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MECHANICAL VENTILATION

Advanced Care Paramedicine

Module: 12
Section: 01b

Objectives

- Describe pressure gradients during ventilation.
- Describe clinical methods of differentiating the frictional and elastic work of breathing.
- Describe essential physiological concerns related to ventilation.
- Describe essential physiological concerns related to oxygenation.
- Describe approach to Mechanical Ventilation within the scope of Practice.

Mechanical Ventilation

- As a result of trauma, illness and surgical conditions some patients may need mechanical ventilatory support
- Clinical Indications
  - Apnea
  - Acute Respiratory Failure
  - Respiratory Insufficiency

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Goals

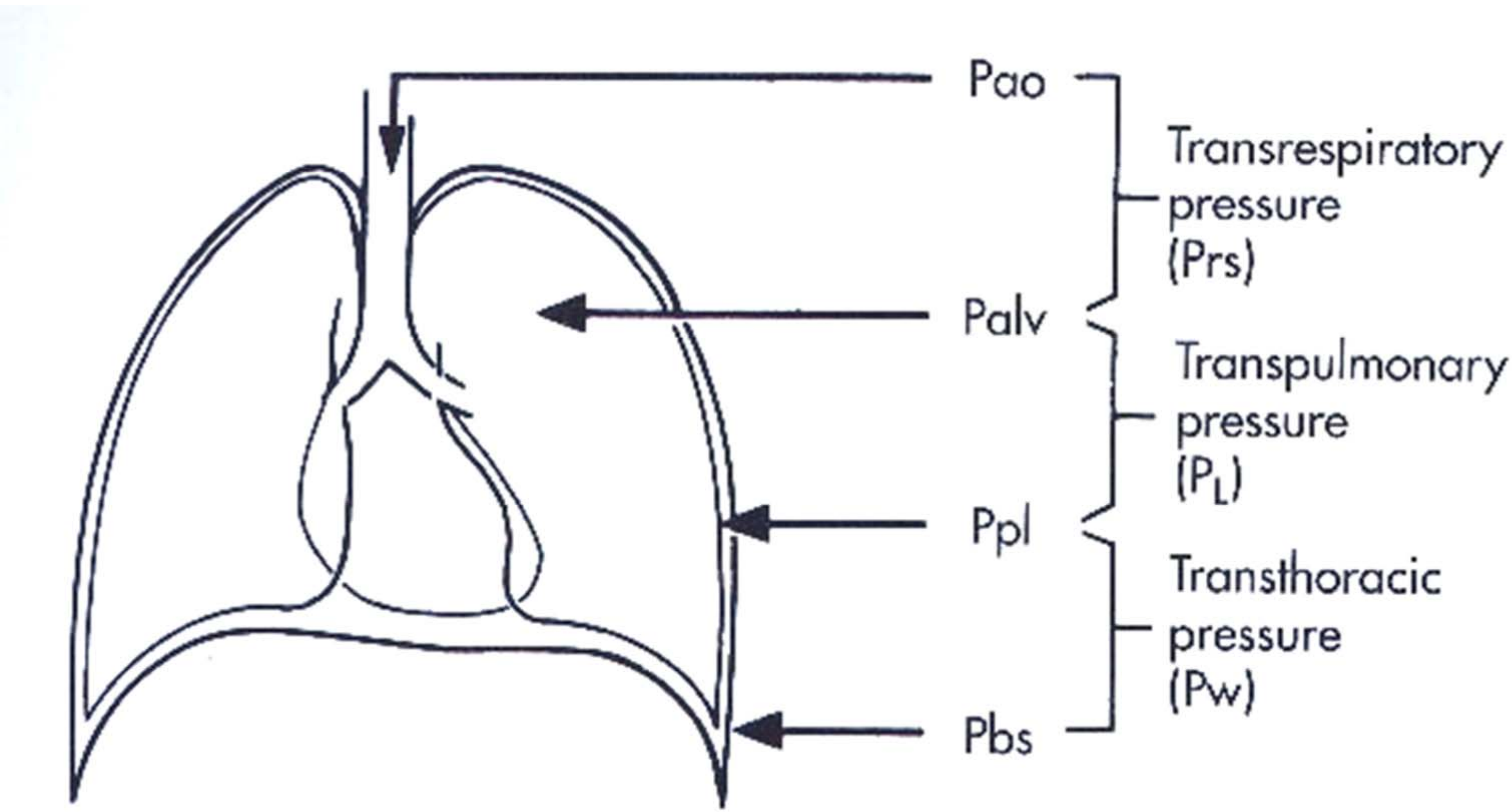
- Improve work of breathing
- Improve ventilation
- Improve oxygenation

Pulmonary Mechanics

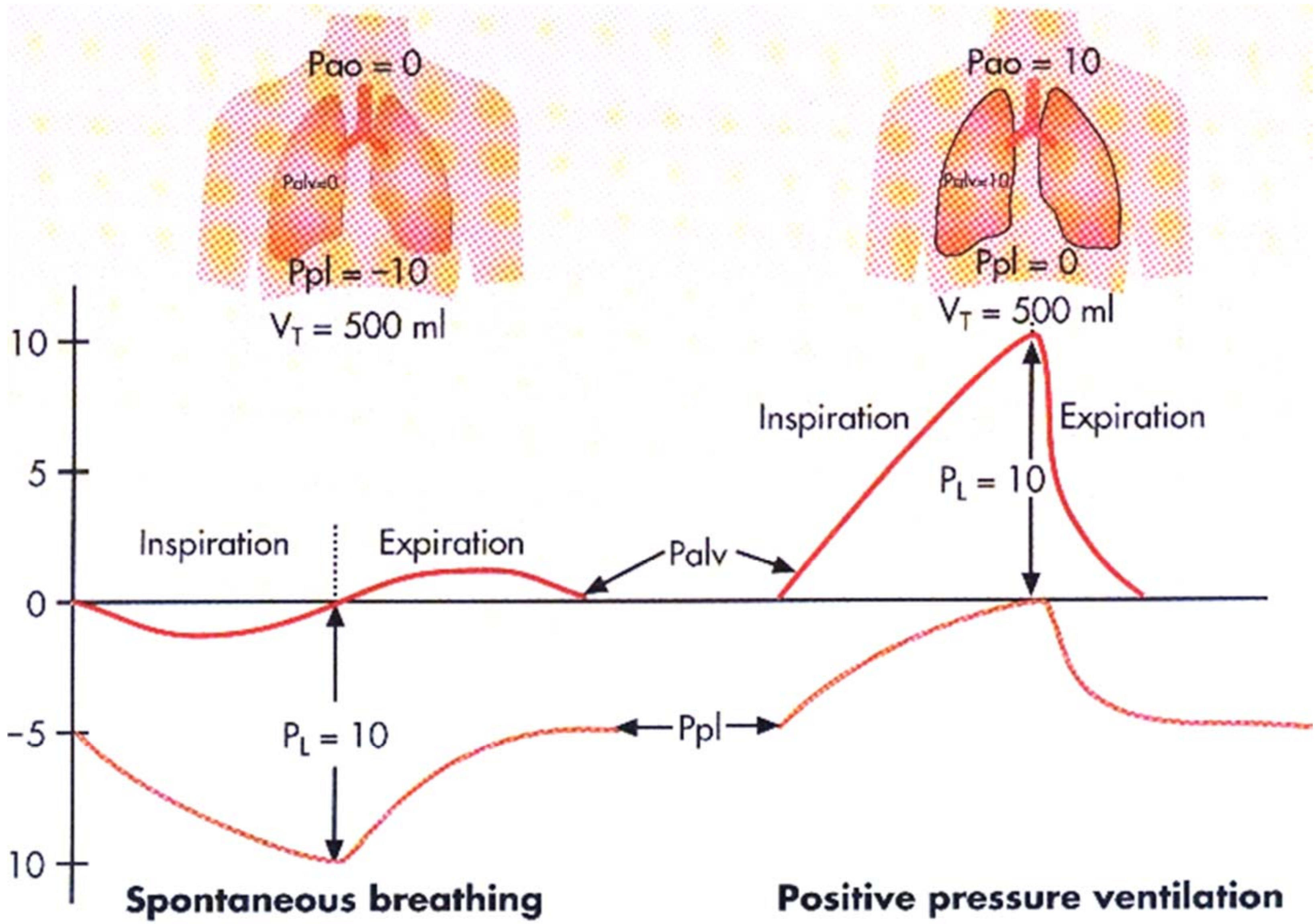
Terminology

- Peak Inspiratory Pressure (PIP)
  - The highest proximal airway pressure during inspiratory phase
  - The less compliance the greater PIP
- Positive End Expiratory Pressure (PEEP)
  - Positive pressure applied during the expiratory phase
- Pressure Manometer (cmH_20)
  - A diagnostic tool to note changes in compliance
    - Pneumo, bronchospasm, kinks in tubing will ↑ pressures
    - Leaks, needle thorocostomy will ↓ pressure

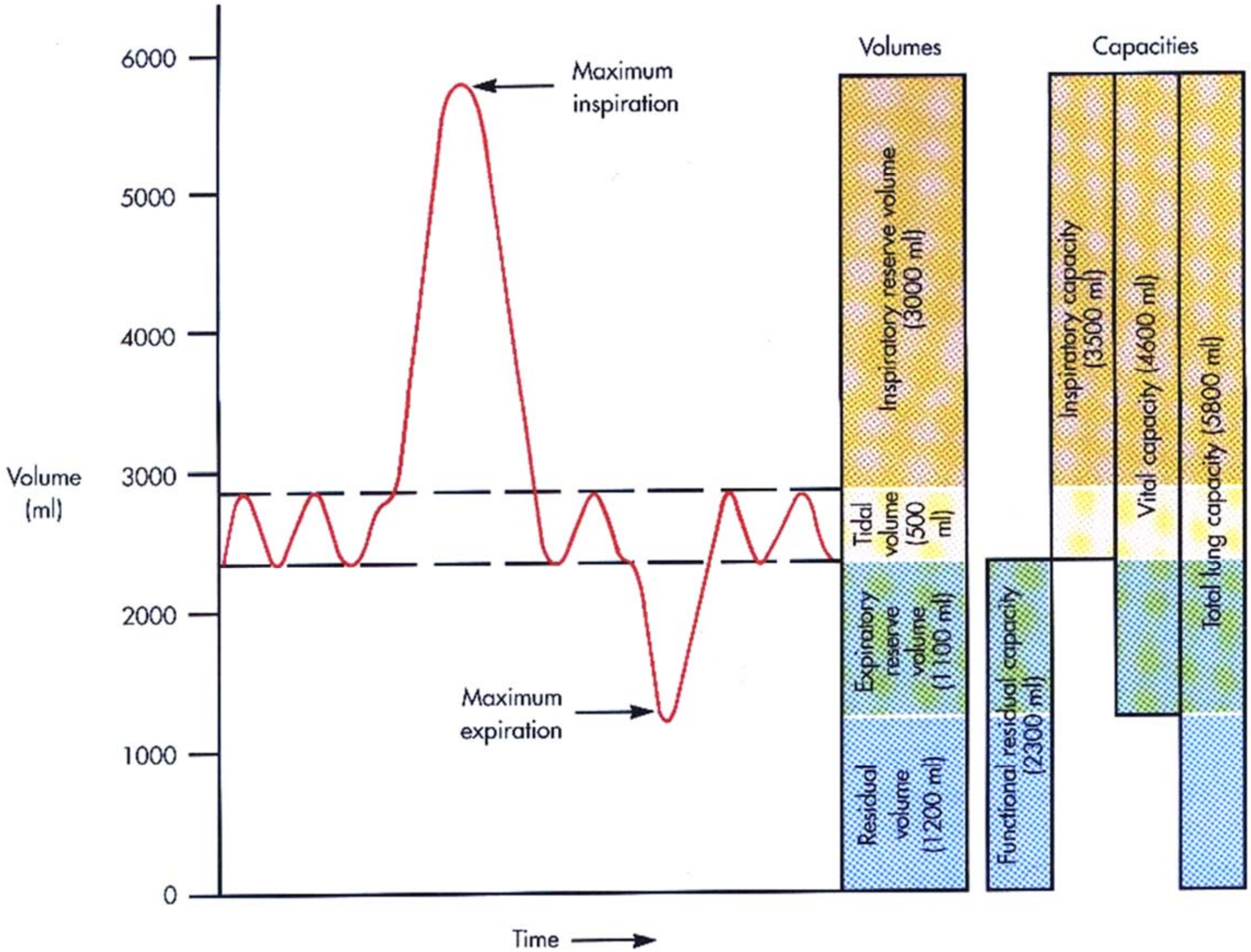
Pressure Gradients



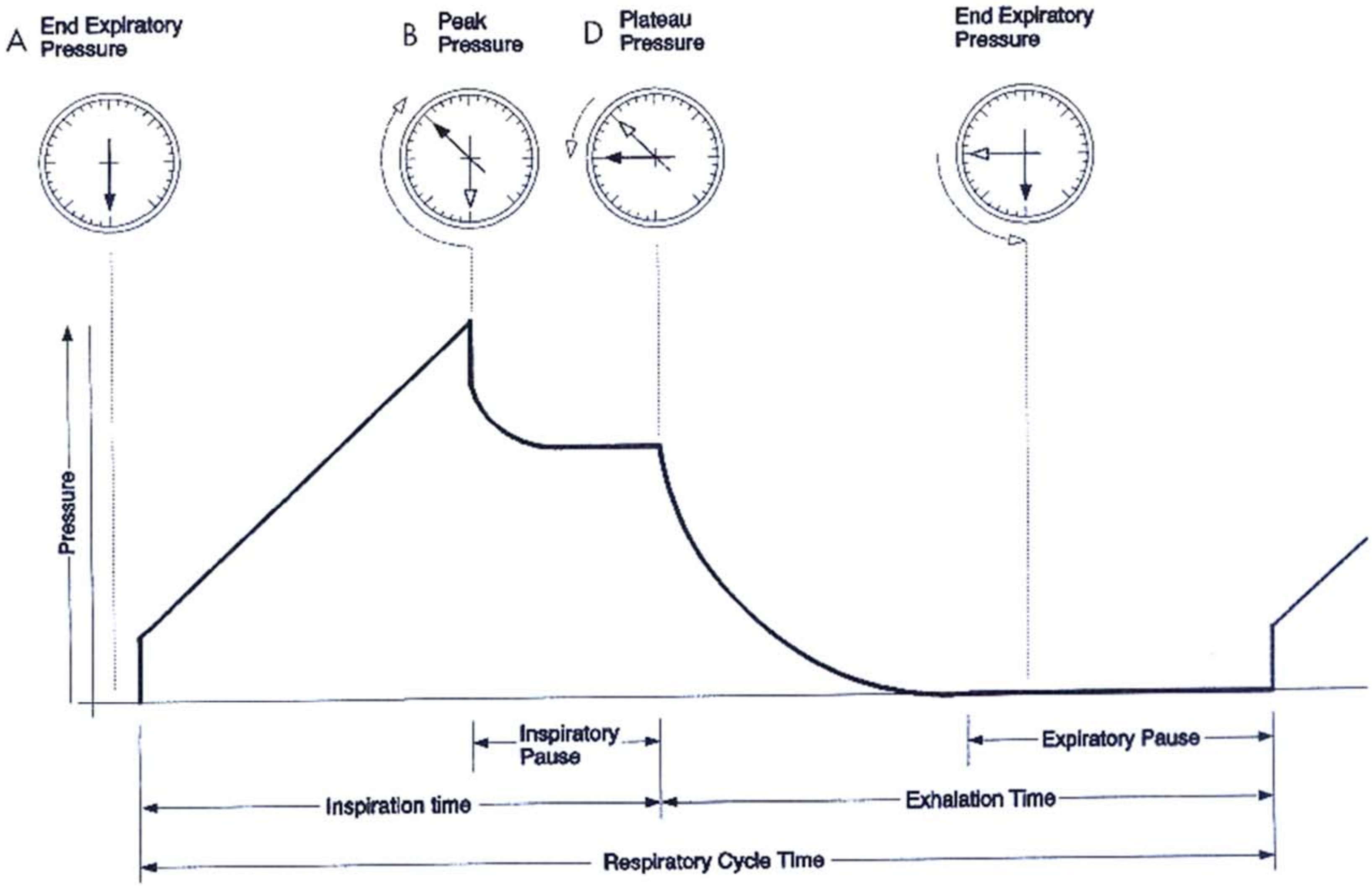
Airway and Intrapleural Pressure



Lung Volumes & Capacities



Ventilatory Pressures



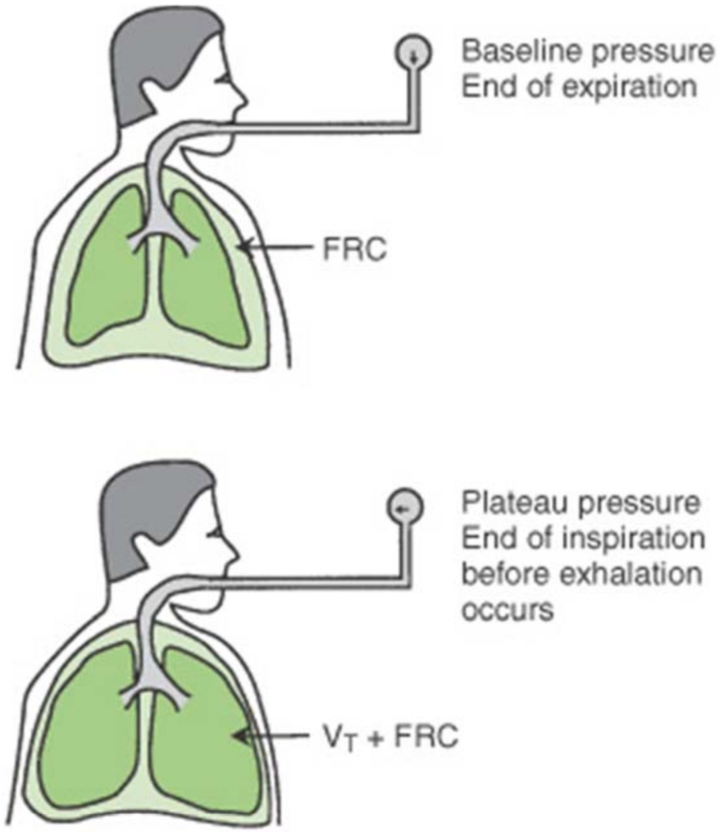


Fig. 2-11 At baseline pressure (end of exhalation), the volume of air remaining in the lungs is the functional residual capacity (FRC). At the end of inspiration, before exhalation starts, the volume of air in the lungs is the tidal volume (V_T) plus the FRC. The pressure measured at this point, with no flow of air, is the *plateau pressure*.

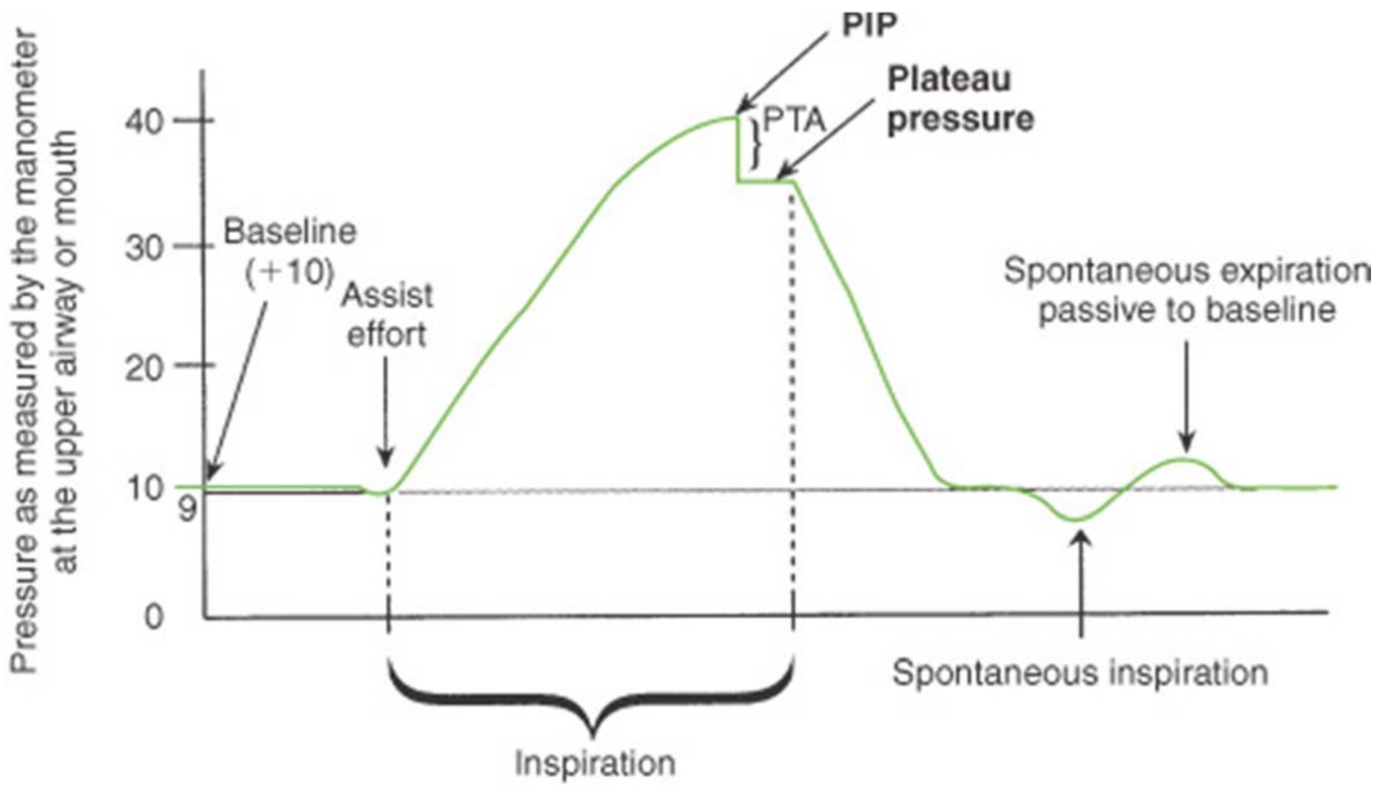


Fig. 2-10 Graph of airway pressures that occur during a mechanical positive pressure breath and a spontaneous breath. Both show an elevated baseline (PEEP is +10 cm H_2O). To assist a breath, the ventilator drops the pressure below baseline by 1 cm H_2O. The assist effort is set at +9 cm H_2O. *PIP*, Peak inspiratory pressure; P_{TA} , transairway pressure. (See text for further explanation.)

PIP

- Is the Peak Inspiratory Pressure increasing?
  - Shoot a plateau pressure (applying an inspiratory hold to measure the AWP in the alveoli)
- Plateau pressure follows nicely under PIP (normal is 30 - 35):
  - No change
    - aspiration, bronchospasm, secretions, tracheal tube, obstruction
  - Increased PP
    - abdominal distension, asynchronous breathing, atelectasis, auto – PEEP, pneumothorax, pulmonary edema

Airway Resistance

- The pressure generated By flow passing through the airways.
- Measured in cmH2O/L/sec
- Raw = Ppk - Ppl /Flow

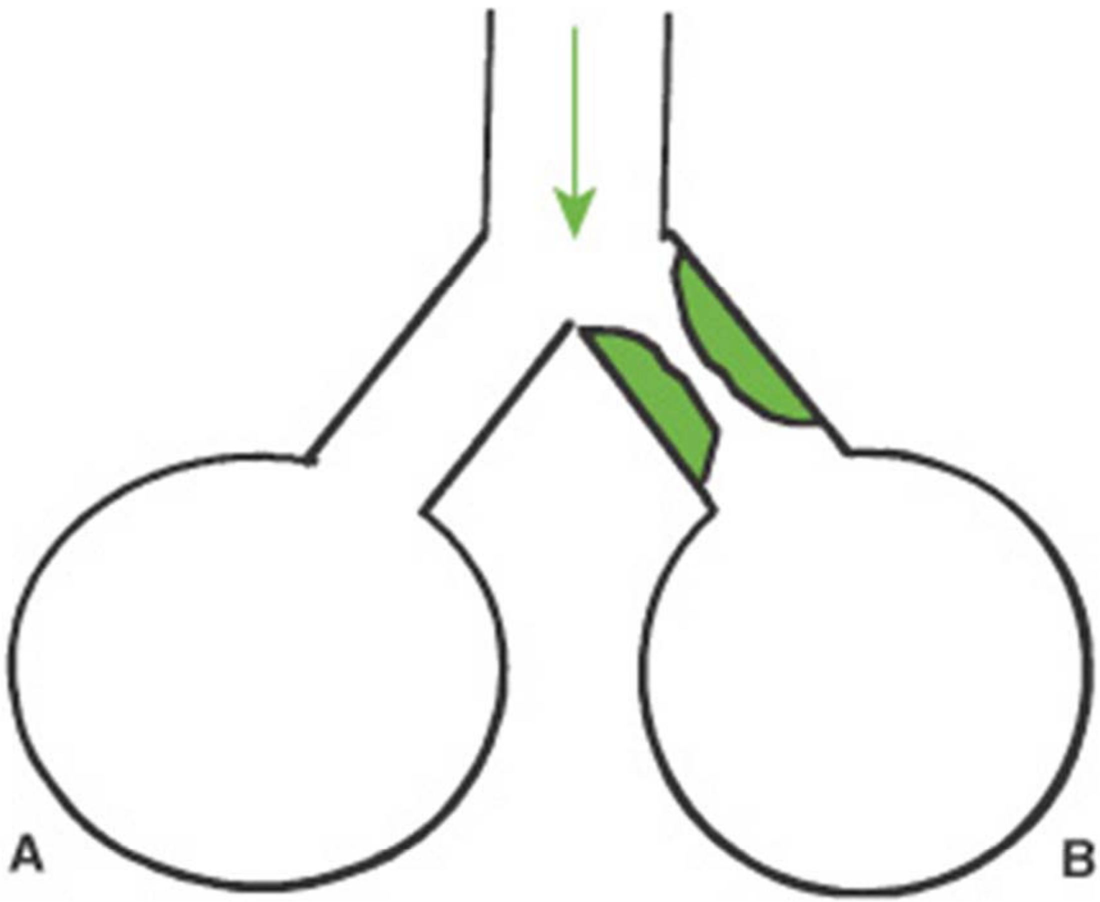


Fig. 2-13 Lung unit *A* is normal. Lung unit *B* shows an obstruction in the airway.

Compliance

- The pressure per unit of inflation volume required to keep the lung expanded under no flow (static) conditions.
- Units are usually ml/cmH_2O

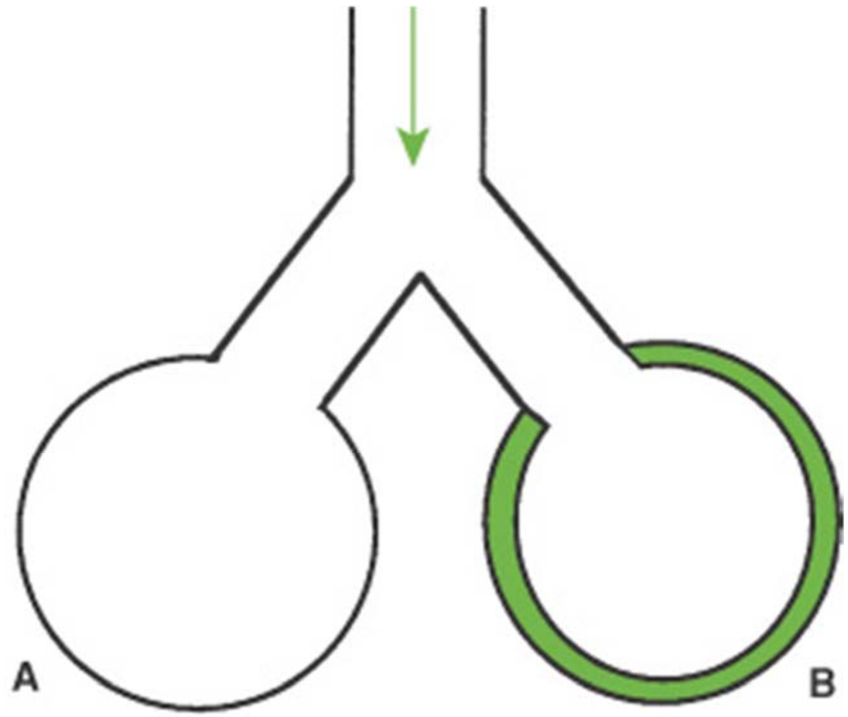
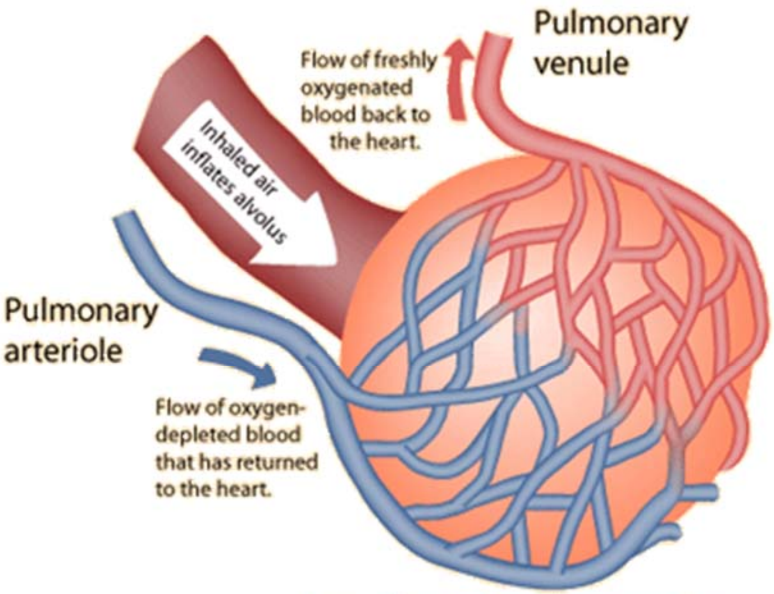
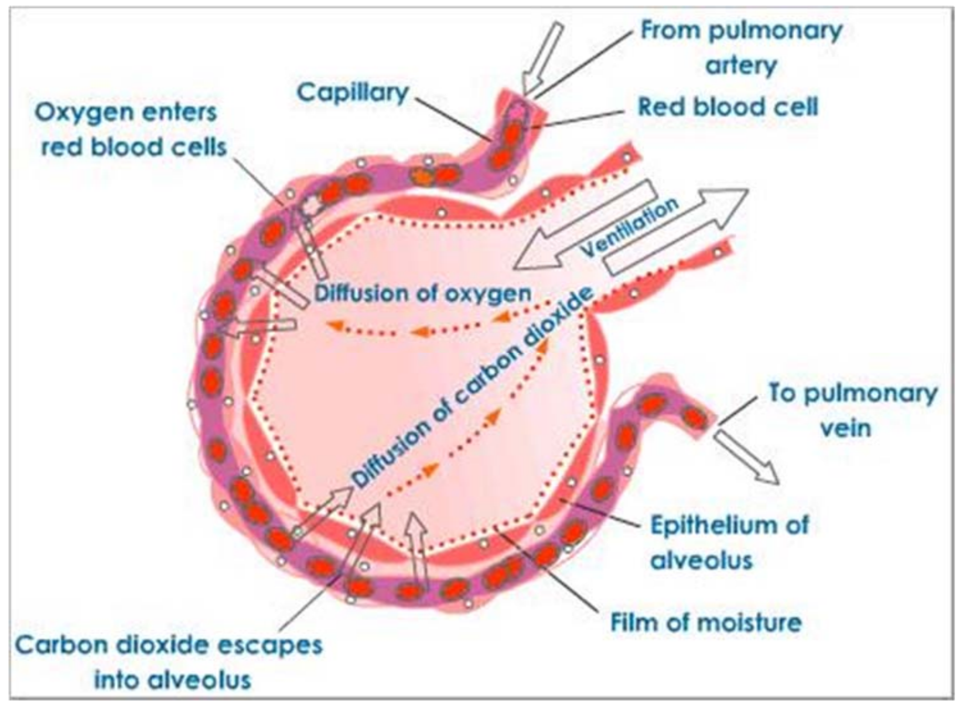


Fig. 2-14 Lung unit *A* is normal. Lung unit *B* shows decreased compliance (see text).

Gas Exchange

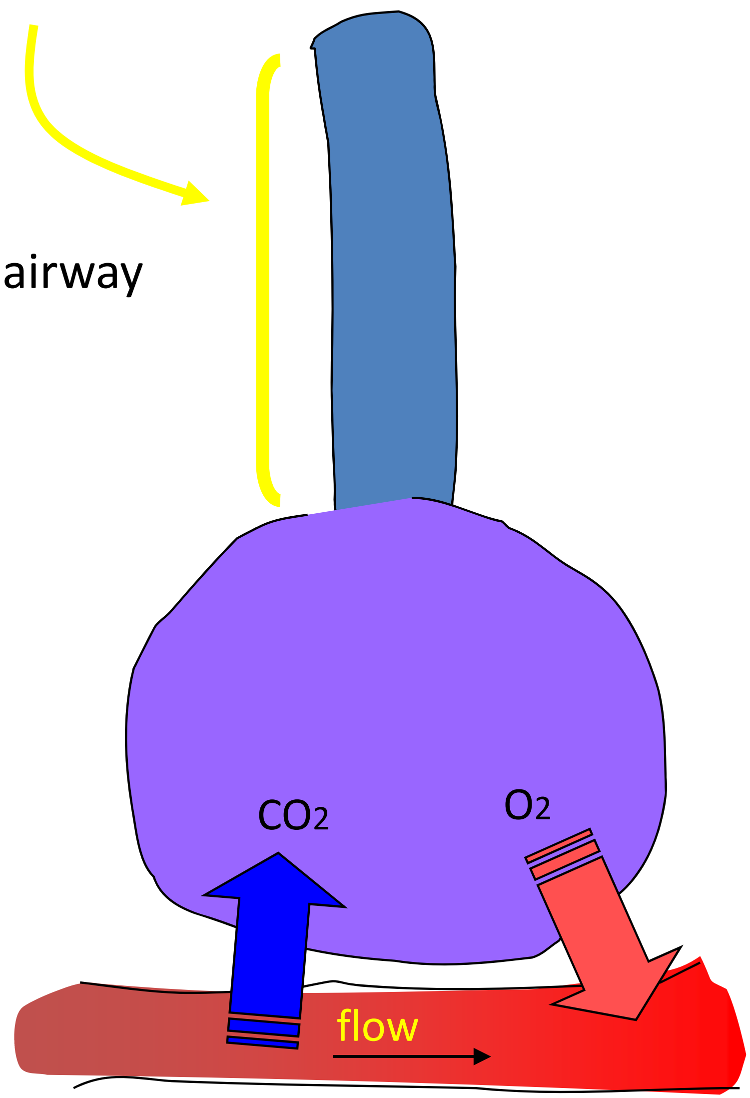


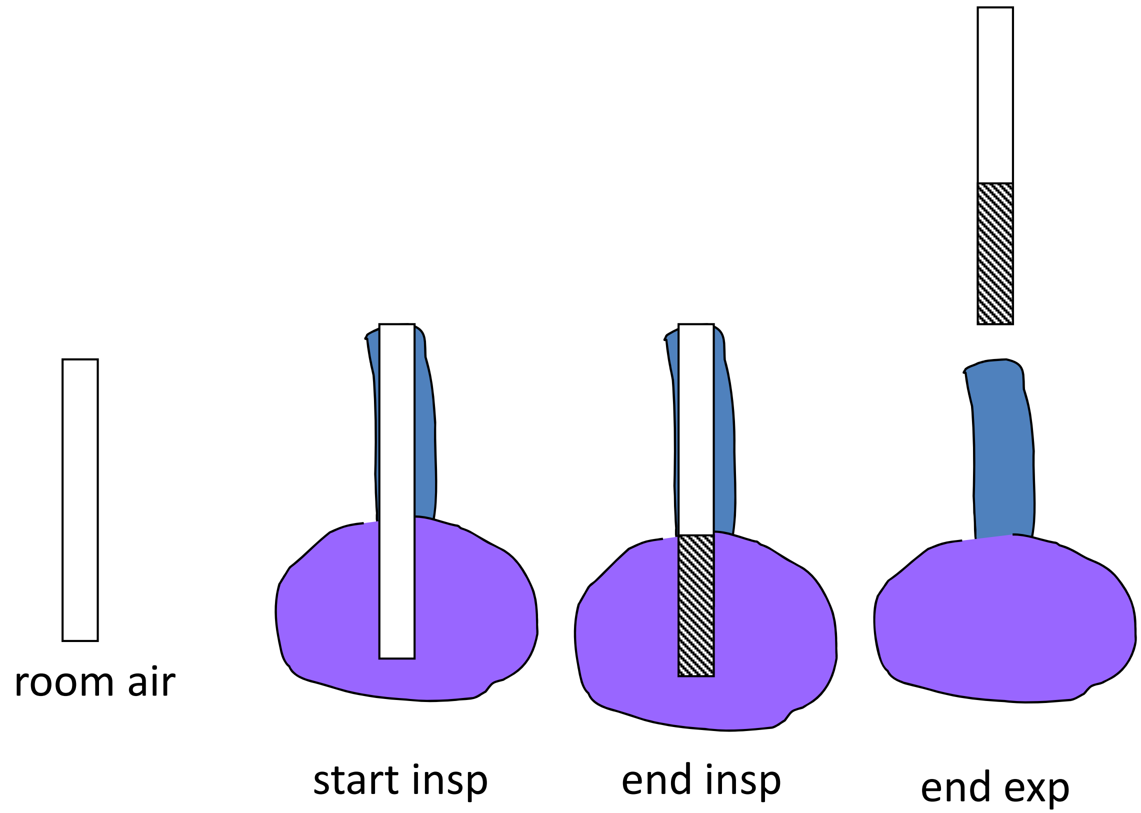
A capillary network covers the surface of the alveolus to facilitate oxygen and carbon dioxide exchange.



Anatomical Deadspace

V_D Anat = 1 ml/lb body wt.





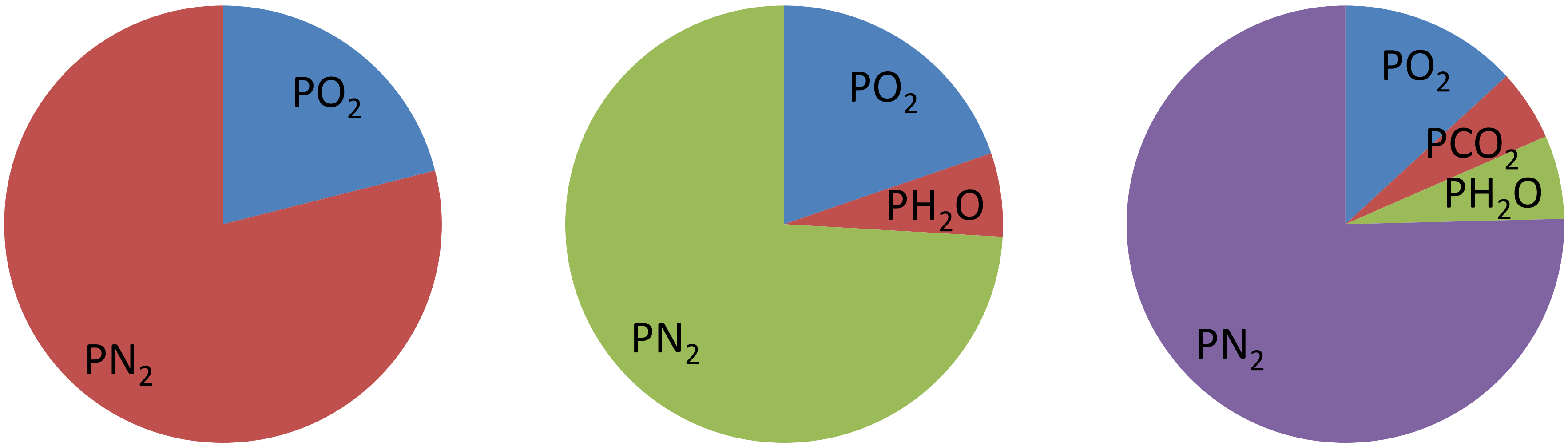
No gas exchange (white) in anatomical dead space

Minute Ventilation

- Minute Ventilation
  - MV = breathing frequency (f) x tidal volume (VT)
  - 5 L/min = 10/min x 500 ml

- Correction for VD Anat:
  - VE = f x (VT – VD anat)
  - 3.5 L/min = 10/min x (500 – 150) ml

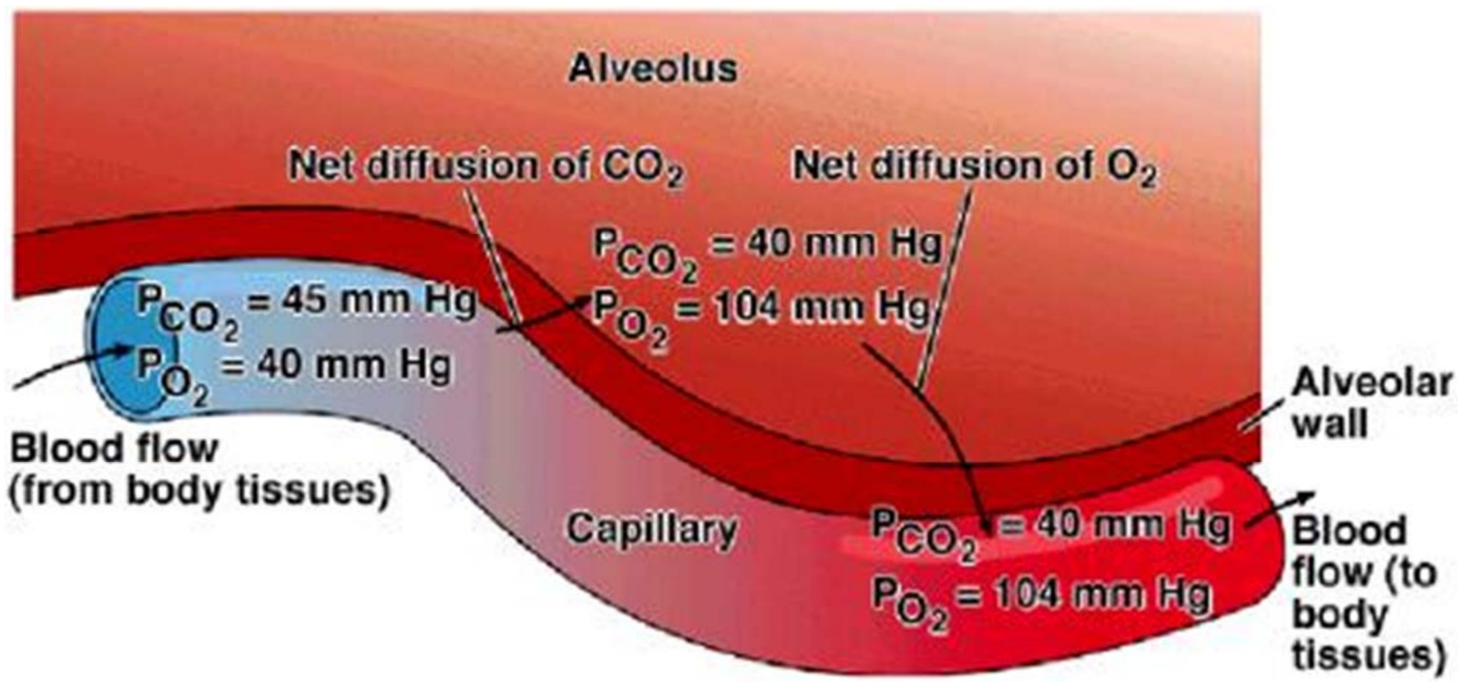
Alveolar PO_2 is < Inspired PO_2



	Dry Room Air	Inspired Air	Alveolar
PO_2	160	150	100
PCO_2	0	0	40
PH_2O (37°C)	0	47	47
PN_2	600	563	573
Total (mmHg)	760	760	760

Alveolar Gas

- Alveolar gas partial pressures determine blood gas tensions



Failure of Ventilation

- Alveolar ventilation
  - Component of Total Minute Ventilation that participates in CO_2 elimination by reaching perfused alveoli
  - The ratio of Dead Space (V_D) to Tidal Volume (V_T) is approximately 0.3
  - Any process that augments wasted ventilation can increase V_D / V_T
  - Unless ventilatory rate is increased, alveolar ventilation will fail

Hypercapnia

- Produced by
  - Alveolar hypoventilation
  - Increased dead space ventilation
  - Increased CO_2 production
    - May be associated with ↑ Metabolic rates
      - Fever will ↑ CO_2 production 13% for every 1 ºC
      - Normal accompanied by ↑ alveolar ventilation to maintain p CO_2

Hypercapnia

- Diagnostic guidelines of hypercapnia

Measurement	Normal	Indicator
Tidal Volume (V_T)	5 -8 ml/kg	< 5 ml/kg
RR	12 – 20 bpm	> 35
Minute Ventilation (V_M)	5 – 6 L/min	> 10 L/min
$PaCO_2$	35 – 45 mmHg	> 50 mmHg
PaO_2	80 – 100 mmHg	< 50 mmHg (Air), < 70 mmHg (Mask)
a-A gradient (with 100% O_2)	25 - 65	> 400
Arterial/alveolar ratio (P_aO_2/P_AO_2)	0.75	< 0.15

Equations

- Arterial Oxygen Content
  - C_aO_2 = ([Hb] x 1.34 ml O_2/g Hb x S_aO_2) + (P_aO_2 x 0.003)
    - Normal C_aO_2
      - Given the following: Hb = 15g/100 ml; S_aO_2 = 97.5%; P_aO_2 = 100 mm Hg
      - C_aO_2 = (15 x 1.34 x 0.975) + (100 x 0.003)
      - C_aO_2 = (19.6 ml/100ml) + (0.3 ml/100ml)
      - C_aO_2 = 19.9 ml/dl
- Venous Oxygen Content
  - C_VO_2 = ([Hb] x 1.34 ml O_2/g Hb x S_vO_2) + (P_vO_2x 0.003)
    - Normal C_VO_2
      - Given the following: Hb = 15g/100 ml; S_VO_2 = 75%; P_vO_2 = 40 mm Hg
      - C_VO_2 = (15 x 1.34 x 0.75) + (40 x 0.003)
      - C_VO_2 = (15.08 ml/100ml) + (0.12 ml/100ml)
      - C_VO_2 = 15.2 ml/dl

Equations

- Arterial Venous Content Difference
  - C(a-v)O2 = C_aO_2 - C_vO_2
  - C(a-v)O2 = 19.9 ml/dl - 15.2 ml/dl
  - C(a-v)O2 = 4.7 ml/dl
  - Tissues extract 4.7 ml of oxygen from each 100 ml of blood.
- Oxygen Extraction Ratio
  - $O_2ER = \frac{C_{(a-V)}O_2}{C_aO_2}$
  - $O_2ER = \frac{4.7\ ml/dl}{19.9\ ml/dl}$
  - $O_2ER = 0.24\ or\ 24\%$
- Oxygen Delivery
  - O_2 DEL (ml/min) = C_aO_2 (ml/100 ml) x 10 x Q (L/min)
  - 995 ml/min
  - 520 - 570 ml/min/m2
- Normal Oxygen Delivery
  - O_2 DEL = (19.9 ml/100ml x 10) x 5 L/min
  - O_2 DEL = 199 ml/L blood x 5 L/min
  - O_2 DEL = 995 ml oxygen/min

Case Discussion

- Is this patient adequately oxygenated?
  - P_aO_2 100 mm Hg
  - S_aO_2 0.975
  - Hb 7 g/dl
  - CO 8 L/min

Ventilators

Transport Ventilators

- Basic concepts
  - Power source
    - Battery/Electric
    - Pneumatically powered
      - Sensitive to changes in source pressure
      - Deplete available oxygen in system quicker
      - Think of the CPAP study
  - Tidal volumes
    - May change from leaks or altitude changes (Flight)
    - Should be assessed regularly with spirometer

Transport Ventilators

- Tidal volume and rate controls
- Anti-asphyxia valve
  - In case of oxygen system failure
- Alarm system
  - Disconnection
  - Depletion of oxygen source
  - Depletion of power source
- Manual trigger

Terminology

- Barometric Pressure
  - Atmospheric pressure (760 mmHg at sea level)
- Capnography
  - Graphical display of [CO_2]
- Capnometry
  - The measurement of pCO_2 in the pt's airway during entire respiratory cycle
- I:E Ratio
  - The ratio of inspiratory time to expiratory time
  - Normal 1:3, 1:2 with MV to prevent air trapping

Types

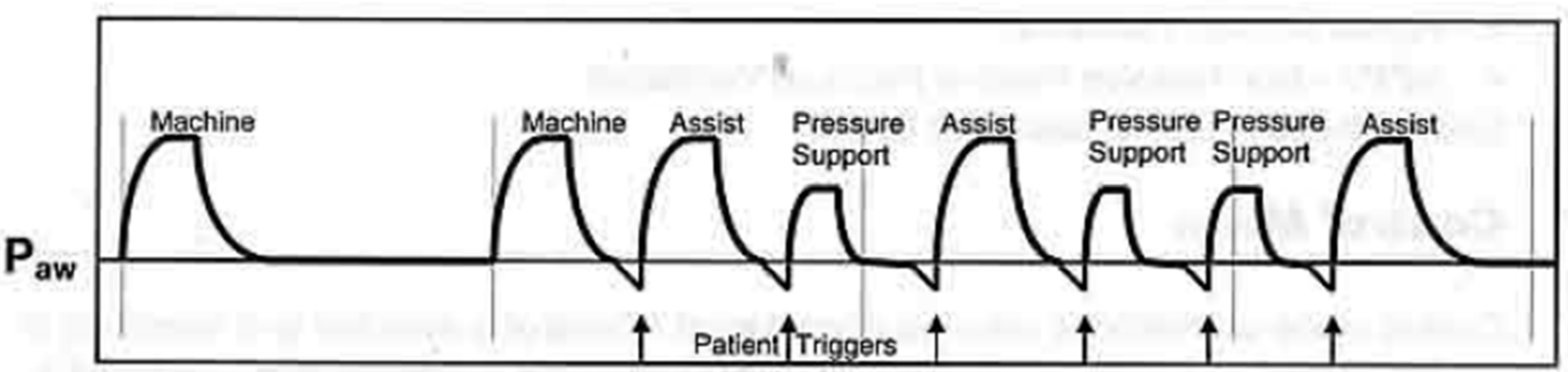
- Universally classed
  - Time-cycled
    - I:E occurs when a set period of time elapses
    - Variables include Volume, pressure and flow
  - Volume-cycled
    - I;E occurs when a set volume of air has been delivered
    - Variables include Pressure, time, I:E ratio, flow
  - Pressure-cycled
    - I:E occurs when a set pressure is reached
    - Variables include Volume, time, I:E and/or flow

Modes

- Volume targeted
  - Volume Control
    - Continuous Mandatory Ventilation (CMV)
    - Intermittent Mandatory Ventilation (IMV)
  - Volume Assist/Control
    - Assisted Mechanical Ventilation (AMV)
    - Synchronized Intermittent Mandatory Ventilation (SIMV)

- Pressure targeted
  - Positive End Expiratory Pressure (PEEP)
  - Continuous Positive Airway Pressure (CPAP)
  - Pressure Support

Waveform


Machine
Machine
Assist
Pressure Support
Assist
Pressure Support
Pressure Support
Assist
Paw
Patient Triggers

Continuous Mandatory Ventilation (CMV)

- Delivers a fixed ventilatory pattern regardless of the pt's respiratory pattern
  - Time triggered
  - Mandatory breaths
    - Volume or Pressure
  - Patient cannot trigger the breath
    - May be difficult to use
    - Sedation, paralytics
    - When pharmaceuticals wear off pt may fight the ventilator and affect hemodynamics

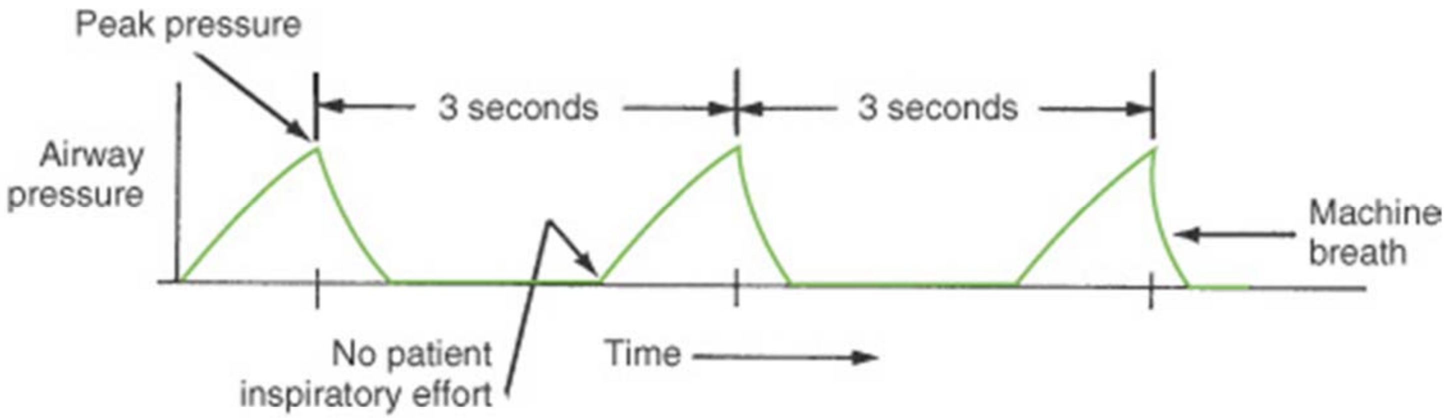


Fig. 4-4 Controlled ventilation pressure curve. Patient effort does not trigger a mechanical breath; rather, inspiration occurs at equal, timed intervals.

Intermittent Mandatory Ventilation (IMV)

- Allows spontaneous breathing by a continuous gas flow between volume controlled breaths
- Pt must accept the ventilator breath when delivered
  - If the rate is set at 12 cycles/min it will deliver a set VT every 5 sec, the pt can breathe spontaneously in between

Assist-controlled Ventilation

- Time or patient triggered
- Minimum Mandatory breath
  - Volume or pressure
- Sensitivity level set
  - To prevent auto triggering
  - To keep machine sensitive to patient effort
    - < - 3 cm H_2O below baseline

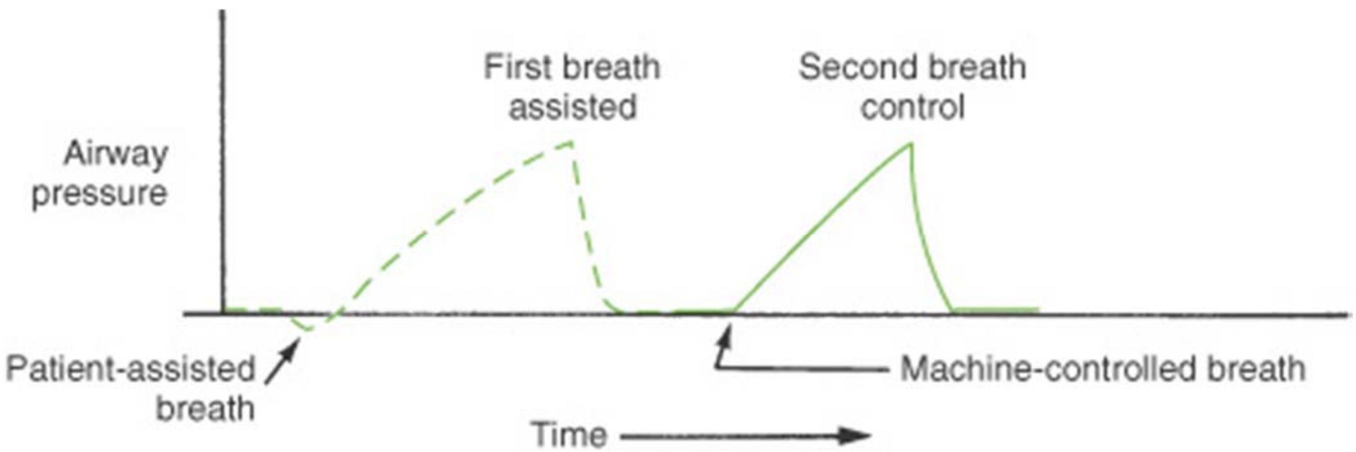


Fig. 4-8 Assist/control pressure curve. A patient-triggered (assisted) breath shows negative deflection of pressure before inspiration, whereas a controlled (time-triggered) breath does not.

Assisted Mechanical Ventilation (AMV)

- Initiates inspiration when the pt creates a sub-baseline pressure (triggers)
- Pt can trigger the ventilator at a rate more rapid then the programmed setting
- Disadvantage is that it allows the pt to increase MV
- May promote hyperventilation, alkalosis and air trapping

Synchronized Intermittent Mandatory Ventilation (SIMV)

- Same as IMV except instead of breathes being volume controlled they are assist/controlled
- Pt may breathe spontaneously without increased impedance with predetermined intervals of ventilated breathes
- The positive pressure breath is synchronized with the pt’s spontaneous breath

Assisted Ventilation

- All breaths are patient triggered
- No set f
  - f control set at zero
- Minimum mandatory breath
  - Volume or pressure

Positive End Expiratory Pressure (PEEP)

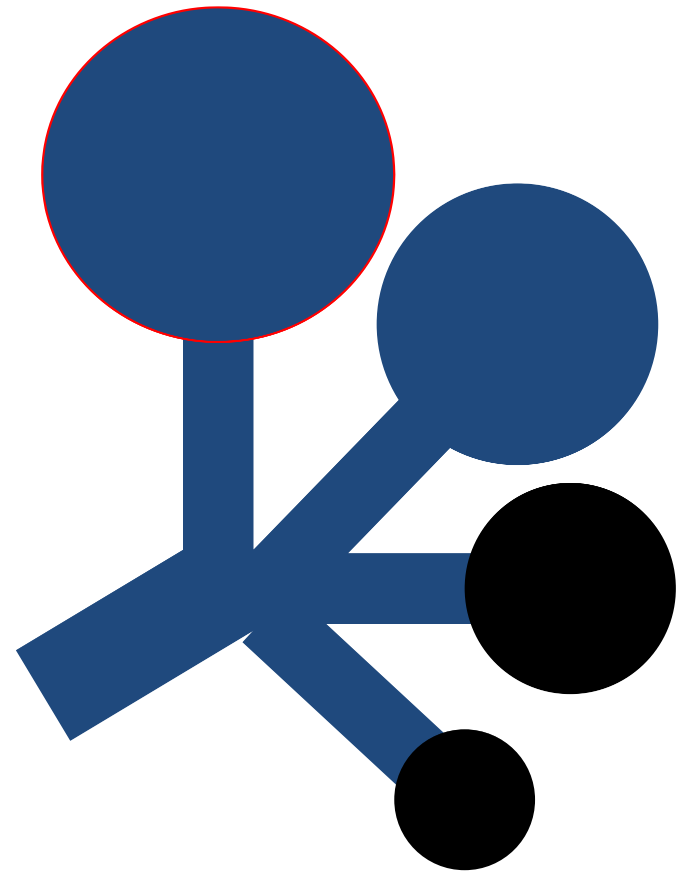
- Indications
  - Acute injury
    - Pulmonary edema, ARDS…
  - Intubated patient
    - We normally have approximately 5 cmH2O
    - The ETT eliminates the ability of the upper airway to control airflow and exert back pressure during expiration
    - Will lead to a ↓FRC

Positive End Expiratory Pressure (PEEP)

- Complications
  - Auto-PEEP
    - Incomplete emptying of the lung (air trapping)
      - May occur with insufficient expiratory time or limited flow
      - Can be seen in pt's with RR > 20 (may be seen COPD with RR > 12)
      - Airway obstruction
    - Can hear expiratory wheezing
  - Fix the cause if possible

Setting the Level of PEEP

- PEEP appears to be protective against ventilator induced lung injury
- Low tidal volume ventilation without PEEP has been demonstrated to cause a decline in compliance
- The smaller the tidal volume, the higher the PEEP level needed to optimize lung mechanics
- It is generally believed that PEEP set below 10 cm H_2O will probably keep healthy alveoli open at end exhalation, but will not be enough to distend diseased airways.
- These airways will then continually open and collapse throughout the ventilator cycle.
- The goal is to set PEEP at a level that does not overdistend healthy alveoli but at the same time does not let diseased airways collapse.



Continuous Positive Airway Pressure (CPAP)

- The application of PEEP to the spontaneously breathing pt
- Baseline pressure is higher then atmospheric pressure
- Pt still able to inspire/expire normally
- Decreases the work of breathing by expanding the alveoli and increasing compliance
- May cause over distention if too much CPAP is applied decreasing compliance

Pressure Support

- Augmentation of spontaneous ventilatory effort by a set amount of pressure
- Pt controls rate and volume
- Differs from CPAP as the pressure is applied only during inspiration
- Eliminates the work of breathing
  - Overcomes the dead space of the tubing in a circuit
  - May be applied with IMV

Ventilator Equations

- Total Cycle Time
  - TCT = TI + TE
  - TCT = 2 sec + 4 sec = 6 sec
- Frequency
  - $f = \frac{1\ min}{TCT}$
- I:E Ratio
  - 1:1 1:2 1:4
- Calculating VI from VT & TI
  - $VI = \frac{VT}{TI}$
- Tidal Volume
  - 5 to 10 ml/kg of IBW
- Selecting Frequency and Tidal Volumes
  - Normal Lungs
    - 10 ml/kg
    - f 8 to 12 min
    - VI 40 - 100 L/min
  - Lung disease
    - VT 6 to 8 ml/kg
    - f 6 to 10 min

Adjusting Minute Ventilation

- Minute Ventilation (MV) = VT X RR
  - MV Desired (VE) $= \frac{PCO_{2\,(Actual)} \text{ X } VE_{(Actual)}}{PCO_{2\,(Desired)}}$
- Adjust the rate or the tidal volume
  - Rate Desired $= \frac{V_{E\,(Desired)}}{V_{T\,(Desired)}}$
  - VT Desired $= \frac{V_{E\,(Desired)}}{Rate_{(Actual)}}$

Example 1

- 36 y/o male, 76 kg who was the driver of a car involved in a MVC. He has sustained a closed head injury and is currently being treated in the ER in Yarmouth. He is intubated and you are going to transfer him to QEII.
  - Ventilator settings: RR 12, V_T 700 ml, FiO2 1.0
  - ABG: pH 7.40, pCO_2 35, pO_2 300, HCO_3^- 26
  - ET CO_2: 33 mmHg

- You are ordered to adjust parameters to maintain an ET CO_2 of 26 – 28 mmHg

Example 1

- MV = (700 ml X 12 bpm) = 8400 ml
- $V_{E\ (Desired)}$ = (35 mmHg X 8400 ml) / (26 mmHg) = 11307 ml = 11.3 L
- You decide to adjust tidal volume
  - $V_{T\ (Desired)}$ = (11307 ml / 12 bpm) = 942 ml
- New vent settings would reflect
  - RR 12, V_T 940 ml, FiO2 1.0

Example 2

- 45 y/o, 80 kg who was working on the roof of his house and fell backwards onto the pavement. He sustained blunt head, neck and chest trauma (rib #'s). He is in the ER in Bridgewater and will be transferred to the QEII.
  - Ventilator settings: RR 12, V_T 800 ml, FiO2 1.0
  - ABG: pH 7.40, pCO_2 40, pO_2 600, HCO_3^- 24
  - ET CO_2: 38 mmHg

- You are ordered to adjust parameters to maintain an ET CO_2 of 26 – 30 mmHg and is concerned with the rib #'s and asks to adjust the rate.

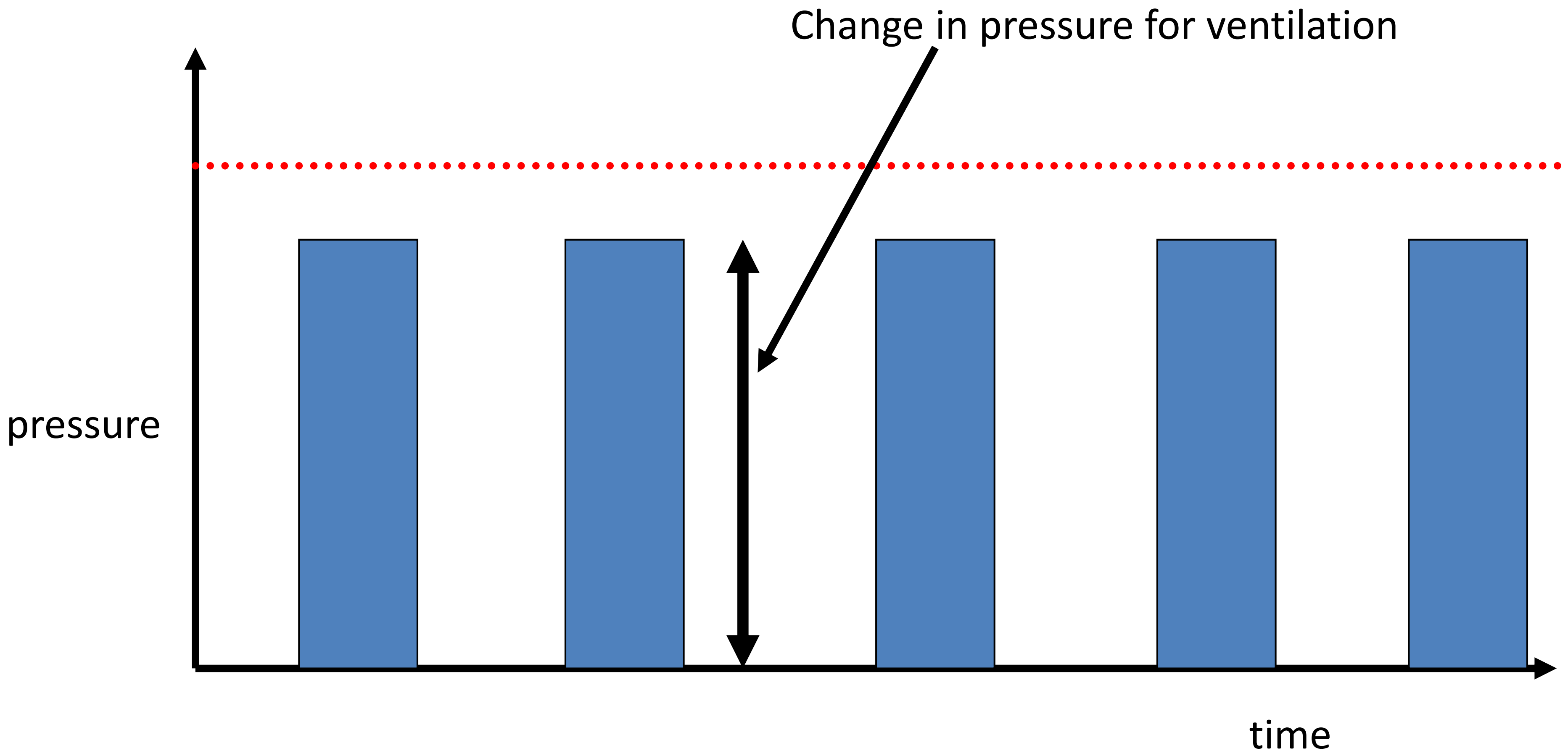
Example 2

- MV = (800 ml X 12 bpm) = 9600 ml
- $V_{E\ (Desired)}$ = (40 mmHg X 9600 ml) / (26 mmHg) = 14769 ml = 14.8 L
- Adjust rate
  - $Rate_{\ (Desired)}$ = (14769 ml / 800 ml/breath) = 18.5 breaths
- New vent settings would reflect
  - RR 19, V_T 800 ml, FiO2 1.0

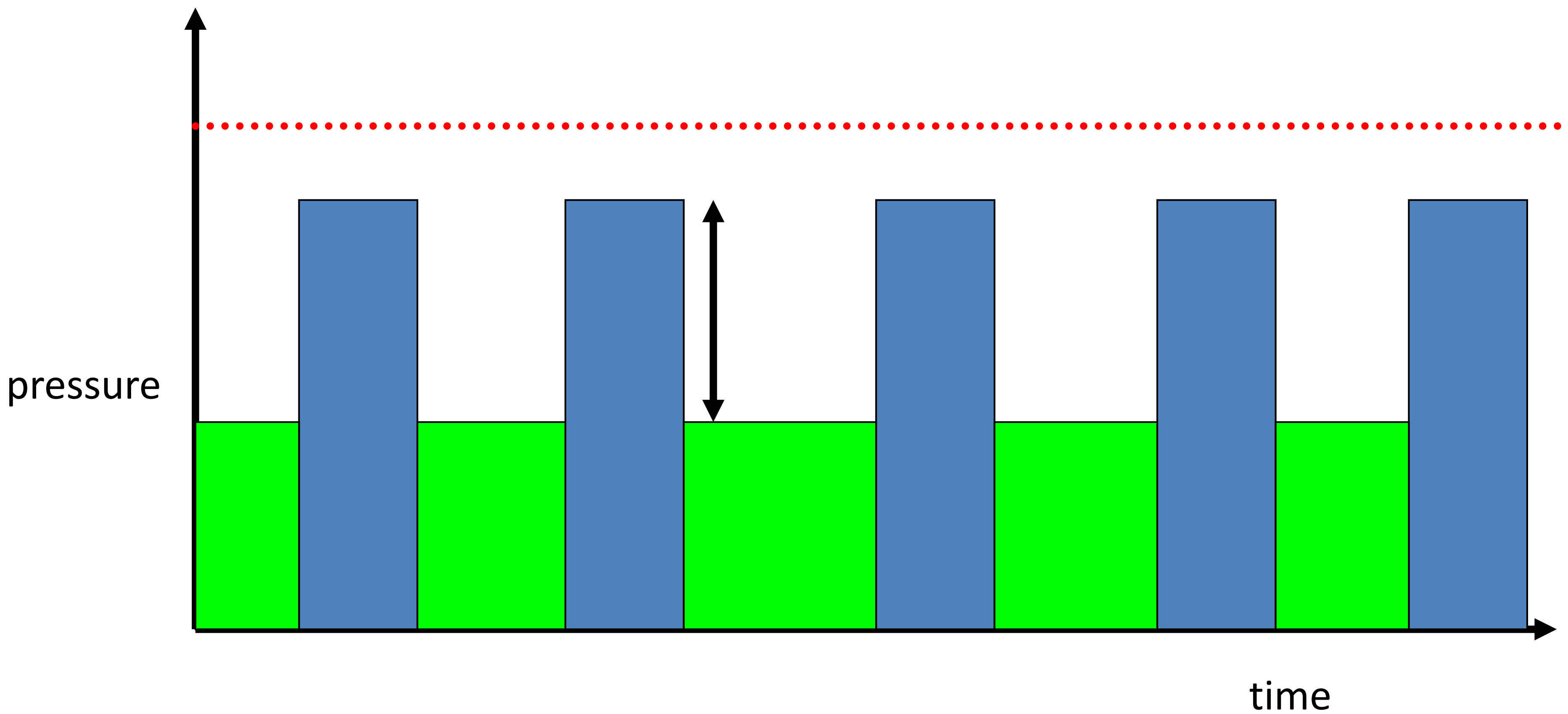
Oxygenation failure

- FiO_2 0.6 or less is goal
- Risk of oxygen toxicity
- Microatelectasis due to loss of nitrogen splinting

Mean airway pressure



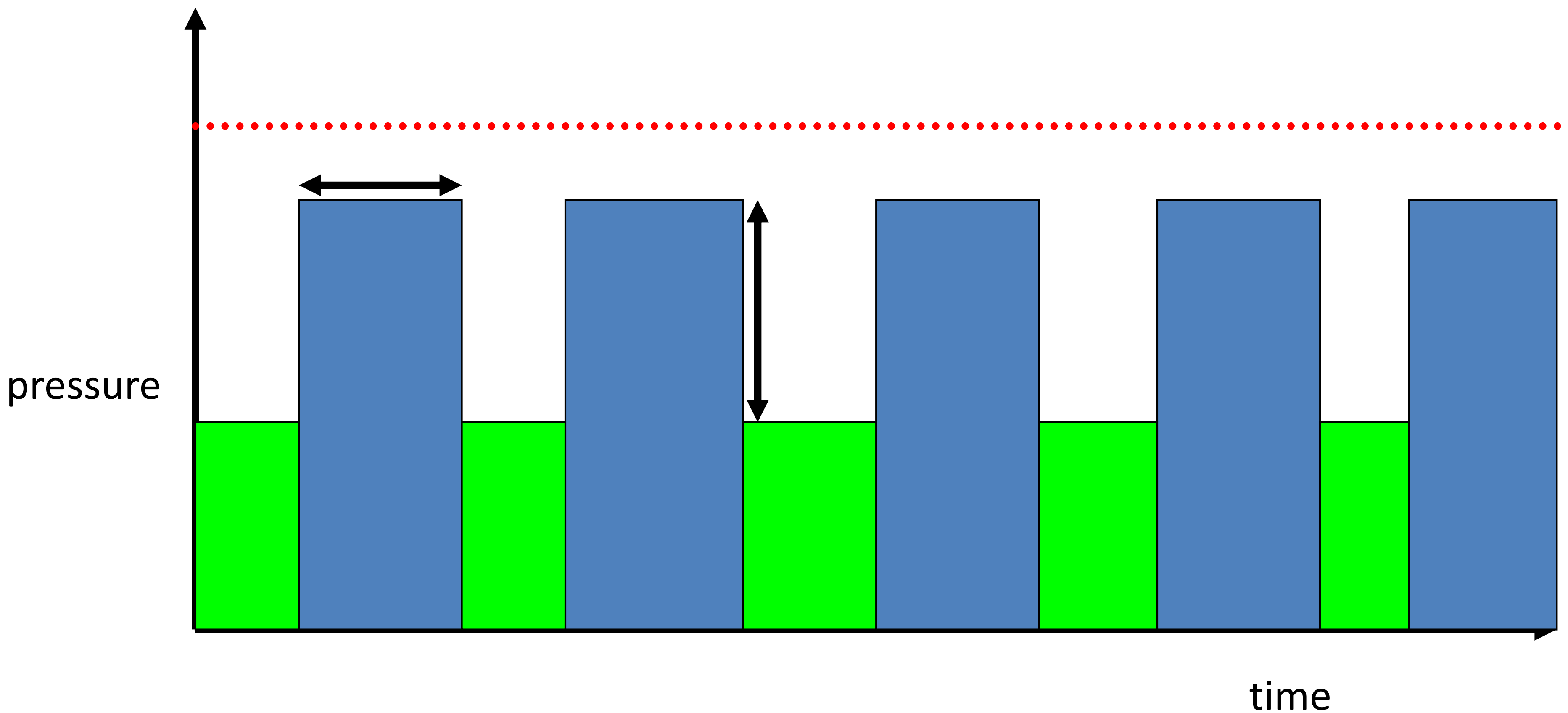
Mean airway pressure



Add PEEP

Improve mean airway pressure without excessive pressure

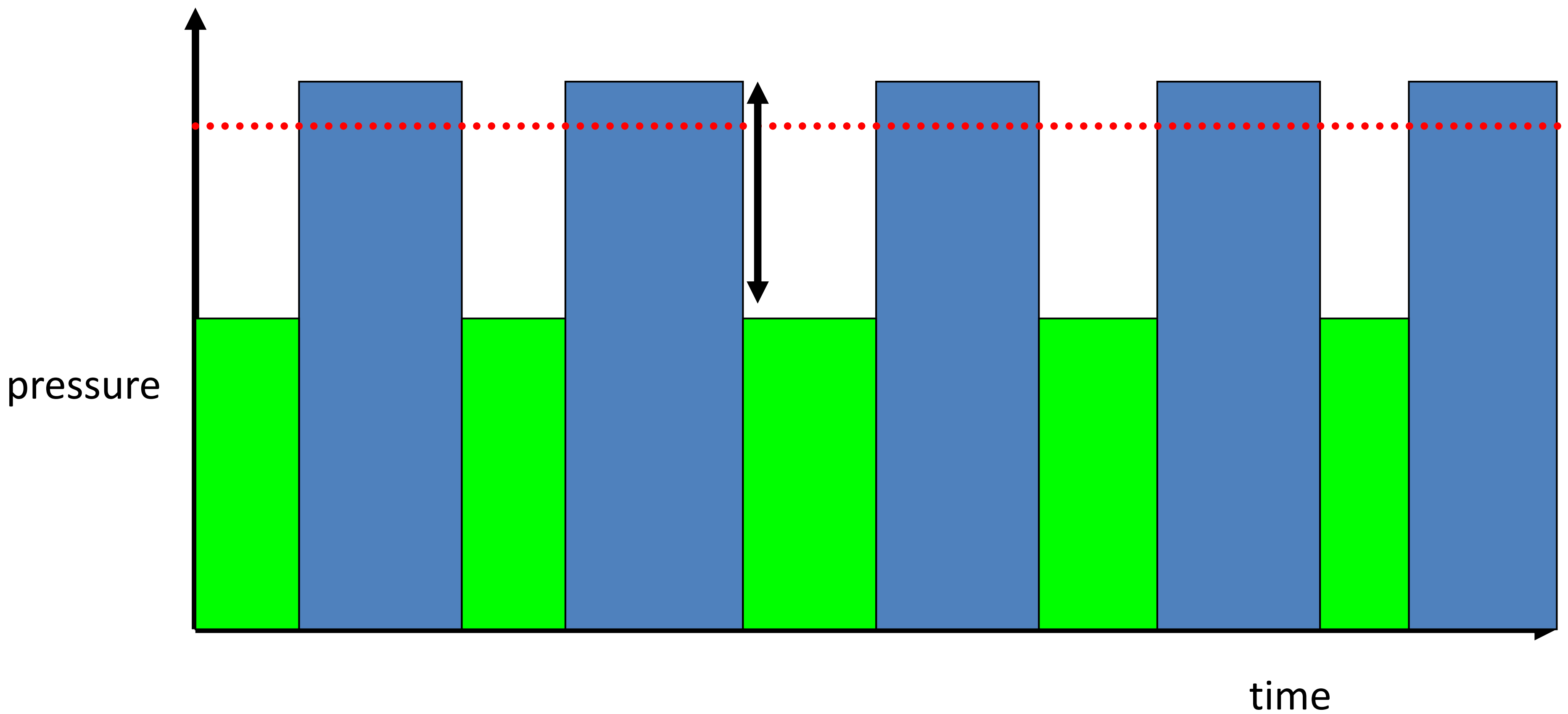
Mean airway pressure



Increased inspiratory:expiratory ratio (time constant factor)

Improve MAP without excessive pressure BUT can get auto-PEEP

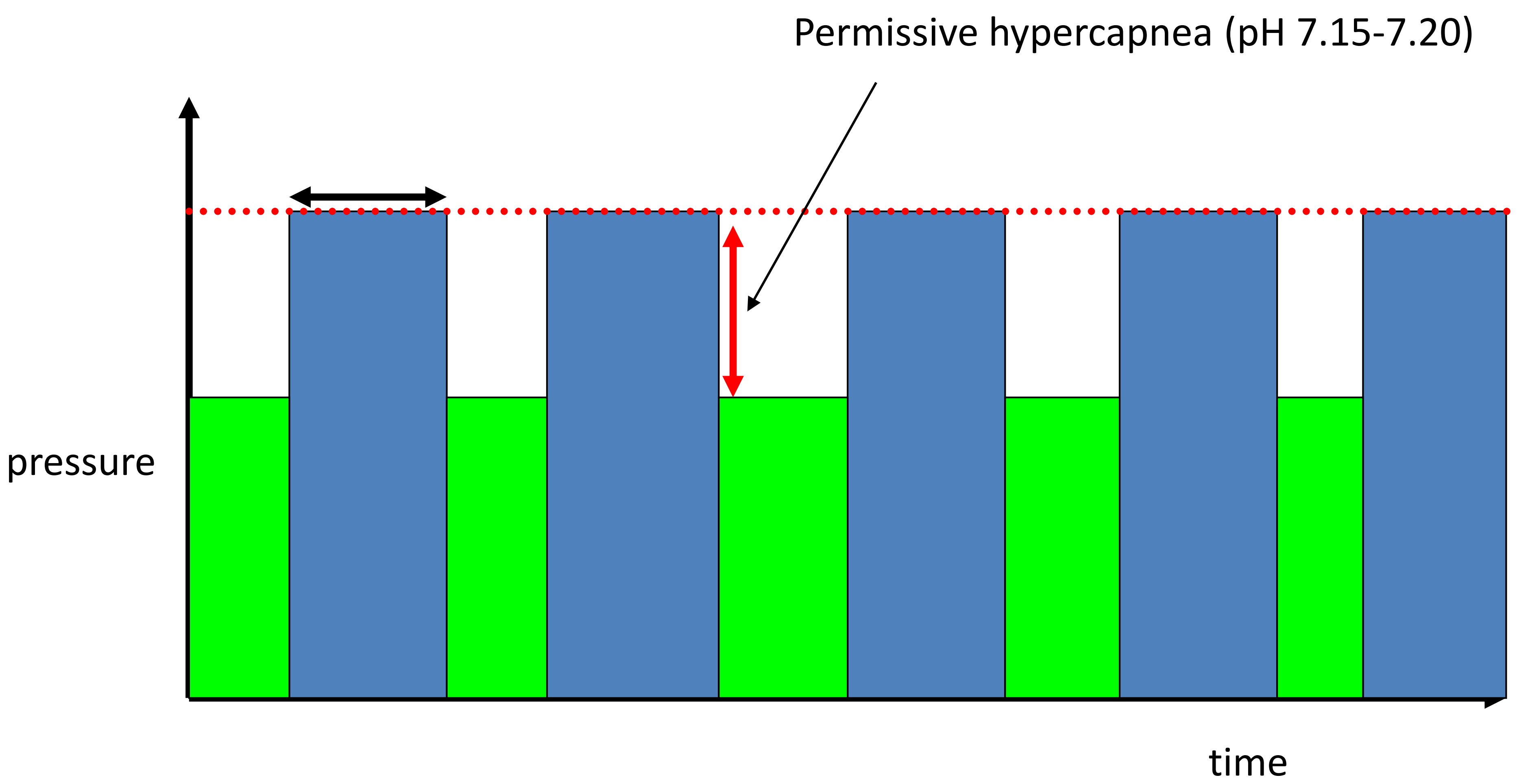
Mean airway pressure



Further increase PEEP

Exceed safe pressures but maintain ventilation

Mean airway pressure



Safe plateau pressure (30-35) but narrowed inspiratory delta-P, decreased minute ventilation

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ORIGINAL ARTICLE

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Ventilation with Lower Tidal Volumes as Compared with Traditional Tidal Volumes for Acute Lung Injury and the Acute Respiratory Distress Syndrome

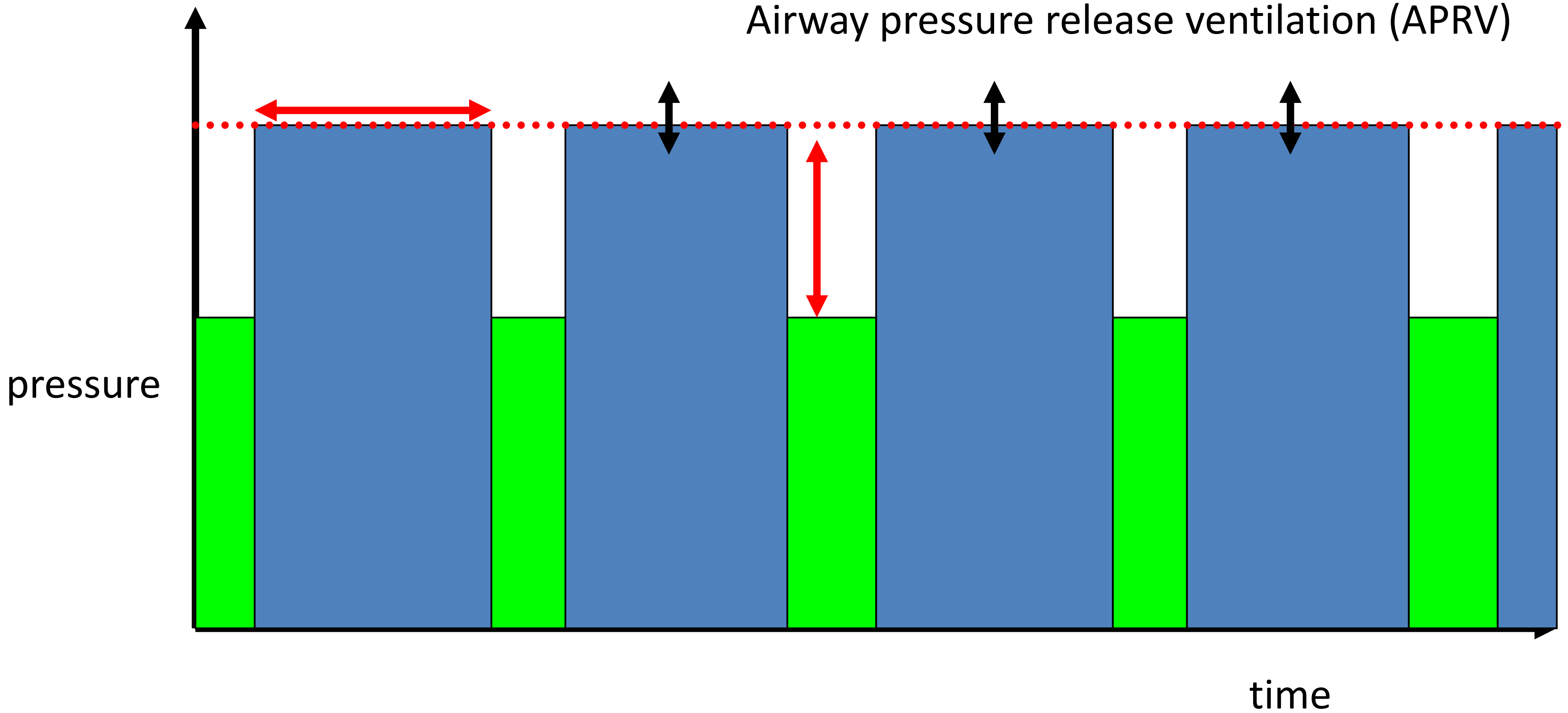
The Acute Respiratory Distress Syndrome Network

- 6 ml/kg versus 12 ml/kg tidal volume
- Mortality 31% versus 39.8%

Mean airway pressure

Extreme inverse-ratio ventilation

Airway pressure release ventilation (APRV)



Longer time at high pressure = higher MAP

Rely on passive exhalation = ? better CO_2 clearance

Better patient comfort