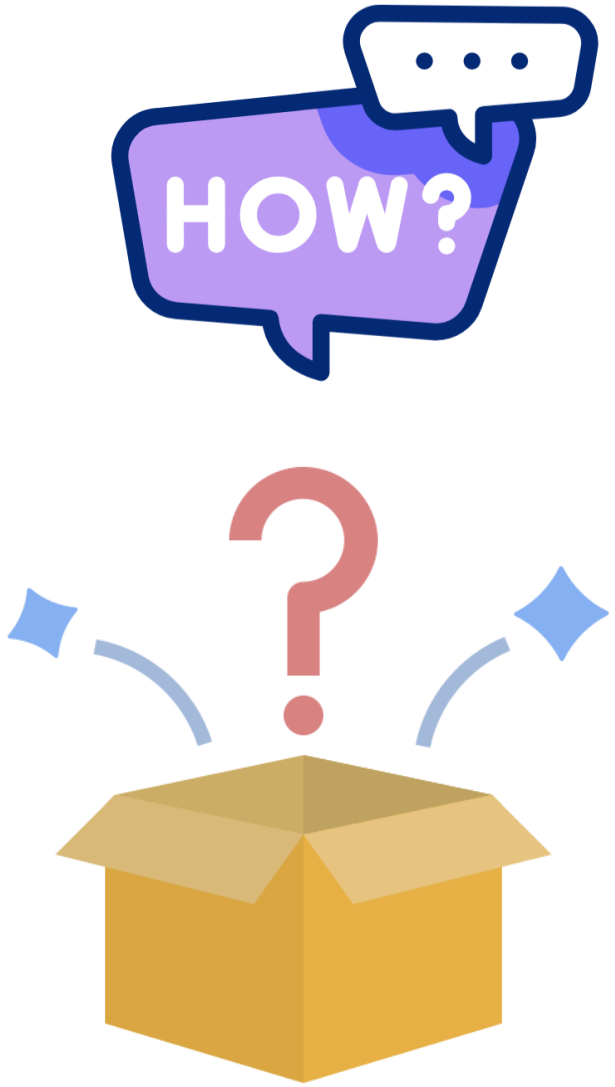


## ◆ Positive end-expiratory pressure

- To minimizing atelectrauma and subsequent biotrauma by prevention of alveolar collapse
- Improvement of oxygenation
- Choosing a level of PEEP ?

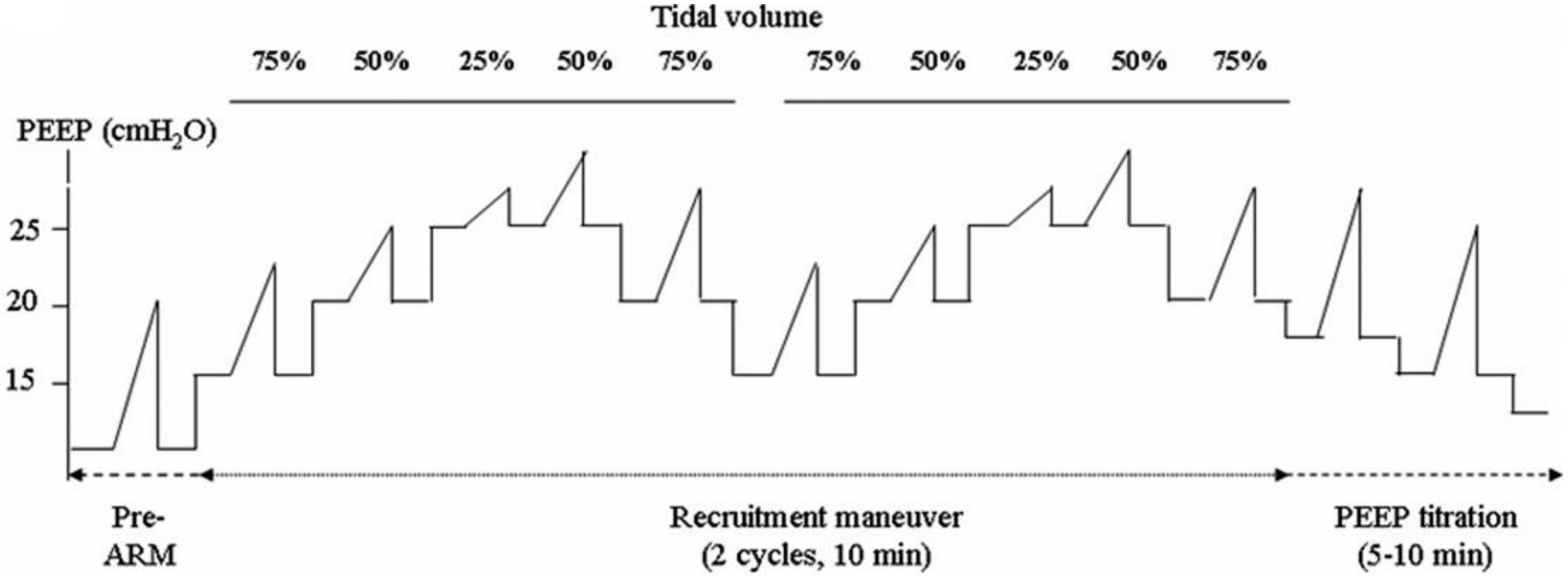
# PEEP setting




1) **Fixed**
   FiO2 –PEEP table

**2) Individualized**
alveolar recruitment c PEEP titration
physiologic approach

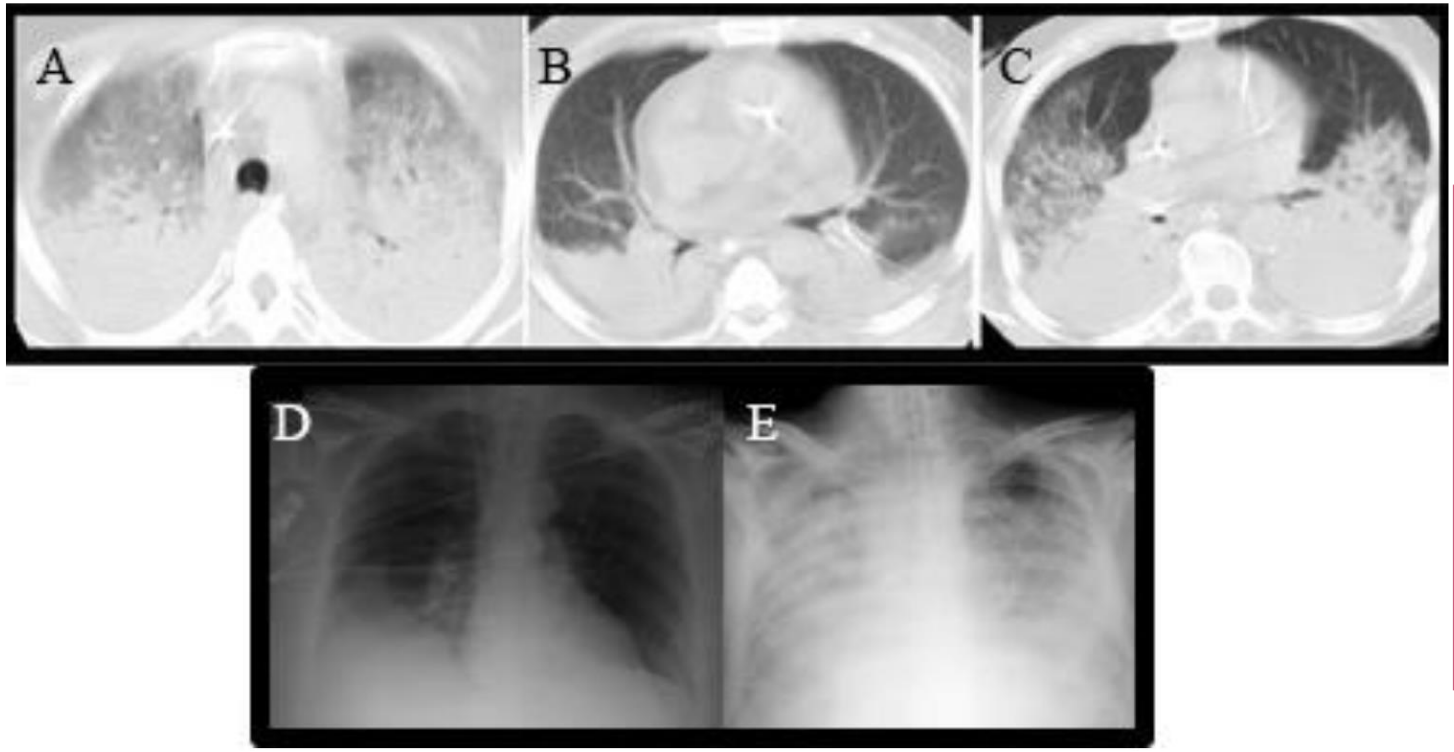
Tidal volume – PEEP combination < Peak Airway Pressure 40 cmH2O
Pause Time : 0.5 sec




*Critical Care* 2009: 13:R22

# ARDS sub-phenotype?

Lung Imaging for Ventilator Setting in ARDS (LIVE) trial

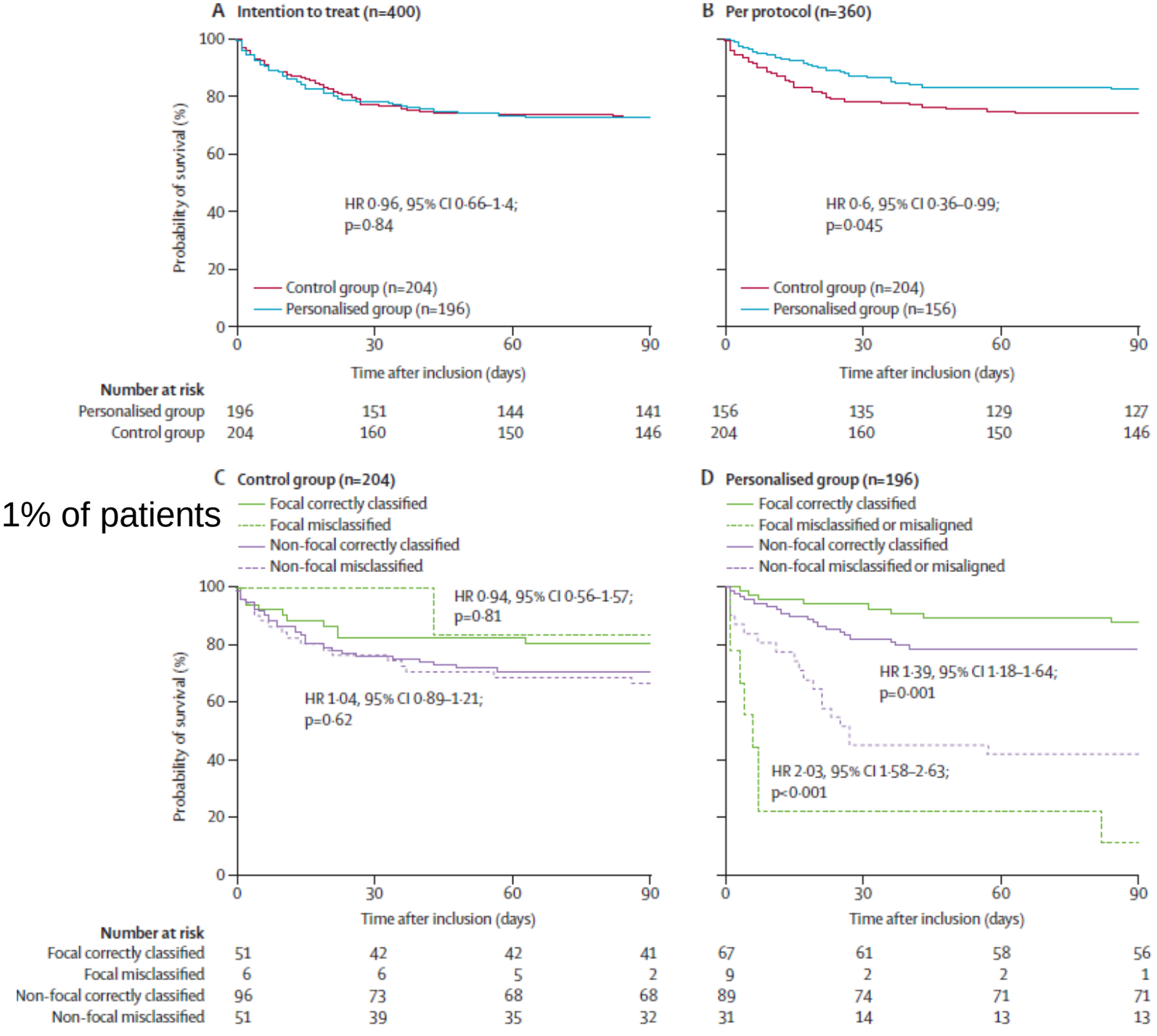



| | Control group (n=204) | Personalised group (n=196) | |
|---|---|---|---|
| | | Focal lung morphology | Non-focal lung morphology |
| Mode of ventilation | Volume control | Volume control | Volume control |
| Tidal volume | 6 mL/kg IBW | 8 mL/kg IBW | 6 mL/kg IBW |
| PEEP | PEEP/$FiO_2$ | 5–9 cm $H_2O$ | To reach Pplat of 30 cm $H_2O$ |
| PEEP-PSV | Free | 5–9 cm $H_2O$ | ≥10 cm $H_2O$ |
| Recruitment manoeuvre | Rescue | Rescue | Mandatory |
| Prone position | Encouraged | Mandatory | Rescue |

IBW=ideal body weight. PEEP=positive-end expiratory pressure. $FiO_2$=fraction of inspired oxygen. Pplat=end-inspiratory plateau pressure. PEEP-PSV=positive-end expiratory pressure used during pressure support ventilation.

Constantin JM, et al. Lancet Respir Med 2019;7: 870–80

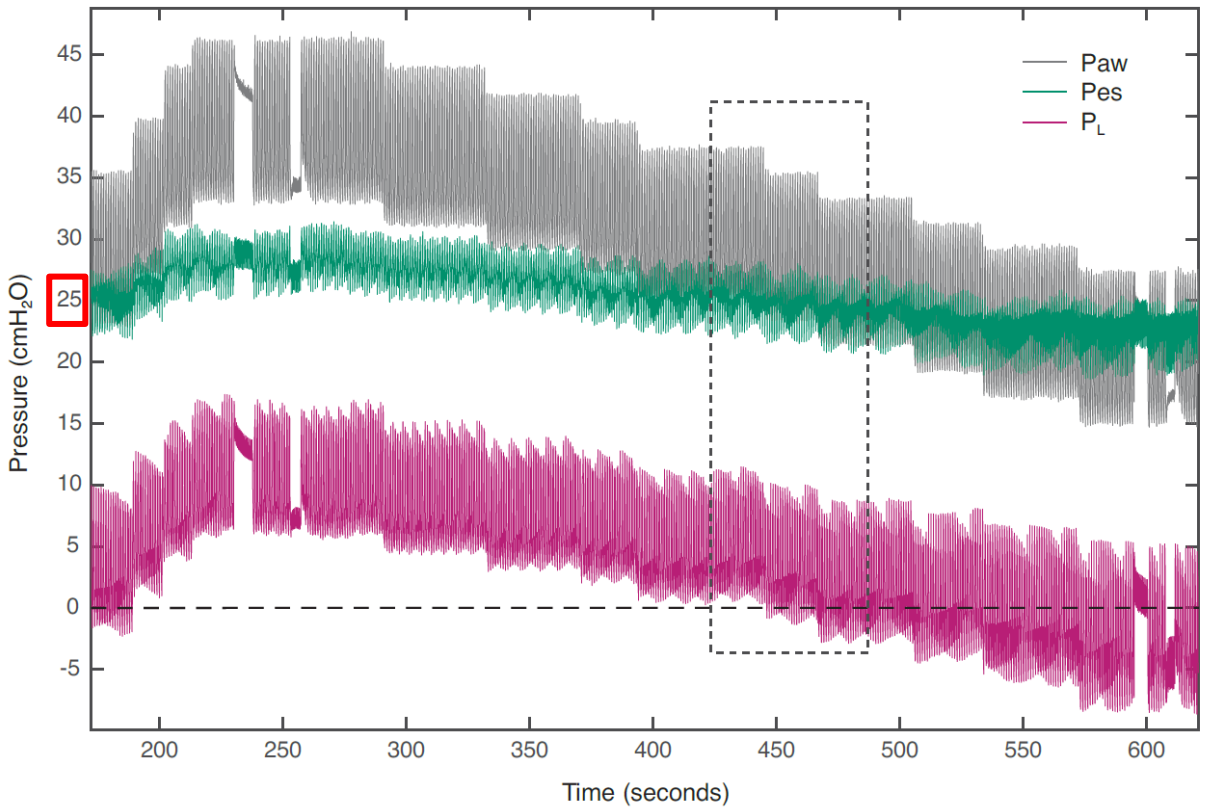
misclassification of 21% of patients

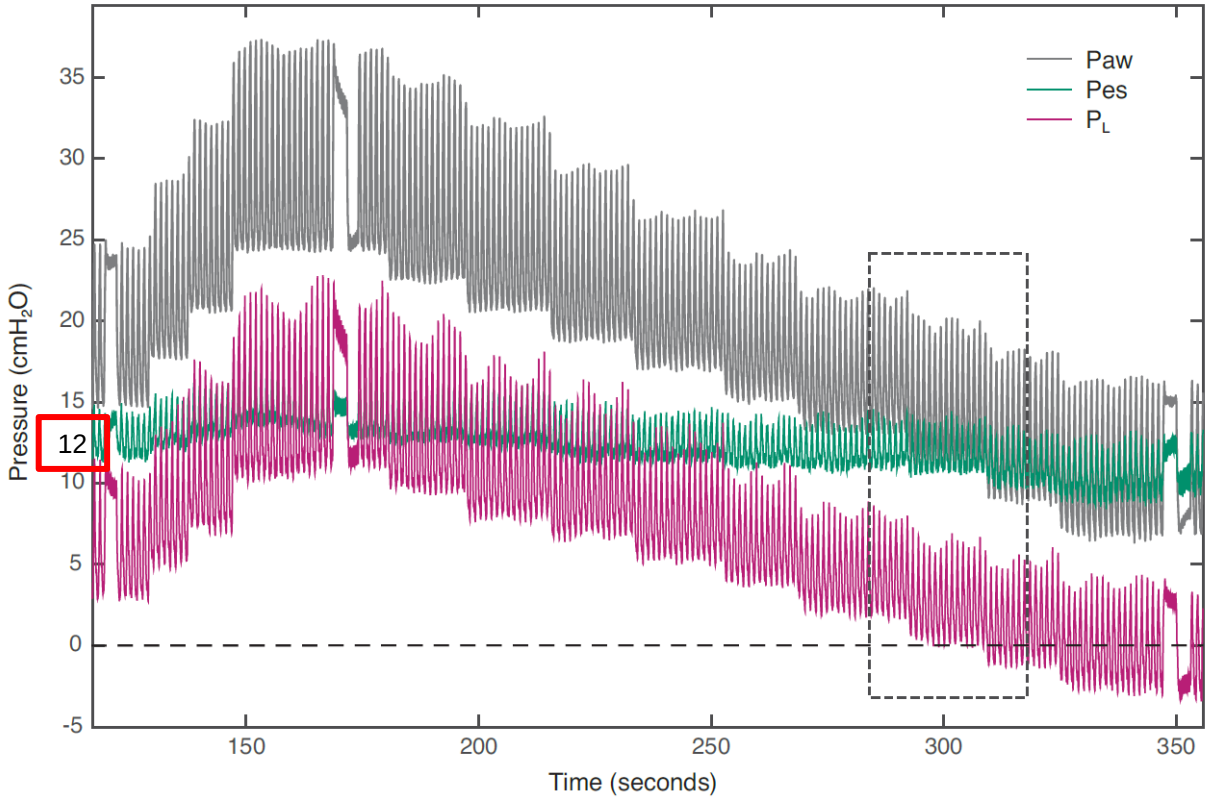


# Physiologic-based approach

- Esophageal pressure-guided PEEP setting
- Pressure-volume curves
- Recruitment-to-inflation ratio (R/I ratio)
- Electrical Impedance Tomography (EIT)-guided PEEP setting
- Lung and diaphragm ultrasound

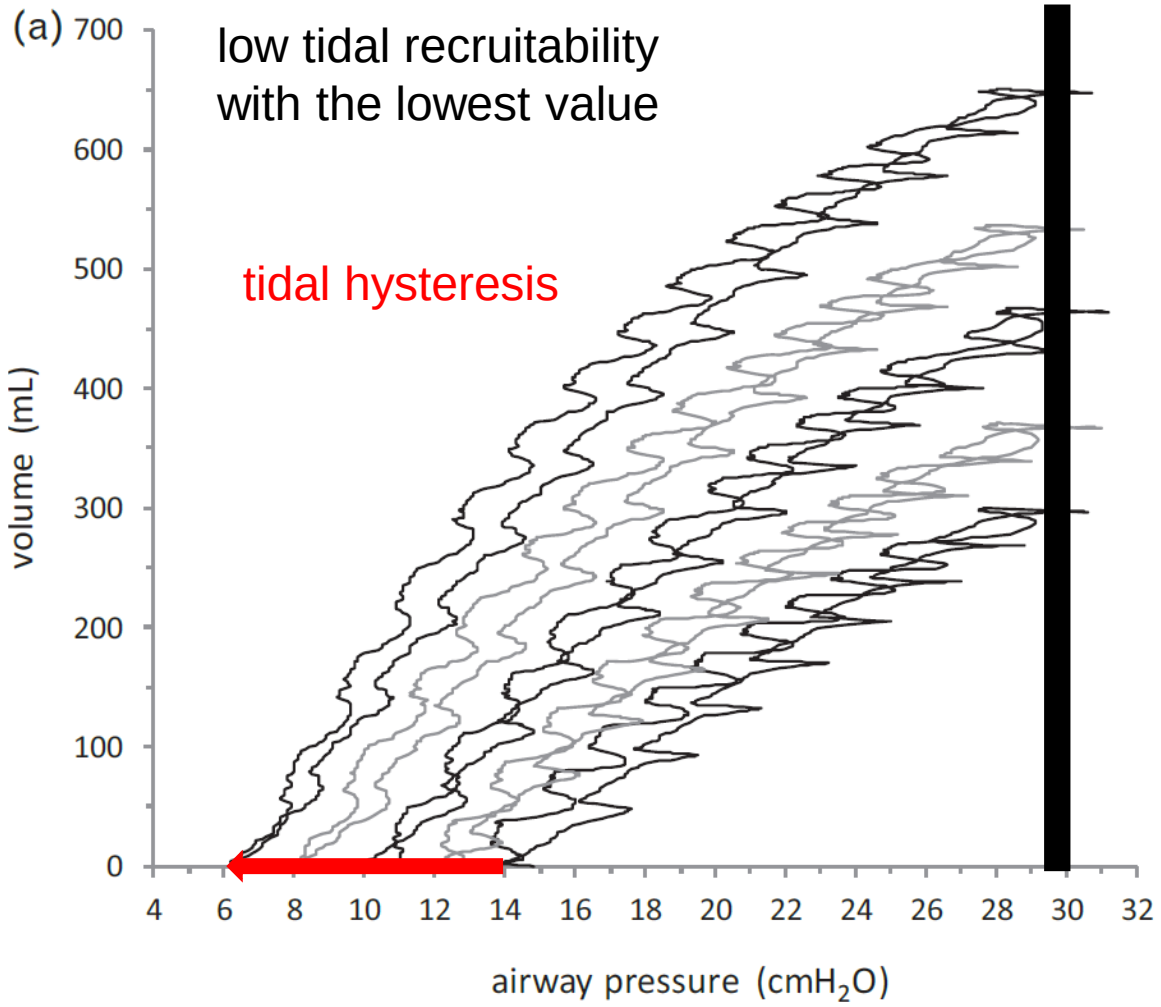
# Esophageal pressure-guided PEEP setting

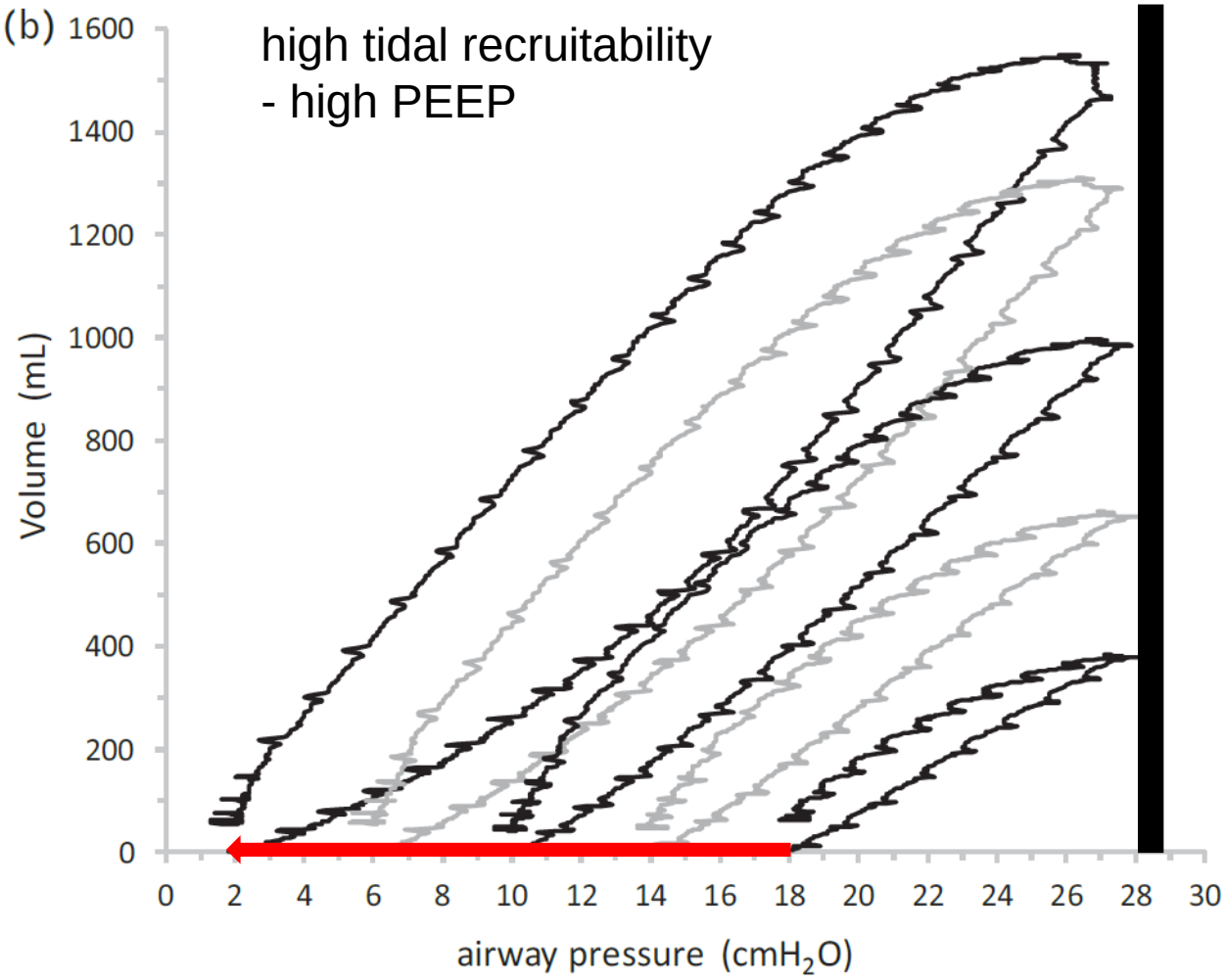



Curr Opin Crit Care 2024;30:28–34

# Multiple quasi-static tidal PV loops



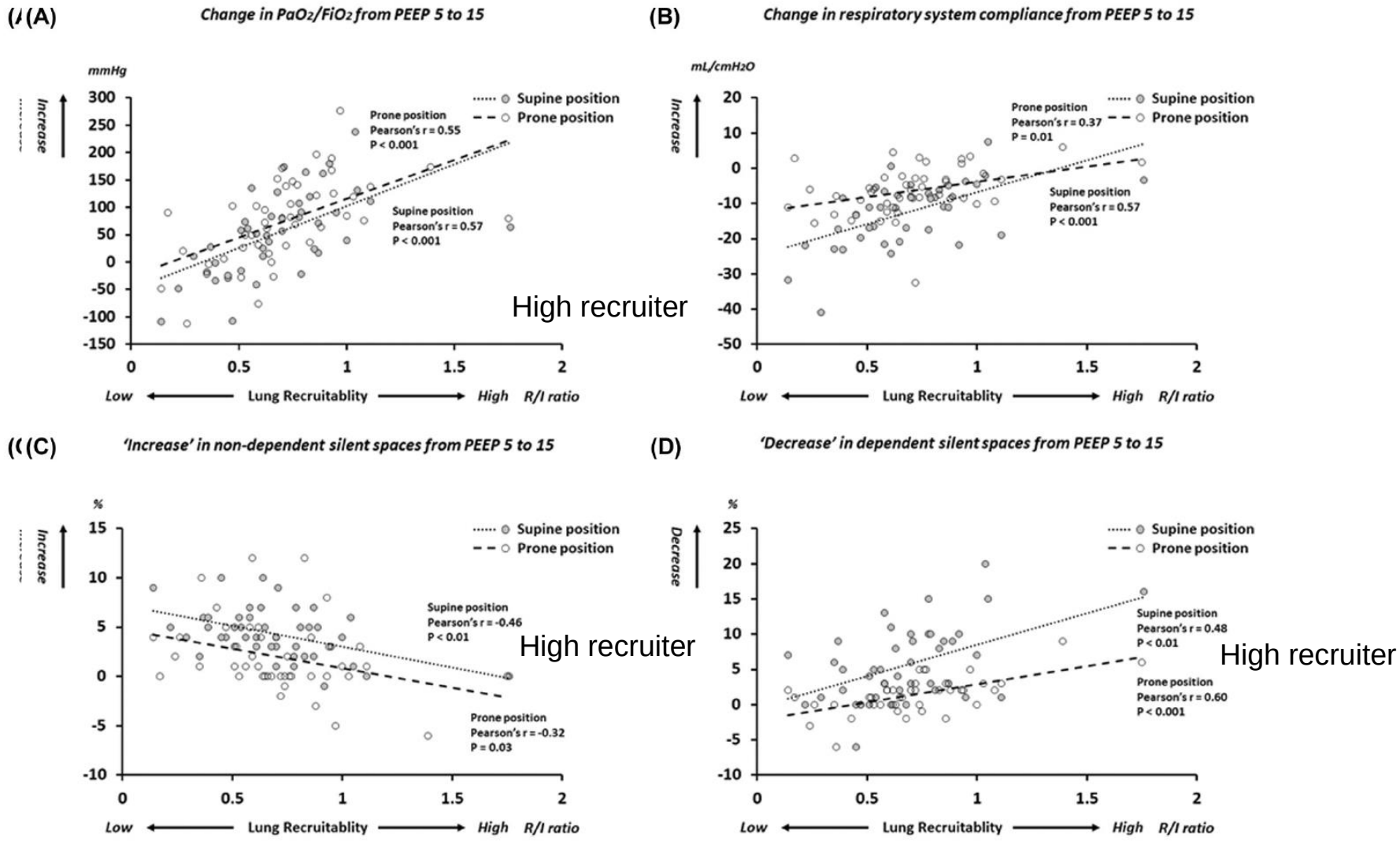

Curr Opin Crit Care 2024;30:35–42

# R/I ratio

- calculated with expiratory tidal volume measured at the time of releasing PEEP 15–5 cmH2O

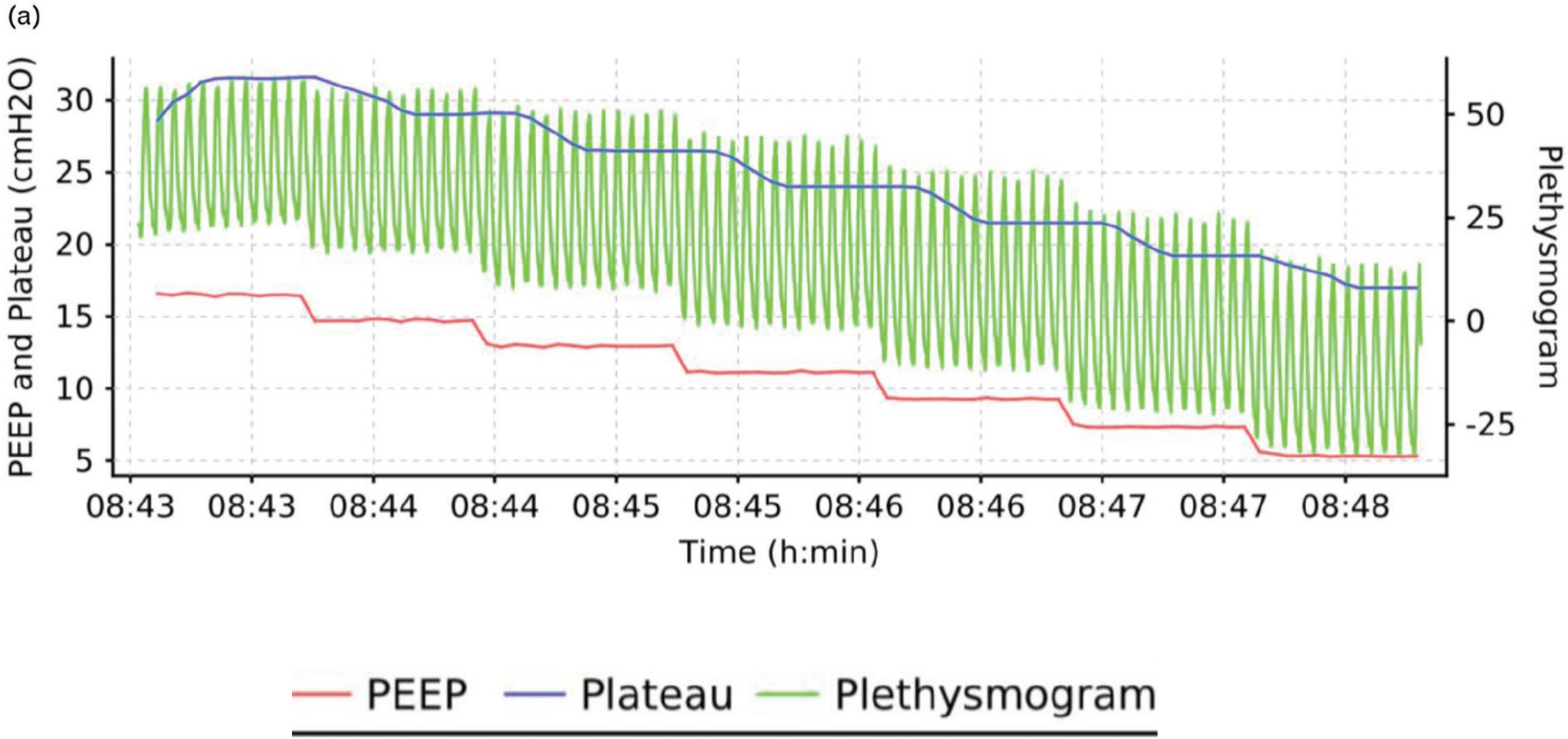
$$\mathrm{Crec} = \frac{\Delta \mathrm{Vrec}}{\mathrm{PEEP_{high}} - \mathrm{PEEP_{low}}}.$$

$$\frac{\mathrm{R}}{\mathrm{I}}\ \text{ratio} = \frac{\mathrm{Crec}}{\mathrm{Crs\ \ at\ \ PEEP_{low}\ or\ above\ \ AOP}}.$$



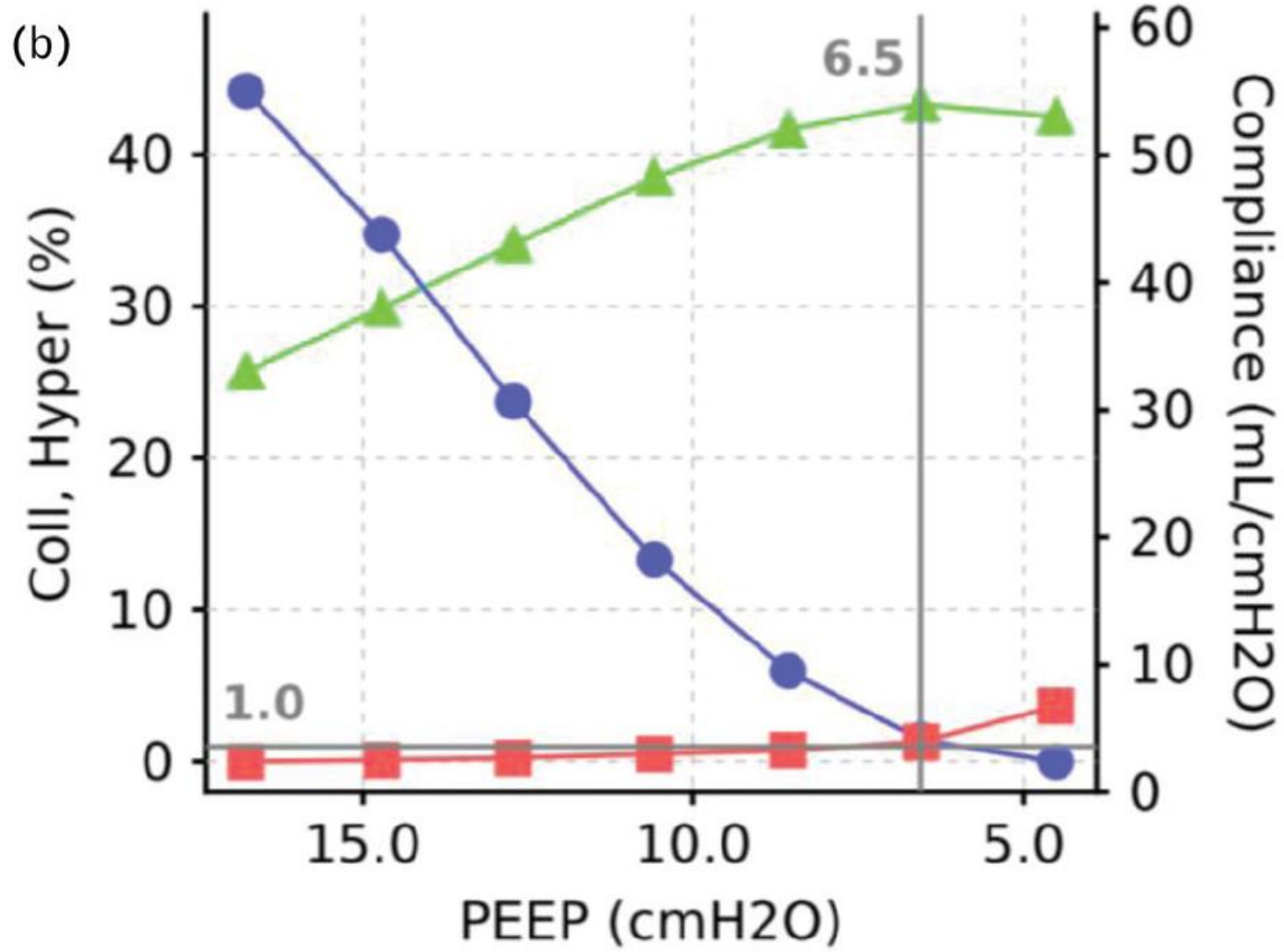

*Crit Care 2023:***27**;152

# EIT

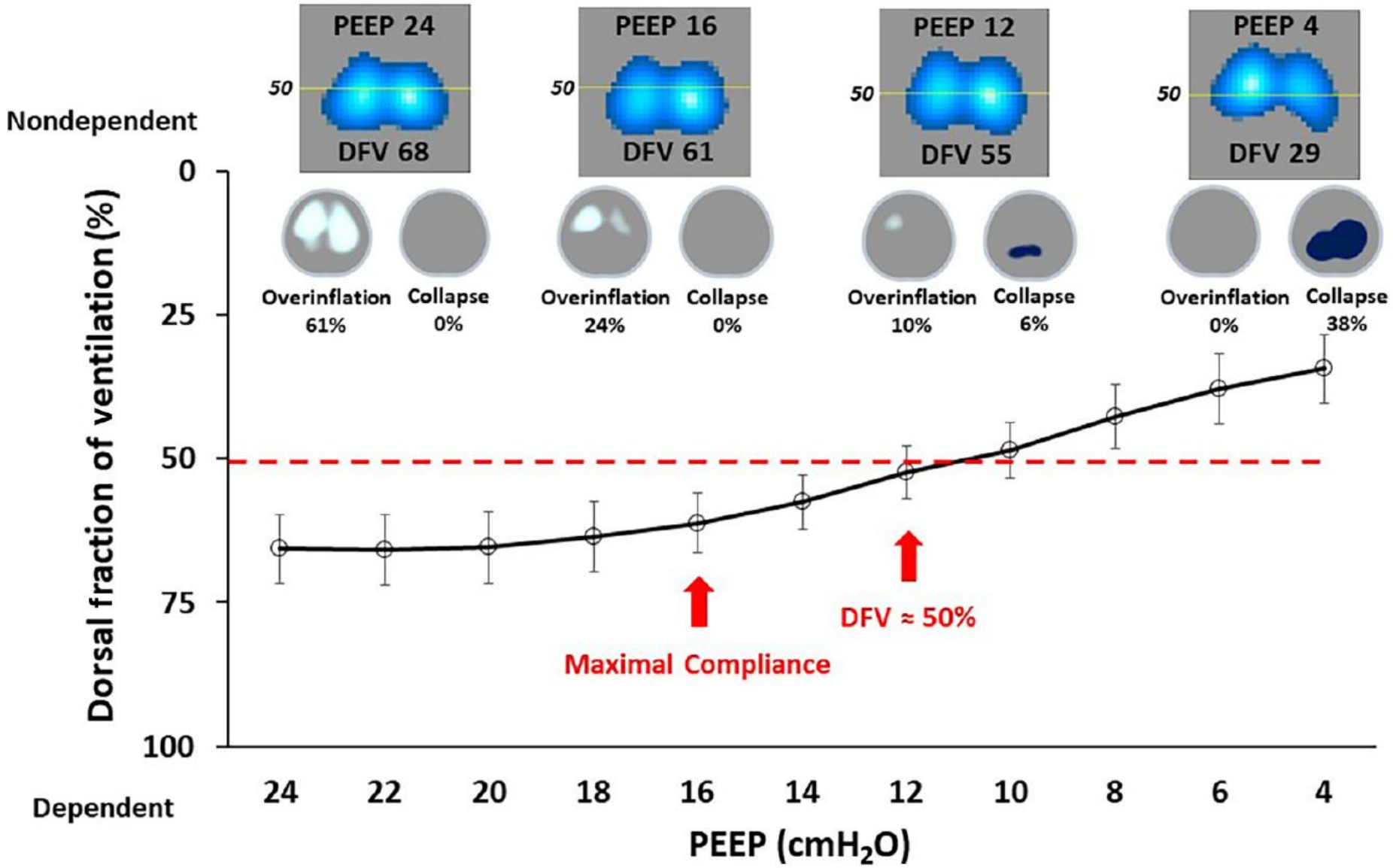



Curr Opin Crit Care 2024;30:43–52

# EIT



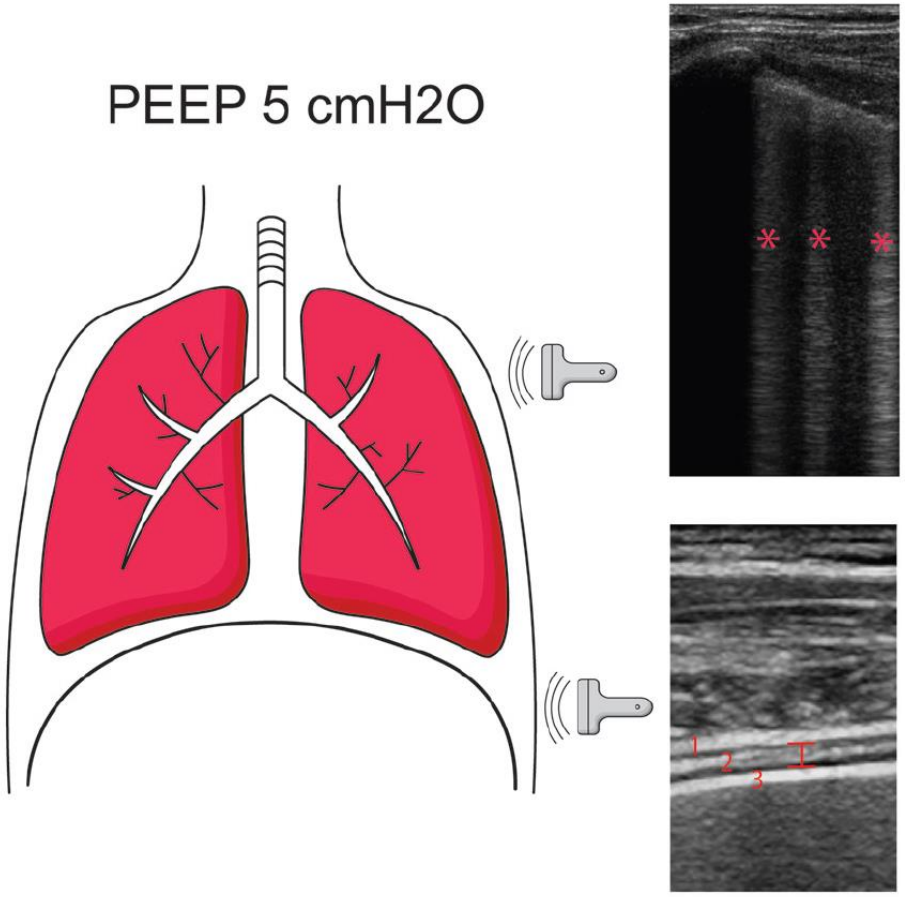

Curr Opin Crit Care 2024;30:43–52

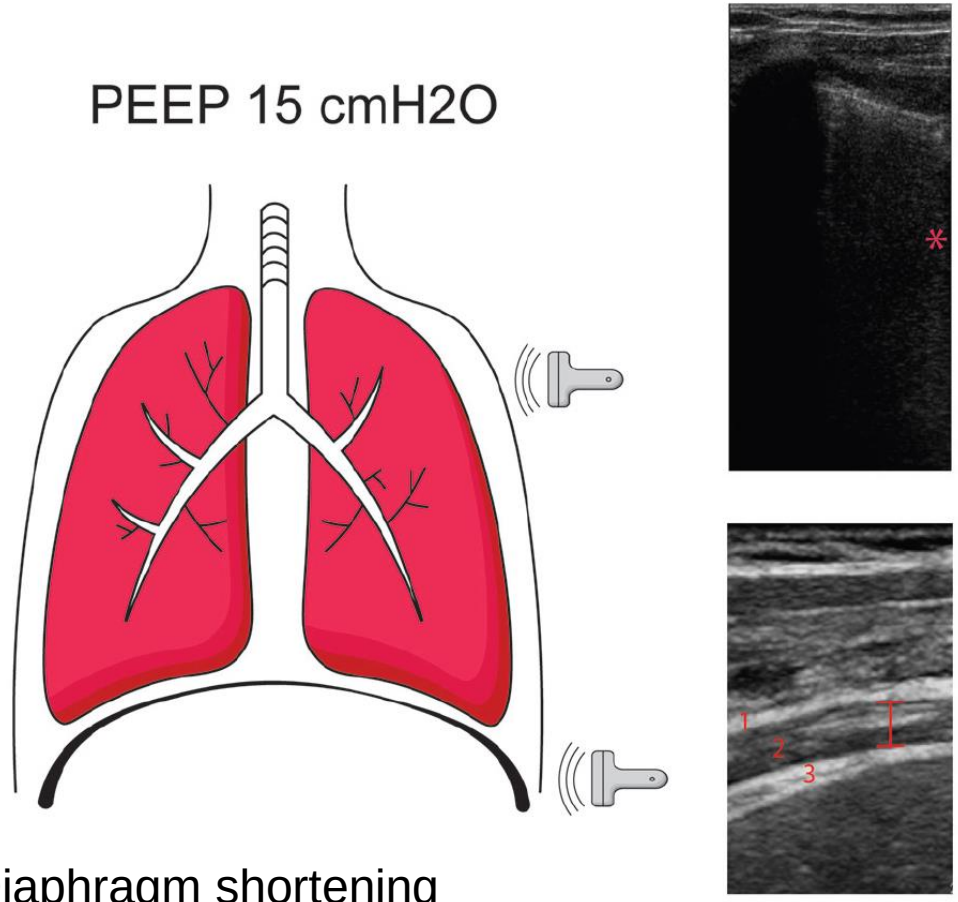



*Am J Respir Crit Care Med* 2019:200:933–937

# lung and diaphragm ultrasound

fluid to gas

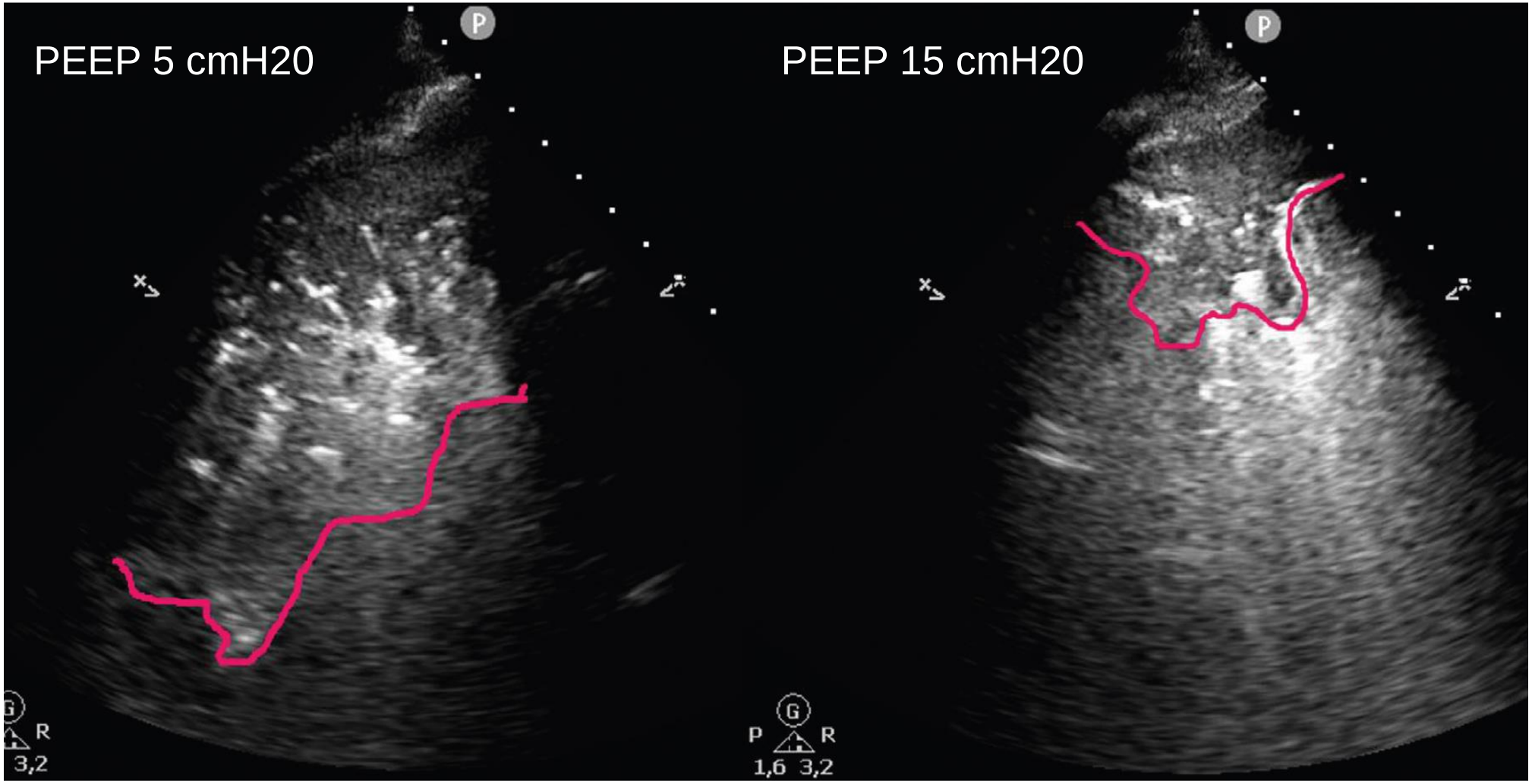



Diaphragm shortening

Curr Opin Crit Care 2024;30:43–52

# lung and diaphragm ultrasound




Curr Opin Crit Care 2024;30:43–52

# Take Home Message

1. Heterogeneity : PEEP 을 설정할 때는 recruitability 를 고려해야 한다
2. Real World: 실제 임상에서는 PEEP level 을 낮게 설정하는 편이다
3. Recruitment maneuver: ARM 을 하는 동안 최소한의 tidal volume을 유지하고, pause time 을 설정한다
4. Titration: ARM 후의 decremental PEEP titration 이 중요하다
5. Maintenance: plateau pressure < 30 cmH20 설정 하에서 PEEP을 유지한다
6. Weaning: PEEP 을 줄일 때도 protocol 이 있어야 한다