# Ventilatory Strategies in Pediatric Respiratory Failure

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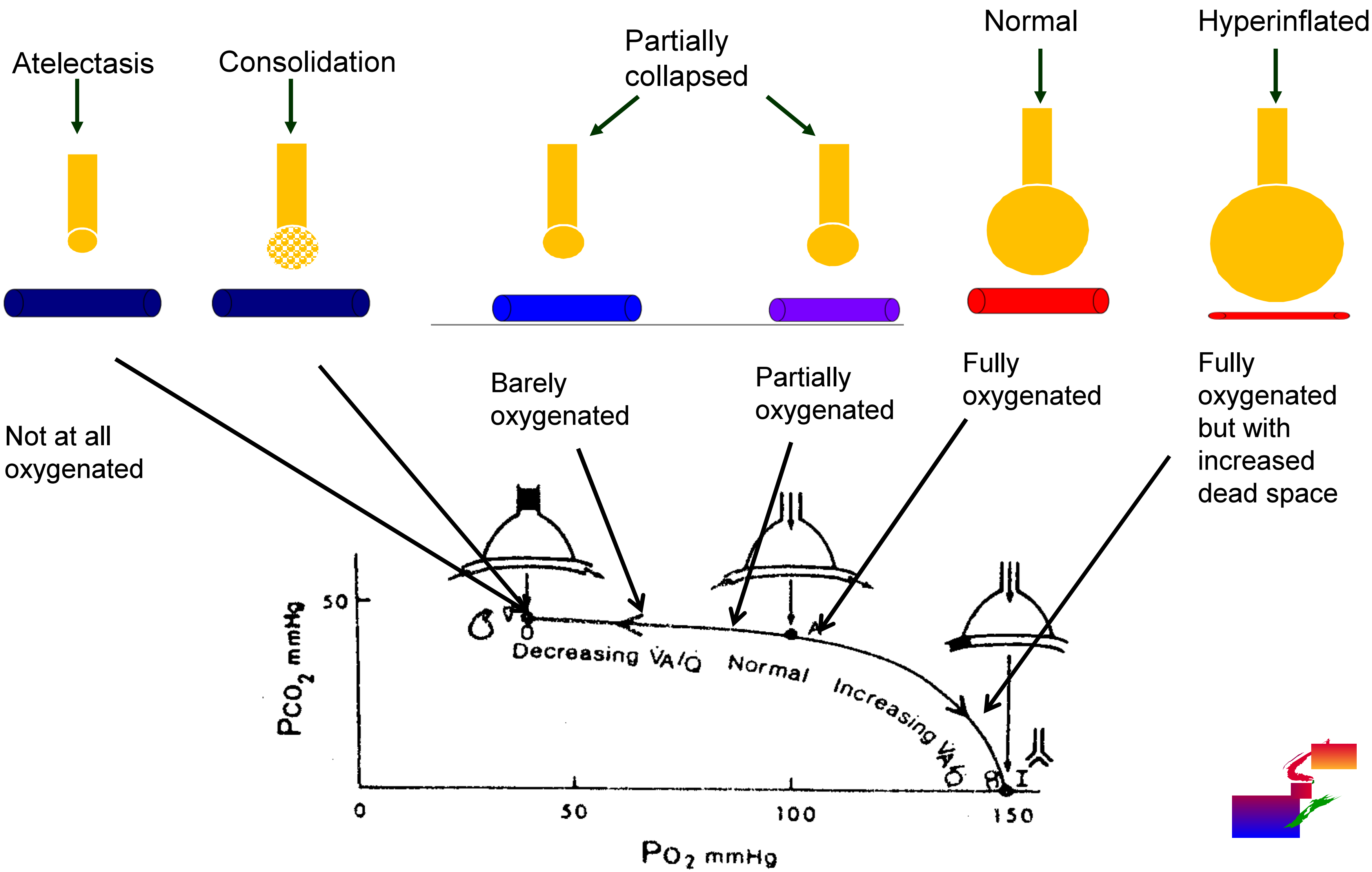
# Gas exchange problems in ARDS

- Oxygenation
  - Intrapulmonary shunting
  - $\frac{\dot{V}}{\dot{Q}}$ mismatch
- Ventilation
  - Increased dead space
  - Intrapulmonary shunting

# Mechanism of hypoxemia in ALI/ARDS



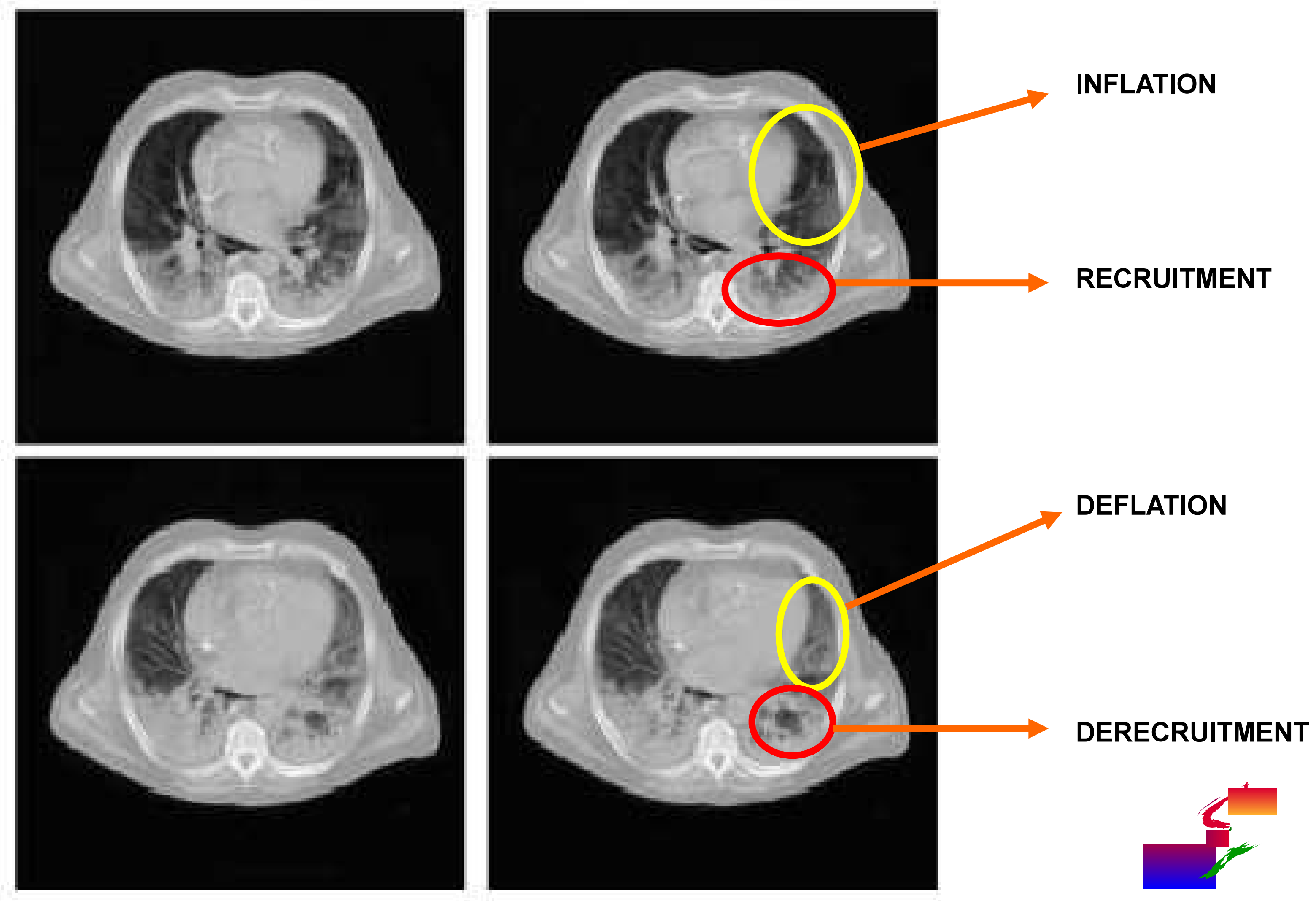
# Goals of management

- Lung management
- Optimizing oxygen delivery to the tissues
- Multiorgan support
- Treating infections
- Preventing adverse outcomes

# Some Definitions

- Inflation
  - Increasing the volume in the lungs
  - Distribution of the volumes may not be homogenous
- Recruitment
  - Increasing the number of open alveoli
  - Inflation not same as recruitment
- Overdistension
  - Overinflation of the alveoli beyond its safe capacity
- Deflation
  - Reduction in the volume of the lung
- Derecruitment
  - Open alveoli collapsing and becoming atelectatic

# Inflation, deflation, recruitment and derecruitment



# Lung management

- Opening the lung
  - Ventilatory strategies
  - Other strategies
- Preventing the lungs from closing
  - Ventilatory strategies
  - Other strategies
- Protecting the lung
  - Preventing ventilator-induced lung injury

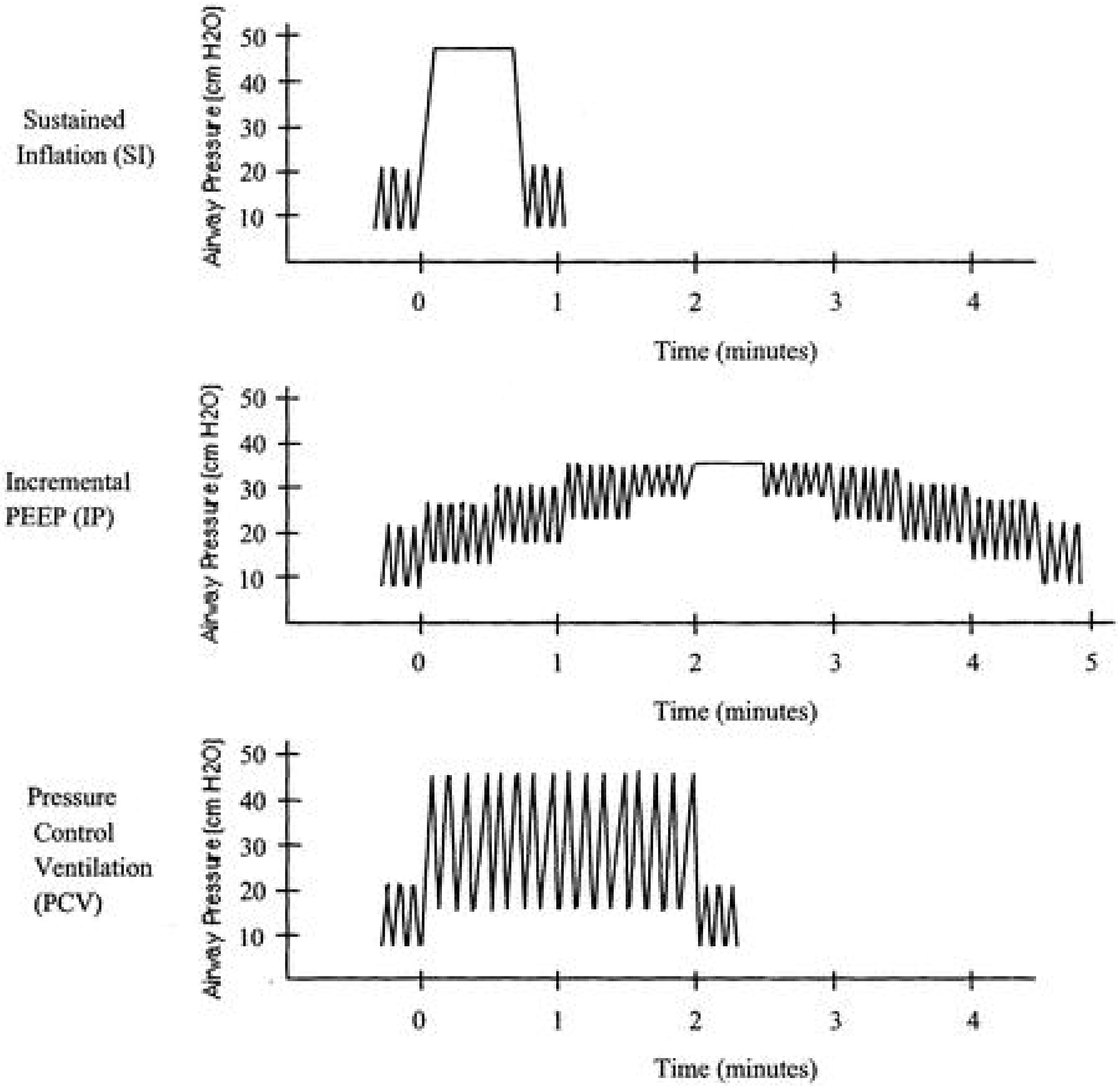
# How to open the lung

- Recruitment
  - Recruitment manuever
  - PEEP
  - Tidal volume
  - Prone positioning
  - Surfactant

# Strategies for recruitment

- Sustained high peak airway pressures
- Periodic increases in peak airway pressure
- Prone positioning
- Prone positio~~ning combined with~~ recruitment maneuvers
- High-frequency ventilation
- Prone positioning combined with high frequency ventilation

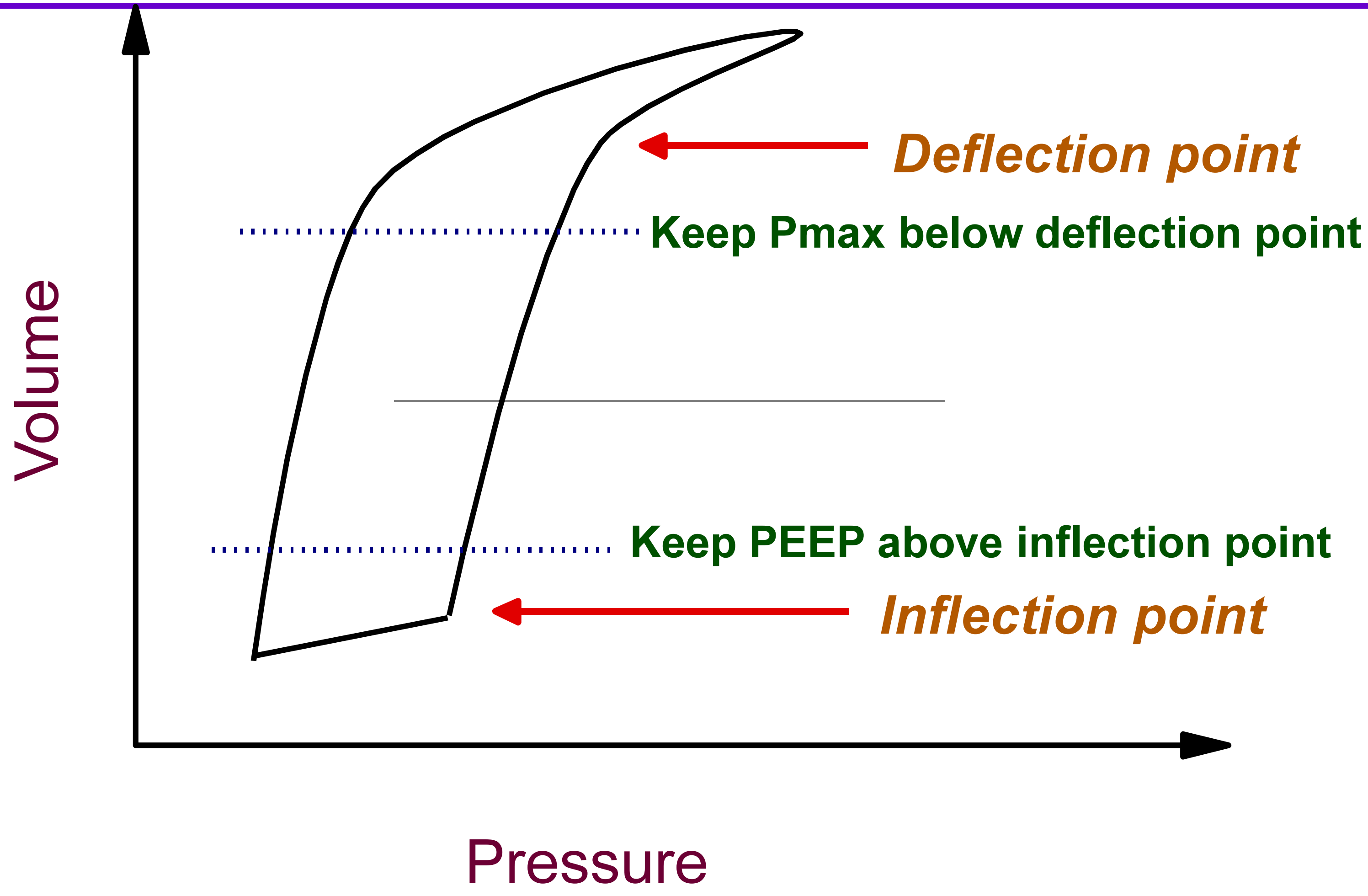
# Recruitment maneuvers



# Recruitment

Recruitment = Increased compliance + Decreased Shunt

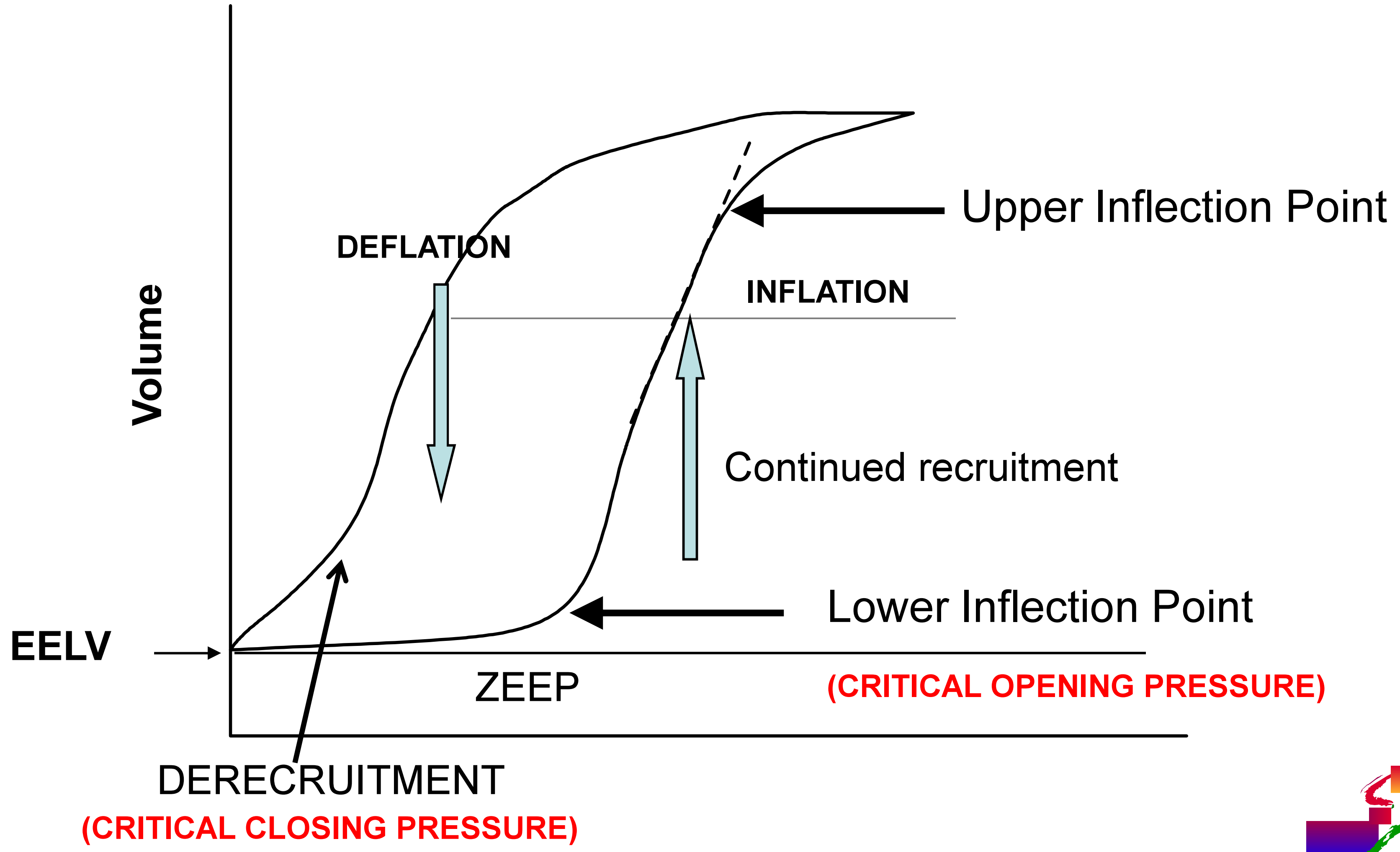
## Recommendations based on pressure-volume loop in acute lung injury



# Interpreting Pressure-Volume Loop

- Inflection point
  - Represents the opening pressure of most of the alveoli
  - PEEP above inflection point = NO DERECRUITMENT
  - No more recruitment during inflation - lung is already open
- Deflection point
  - Represents the point at which the alveoli are overdistended
  - Keeping peak airway pressure below this point prevents ventilator-induced lung injury

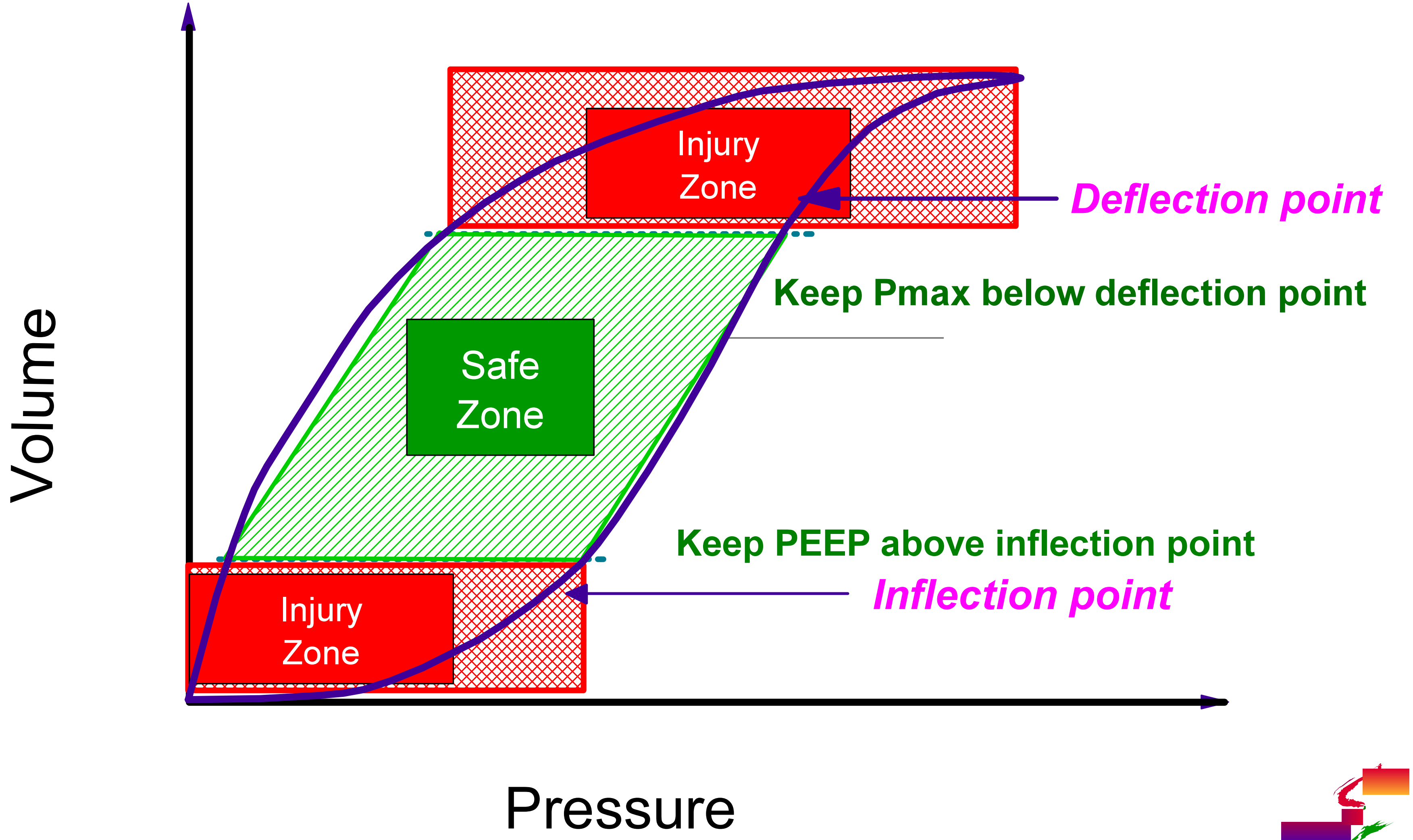
# Static-Pressure Volume Loop



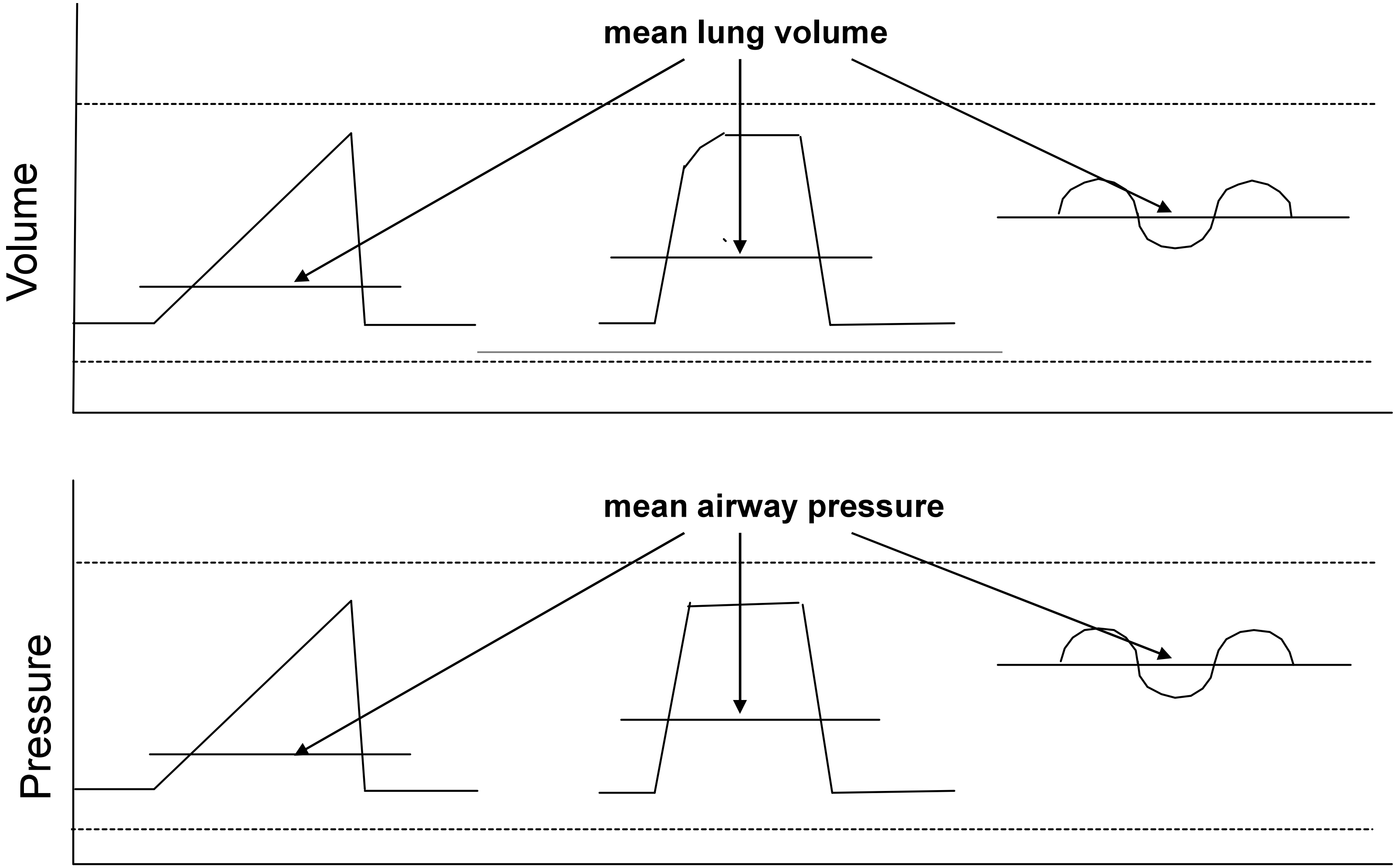
# Important

- Static pressure-volume loops using super syringe or quasi-static pressure-volume loops with low-flow and long-inspiratory time inflation (validated in adults)
- Dynamic pressure-volume loops (Ventilator Graphics) cannot be used to identify inflection point

# Safe zone for ventilation



# Modes of ventilation



# Case 1

- 10 yr old with bilateral pneumonia (35 kg)
- PaO2/FiO2 – 120 (FiO2 1.0)
- Pressure control ventilation
- Effective Vt = 7 mL/kg
- Rate = 20/min
- PIP = 30
- PEEP = 6

# PEEP-Titration

**Recruitable**

| PEEP | Vt-UP | Vt-Down |
|---|---|---|
| **6** | 120 | 135 |
| **8** | 125 | ~~140~~ |
| **10** | 140 | 160 |
| **12** | 160 | 180 |
| **14** | 160 | 170 |
| **16** | 130 | 130 |

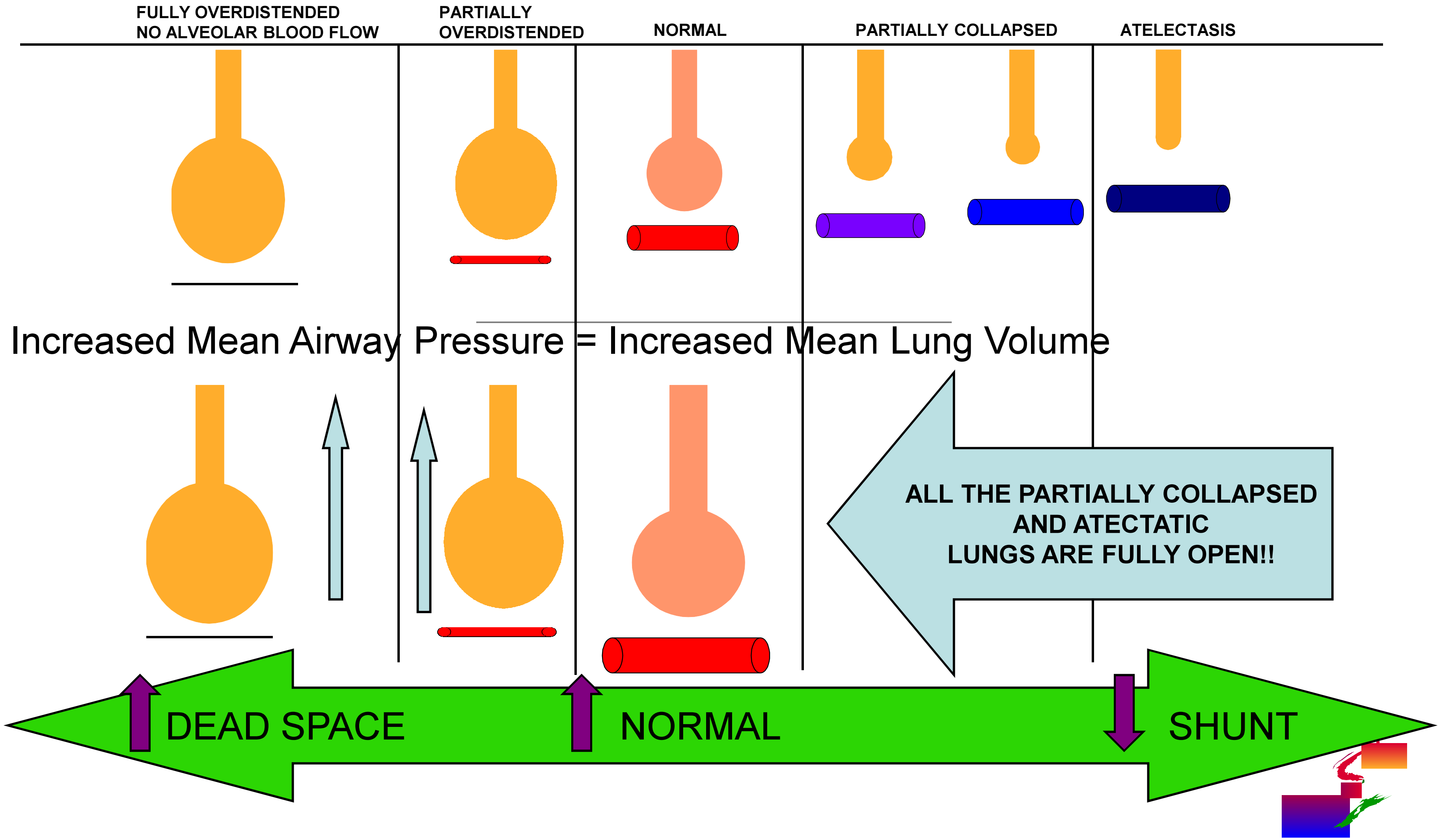
Pressure control

Δ Pressure (PIP – PEEP) was kept constant

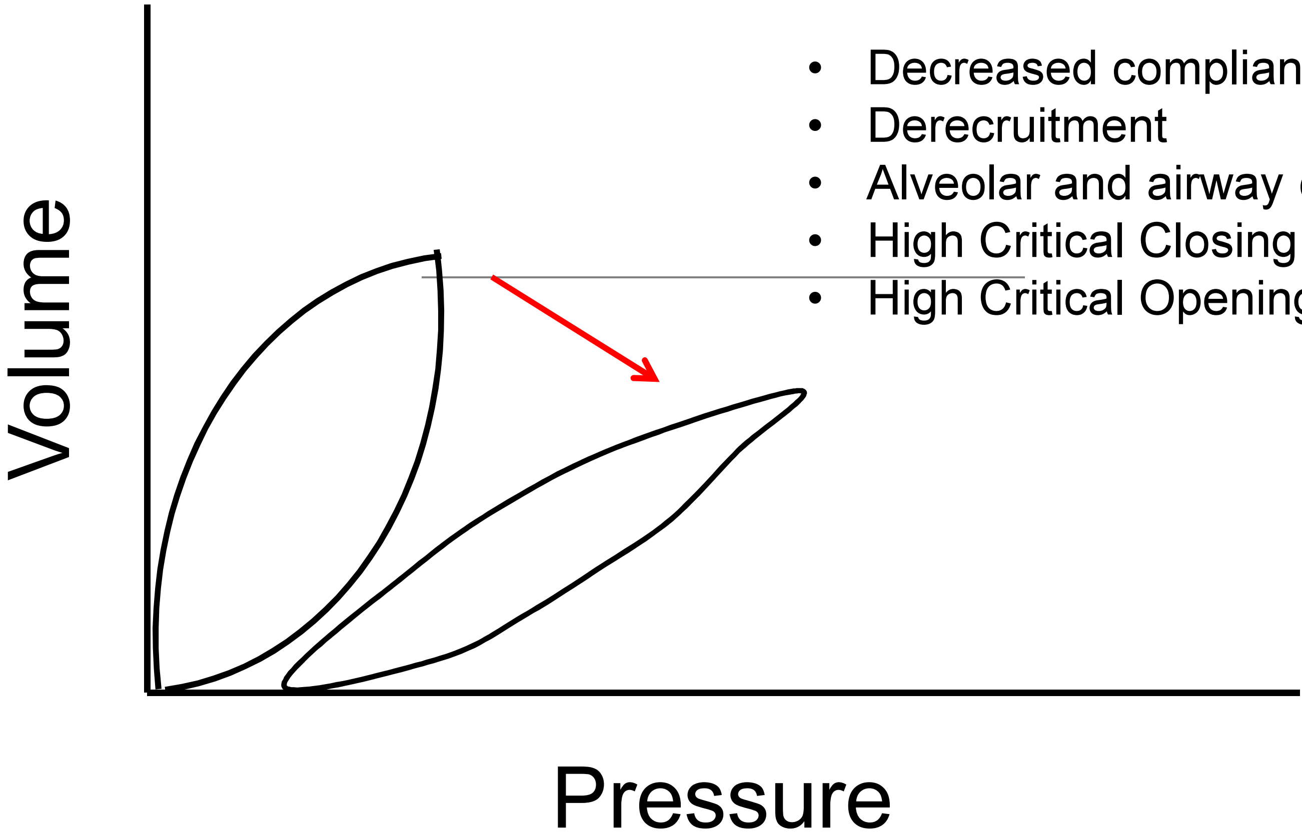
# Case 1

- 10 yr old with bilateral pneumonia (35 kg)
- PaO2/FiO2 – 450 (FiO2 1.0)
- Pressure control ventilation
- Effective Vt = 7 mL/kg
- Rate = 20/min
- PIP = 30
- PEEP = 10

# Model 1 - Completely Recruitable lung

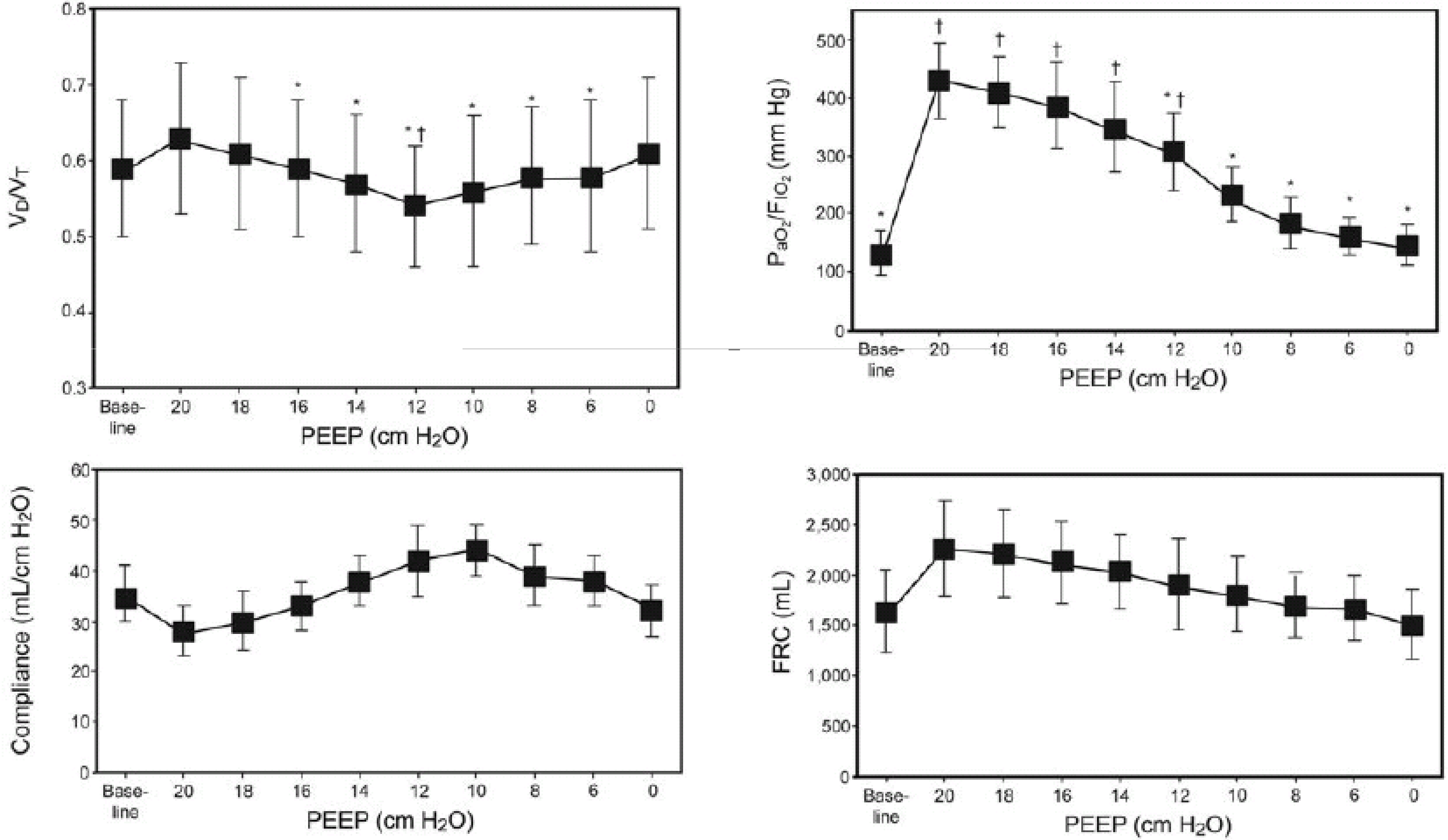


# Changes in lung mechanics




- Decreased compliance
- Derecruitment
- Alveolar and airway collapse
- High Critical Closing Pressure
- High Critical Opening Pressure

# Effect of PEEP on recruitable lung



# Case 2

- 2 yr old with bilateral pneumonia (15 kg)
- PaO2/FiO2 – 150 (FiO2 – 1.0)
- Pressure control ventilation
- Effective Vt = 7 mL/kg
- Rate = 20/min
- PIP = 30
- PEEP = 6

# PEEP-Titration

**Partially Recruitable**

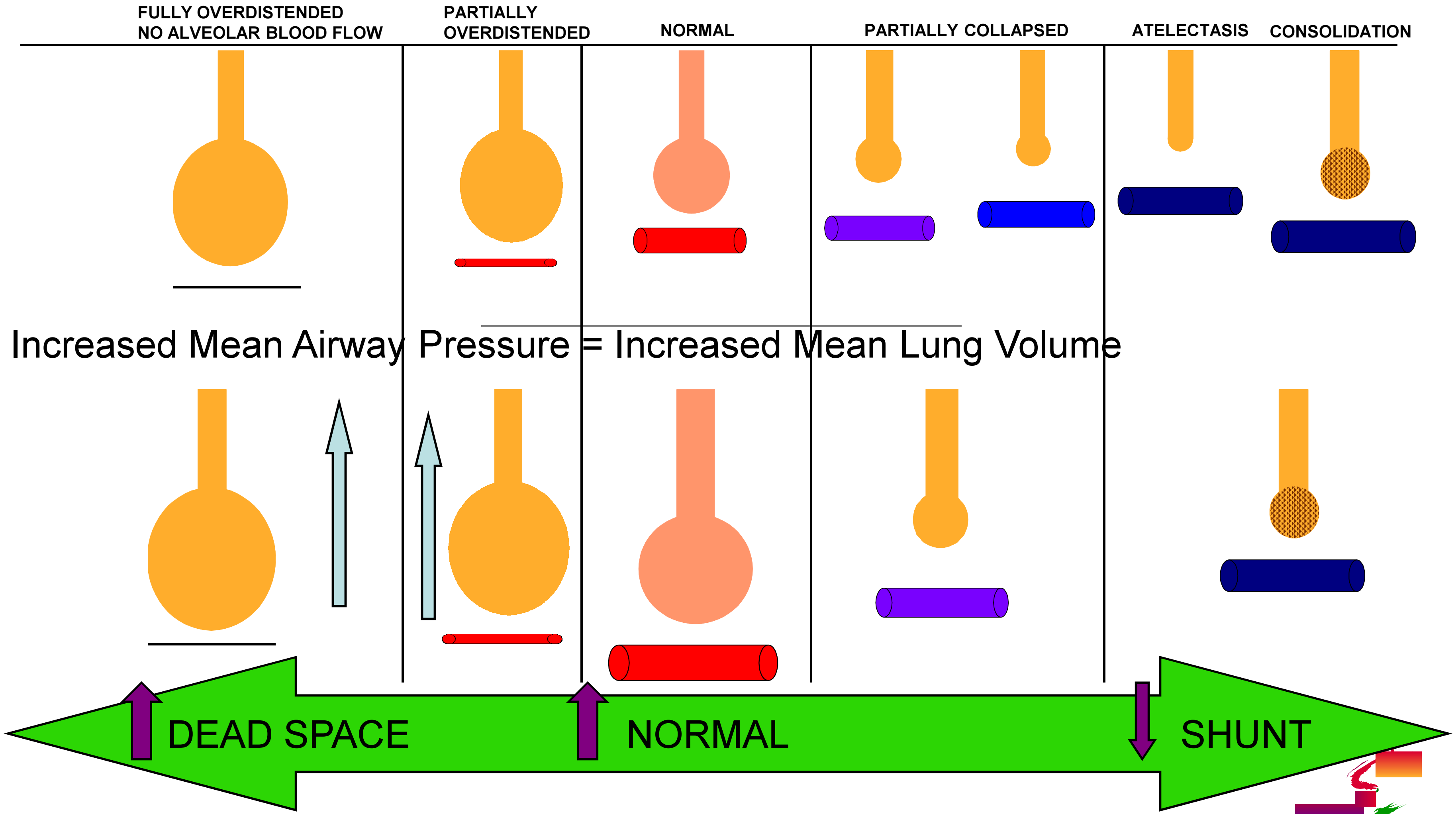
| PEEP | | Vt-UP | Vt-Down | |
|---|---|---|---|---|
| **6** | | 120 | 120 | |
| **8** | | 120 | 130 | |
| **10** | | 120 | 140 | |
| **12** | | 125 | 145 | |
| **14** | | 130 | 140 | |
| **16** | | 110 | 110 | |

Pressure control
Δ Pressure (PIP – PEEP) was kept constant

# Case 2

- 2 yr old with bilateral pneumonia (15 kg)
- PaO2/FiO2 – 225 (FiO2 – 1.0)
- Pressure control ventilation
- Effective Vt = 6 mL/kg
- Rate = 20/min
- PIP = 32
- PEEP = 14
- PaCO2 increased from 42 mmHg to 50 mmHg

# Model 2 – Partially Recruitable lung



# Case 3

- 6-month old with bilateral pneumonia (15 kg)
- PaO2/FiO2 – 100 (FiO2 – 1.0)
- Pressure control ventilation
- Effective Vt = 7 mL/kg
- Rate = 20/min
- PIP = 28
- PEEP = 6

# PEEP-Titration

**Not Recruitable**

| PEEP | | Vt-UP | Vt-Down |
|---|---|---|---|
| **6** | | 120 | 120 |
| **8** | | 120 | 120 |
| **10** | | 120 | 120 |
| **12** | | 110 | 110 |
| **14** | | 100 | 100 |
| **16** | | 90 | 90 |

Pressure control
Δ Pressure (PIP – PEEP) was kept constant

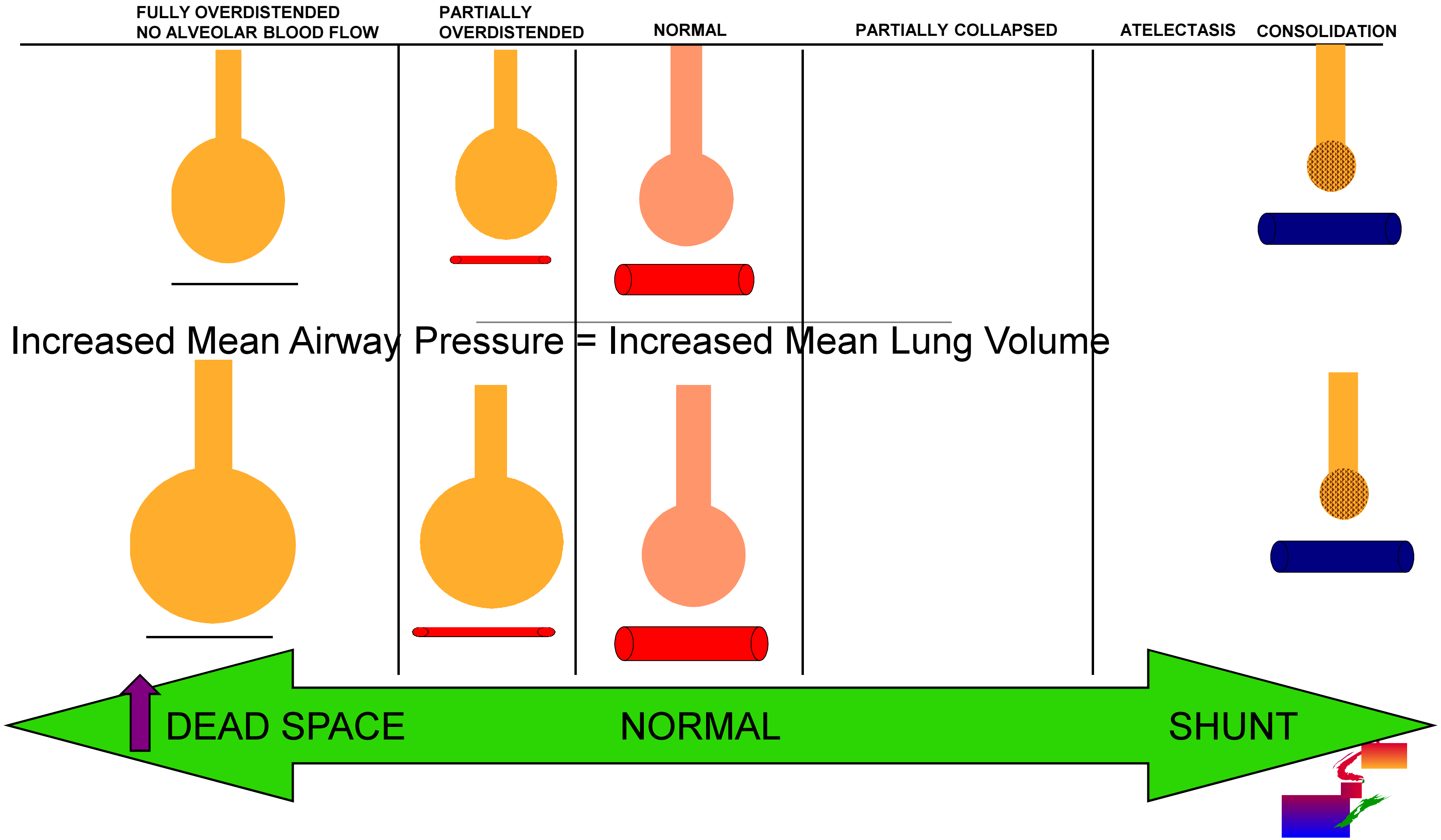
# Case 3 – What was done at night

- 6-month old with bilateral pneumonia (15 kg)
- Pressure control ventilation
- Effective Vt = 6 mL/kg
- Rate = 20/min
- PIP = 34
- PEEP = 12
- PaO2 on 100% oxygen – 50 mmHg
- SpO2 – 85%
- HFOV Machine was brought to the room
- Inhaled NO was ordered
- ECMO team was called

# Case 3 What we did afterwards

- Effective Vt = 7 mL/kg
- Rate = 20/min
- PIP = Decreased from 34 to 28
- PEEP = Decreased from 12 to 6
- PaO2 on 100% oxygen increased from 50 to 100 mmHg
- Prone positioning – PaO2 increased from 100 to 150 mmHg
- We did try inhaled NO
- No response to NO after 2 hours of NO. So taken off NO
- I would recommend leaving this child alone. Keep checking whether the lung can be recruited twice or three times a day and if so, select an appropriate PEEP
- No role for HIGHER AIRWAY PRESSURES UNLESS THE LUNG IS SHOWN TO BE RECRUITABLE!!!!

# Non-Recruitable lung



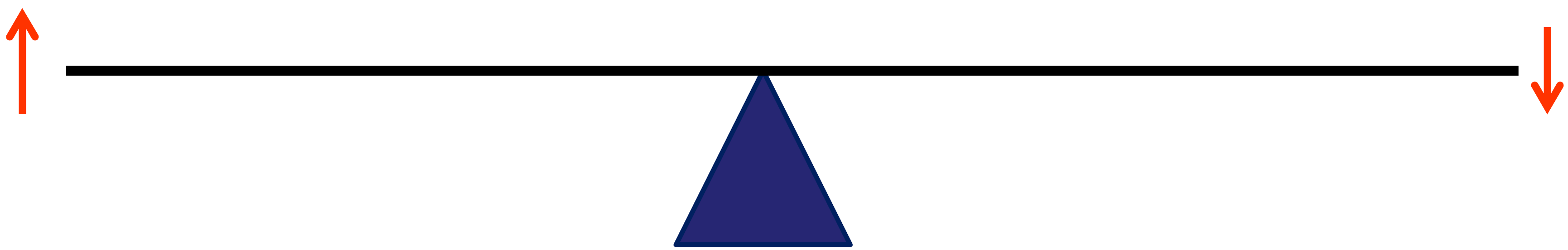
# Summary of variables for recruitment with PEEP

- Improved compliance
- Improved oxygenation
- Improved ventilation or no change in ventilation
- No change in ~~hemodynamics or~~ improved hemodynamics

# Yin-Yang of PEEP

Positive effects
- Recruitment
- Decreased shunt
- Decreased PVR
- Decreased LV Afterload
- Improved lung compliance
- Decreased VILI

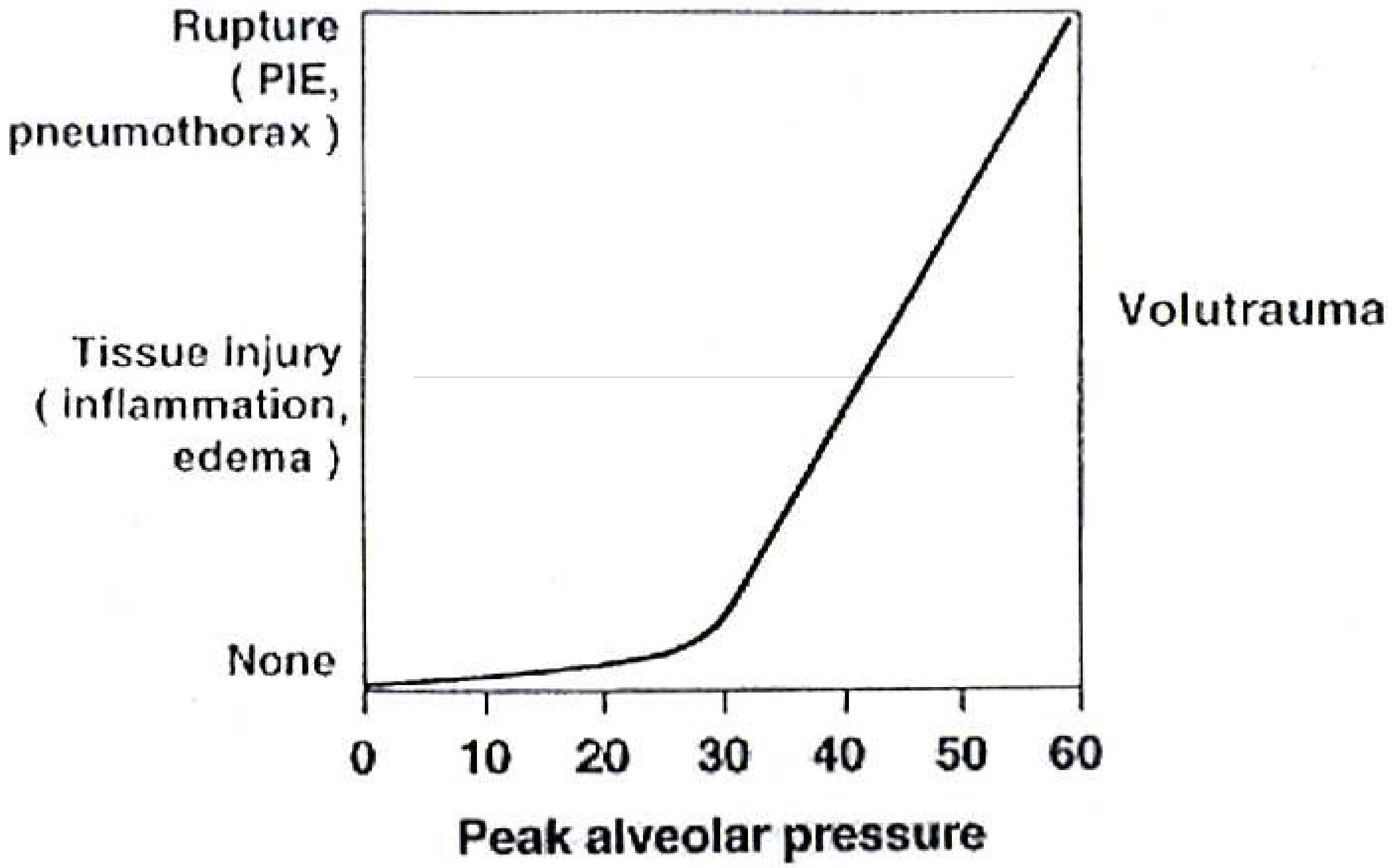
Negative effects
- Overdistension
- Increased VILI
- Increased shunt
- Increased PVR
- Decreased venous return
- Decreased cardiac output



# Lung Protective Strategies

- Recruit the lung
  - Minimizes Atelectotrauma
- Keep Alveolar Pressures below 35 cms $H_2O$
  - Small tidal volumes
  - HFOV
- Avoid high $FiO_2$
  - Wean $FiO_2$ as quickly as possible to <0.6
- Prone positioning (?)

# Ventilator-Induced Lung Injury



# Goals for oxygenation

- Maintain PaO2 of 50-60 mmHg or SpO2 of 90-95%
- Mean lung volume is the primary determinant of oxygenation
- Optimal PEEP
- Mean airway pressure ~ mean lung volume
- Avoid "toxic" inspired oxygen concentration

# Goals for ventilation

- Small tidal volumes (6-8 mL/kg)
- Keep alveolar pressure less than 35 cms H2O (preferably less than 30 cms H2O)
- Permissive hypercapnia

# Management – Change in practice over time

# Have changes in ventilation practice improved outcome in children with acute lung injury?*

Waleed H. Albuali, MD; Ram N. Singh, MD, FRCPC; Douglas D. Fraser, MD, PhD, FRCPC; Jamie A. Seabrook, MA; Brian P. Kavanagh, MD, FRCPC; Christopher S. Parshuram, MD, FRACP; Alik Kornecki, MD

(Pediatr Crit Care Med 2007; 8:324–330)

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Table 2. Mortality between study groups and according to underlying conditions[a]

| | Past (1988–1992) (%) | Recent (2000–2004) (%) | $p$ Value |
|---|---|---|---|
| Total | 79 | 85 | |
| Survivors | 51 (65) | 67 (79) | .04 |
| Nonsurvivors | 28 (35) | 18 (21) | |
| Immunodeficiency | | | |
| Total | 13 (16) | 13 (15) | .84 |
| Survivors | 5 (38) | 5 (38) | .99 |
| ARDS[b] | | | |
| Total | 58 (73) | 72 (85) | .08 |
| Survivors | 33 (57) | 54 (75) | .03 |
| Sepsis | | | |
| Total | 26 (33) | 29 (34) | .87 |
| Survivors | 9 (35) | 19 (66) | .02 |

(Pediatr Crit Care Med 2007; 8:324–330)

Table 3. Modality of ventilation and mean respiratory and ventilatory values during the first 3 days of ventilation

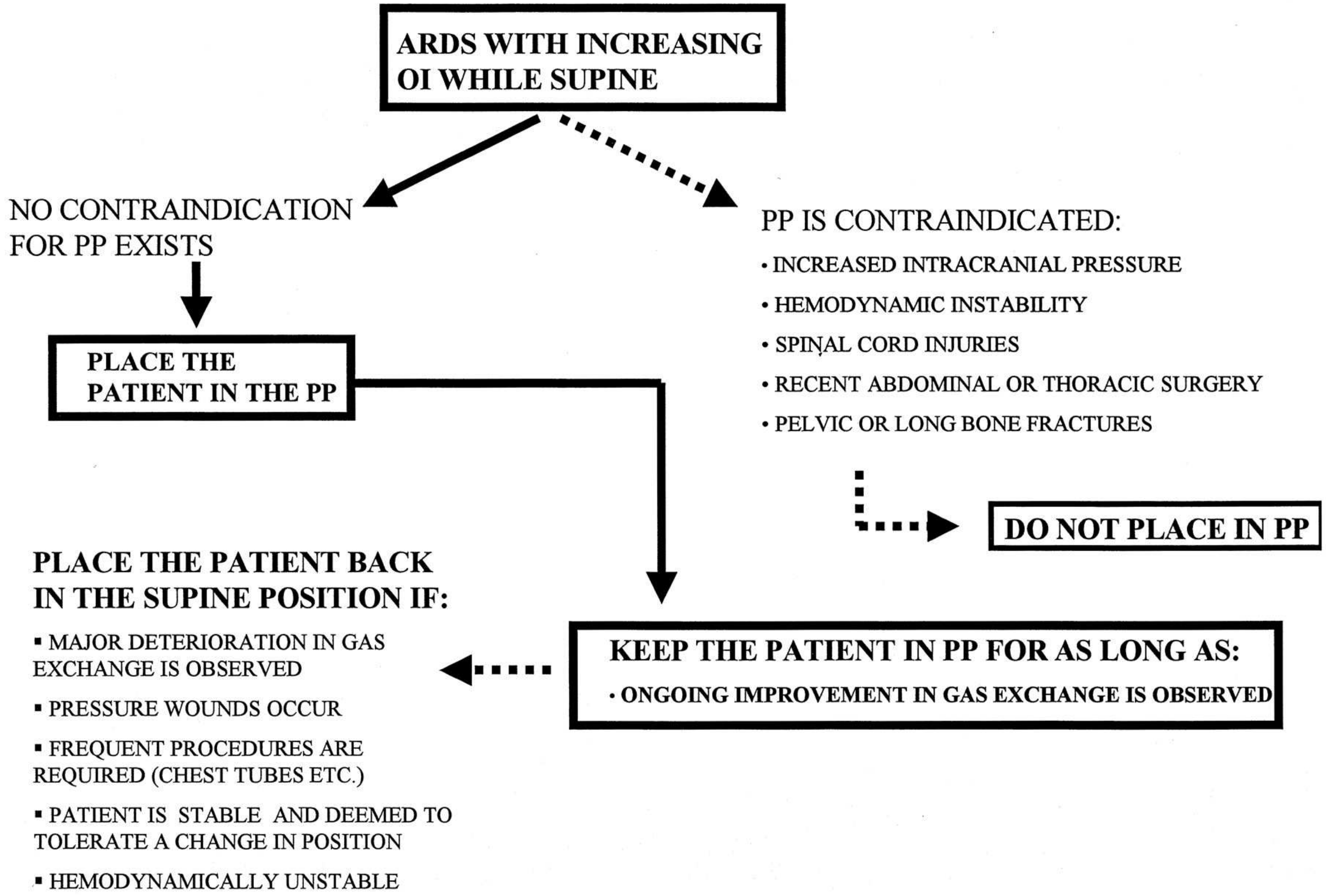
| | Past (1988–1992) (n = 79) | Recent (2000–2004) (n = 85) | $p^a$ Value |
|---|---|---|---|
| VT, mL·kg$^{-1}$ | 10.2 ± 1.7 (211) | 8.1 ± 1.4 (233) | <.001 |
| PIP, cm $H_2O$ | 31.5 ± 7.3 (223) | 27.8 ± 4.2 (233) | <.001 |
| PEEP, cm $H_2O$ | 6.1 ± 2.7 (223) | 7.1 ± 2.4 (232) | .007 |
| $Paco_2$, mm Hg | 37.0 ± 5.0 (225) | 47.2 ± 11.8 (231) | <.001 |
| $Pao_2$, mm Hg | 84.4 ± 14.4 (225) | 78.9 ± 14.9 (245) | .017 |
| OI | 14.7 ± 5.0 (223) | 17.7 ± 5.3 (232) | <.001 |
| $Pao_2/Fio_2$ | 153.0 ± 59.9 (225) | 139.2 ± 53.1 (239) | .12 |
| VI | 28.4 ± 13.6 (225) | 28.6 ± 15.6 (235) | .94 |
| PC, % | 52 (225) | 55 (245) | .99 |
| VC, % | 47 (225) | 37 (245) | .02 |
| HFOV, % | 1 (225) | 8 (245) | <.001 |

VT, tidal volume; PIP, peak inspiratory pressure; PEEP, positive end-expiratory pressure; OI, oxygenation index; VI, ventilation index; PC, pressure control; VC, volume control; HFOV, high-frequency oscillatory ventilation.

[a]Independent samples *t*-tests with the Bonferroni correction ($p = .05/3 = .017$) were used to test for significant differences between the groups. In parentheses, the number of ventilation days.

# Management – Prone positioning

# A practice algorithm for prone positioning




Relvas M S et al. Chest 2003;124:269-274

# Noninvasive ventilation

# A prospective, randomized, controlled trial of noninvasive ventilation in pediatric acute respiratory failure*

Leticia J. Yañez, MD; Mauricio Yunge, MD; Marcos Emilfork, MD; Michelangelo Lapadula, MD; Alex Alcántara, MD; Carlos Fernández, MD; Jaime Lozano, MD; Mariana Contreras, MD; Luis Conto, MD; Carlos Arevalo, MD; Alejandro Gayan, MD; Flora Hernández, RN; Mariela Pedraza, MD; Marion Feddersen, MD; Marcela Bejares, MD; Marta Morales, MD; Fernando Mallea, MD; Maritza Glasinovic, MD; Gabriel Cavada, PhD

(Pediatr Crit Care Med 2008; 9:484–489)

# NIV vs Control patients

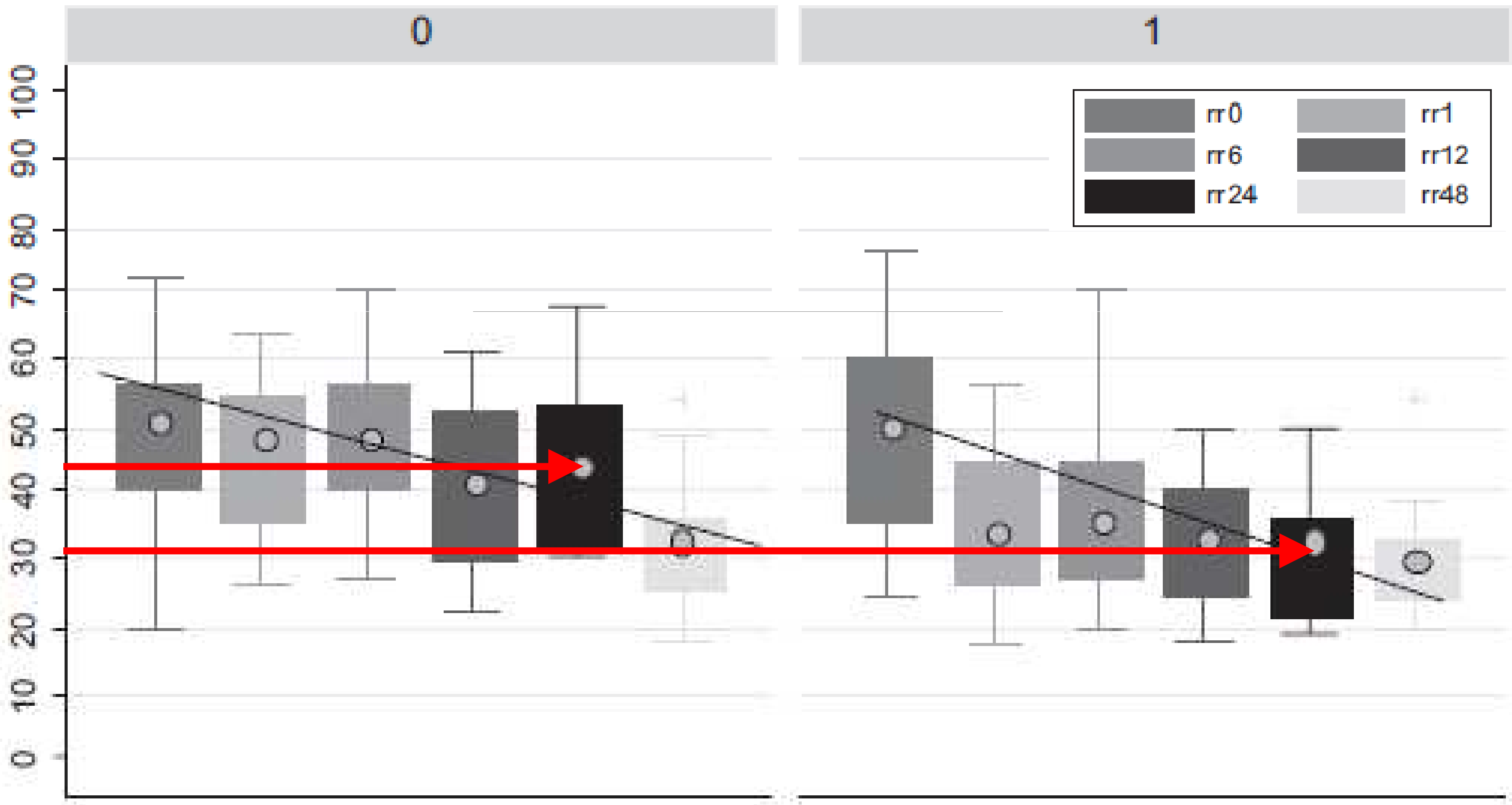
Table 1. Baseline demographic and physiological parameters (median)

| | Control Group (n = 25) | NIV Group (n = 25) | *p* |
|---|---|---|---|
| Male:female | 13:12 | 17:8 | 0.368 |
| Age (months) | 18 (1–144) | 16 (2–156) | 0.58 |
| Downes score | 7 (6–8) | 7 (5–8) | 0.811 |
| Tal score | 7 (4–9) | 7 (4–8) | 0.531 |
| Heart rate (beats/min) | 152 (125–177) | 154 (99–200) | 0.637 |
| Respiratory rate (breaths/min) | 51 (28–72) | 50 (36–76) | 0.980 |
| pH | 7.36 (7.22–7.45) | 7.39 (7.1–7.49) | 0.672 |
| $Po_2$ (mm Hg) | 109 (53–248) | 89 (34–345) | 0.06 |
| $Pco_2$ (mm Hg) | 37.4 (25–64) | 39.1 (27–81) | 0.329 |
| $Fio_2$ | 0.5 (0.21–1) | 0.5 (0.3–1) | — |
| $Pao_2/Fio_2$ | 190 (101–400) | 150 (100–383) | 0.115 |

—, *p* value was not calculated; NIV, noninvasive ventilation.

**(Pediatr Crit Care Med 2008; 9:484–489)**

# RR over time




(Pediatr Crit Care Med 2008; 9:484–489)

# Outcomes

Table 3. Complications, patient outcome, and ICU stay

| | Control Group (n = 25) | NIV Group (n = 25) | *p* |
|---|---|---|---|
| Intubation, n (%) | 15 (60%) | 7 (28%) | 0.045 |
| Days of invasive ventilation (mean days) | 3.1 | 2.6 | — |
| ICU length of stay (mean days) | 5.5 ± 2.7 | 6.7 ± 5.9 | 0.19 |
| Hospital length of stay (mean days) | 10.6 ± 4.8 | 10.4 ± 7.9 | 0.51 |

ICU, intensive care unit; NIV, noninvasive ventilation; —, *p* value was not calculated.

(Pediatr Crit Care Med 2008; 9:484–489)

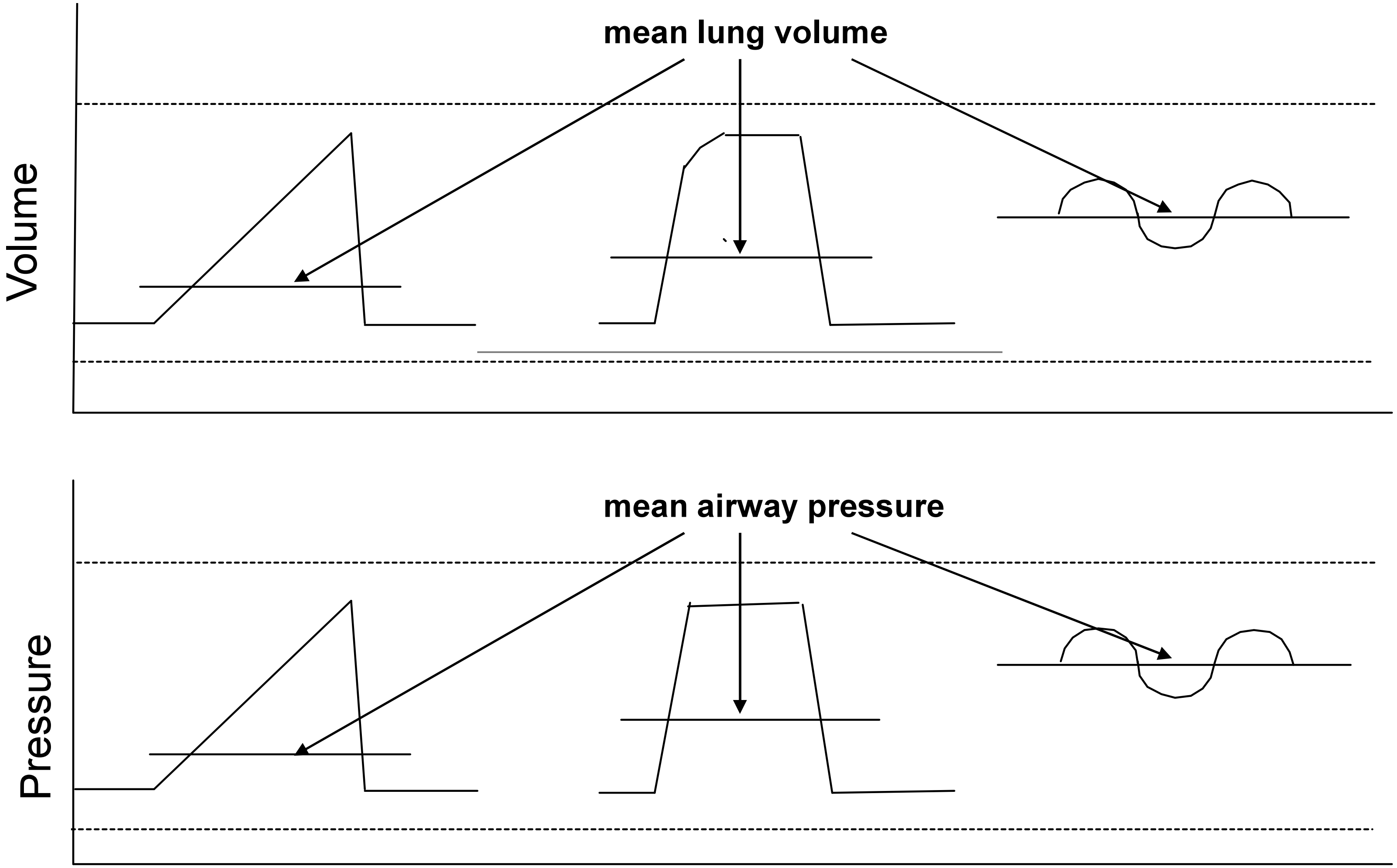
# Other Strategies

- Inverse-ratio ventilation
  - Increases mean airway pressure without increasing peak inspiratory pressure
- Airway-pressure release ventilation
  - Limits peak airway pressure
  - Allows spontaneous breathing
  - Useful in milder lung injury
- Permissive hypercapnia
  - Allows limitation of peak airway pressure
  - Allows PaCO2 to rise with compensation of pH

# Management - HFOV

- Is useful only when the lung is recruitable
- Start with a Mean Airway Pressure 3-6 cms $H_2O$ higher than the Conventional Mechanical Ventilation
- Determinants of oxygenation
  - Mean airway pressure and $FiO_2$
- Determinants of ventilation
  - Amplitude – "Adequate Chest Wiggle"
  - Frequency – 6-10 Hz
  - Bias flow – 20-40 L/min

# Modes of ventilation



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  - Allows $PaCO_2$ to rise with compensation of pH

# Other Strategies

- Fluid management
  - Fluid restriction with early diuresis does improve pulmonary function and outcome (Chest 1990;97:1176, Chest 1991;100:1068)
- Optimizing oxygen transport
  - Optimize oxygen delivery
  - Delivery-dependent consumption in some pts

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