

## **Hassan Soleimanpour**

Professor of Anesthesiology and Critical Care, Emergency Medicine Department, TUOMS

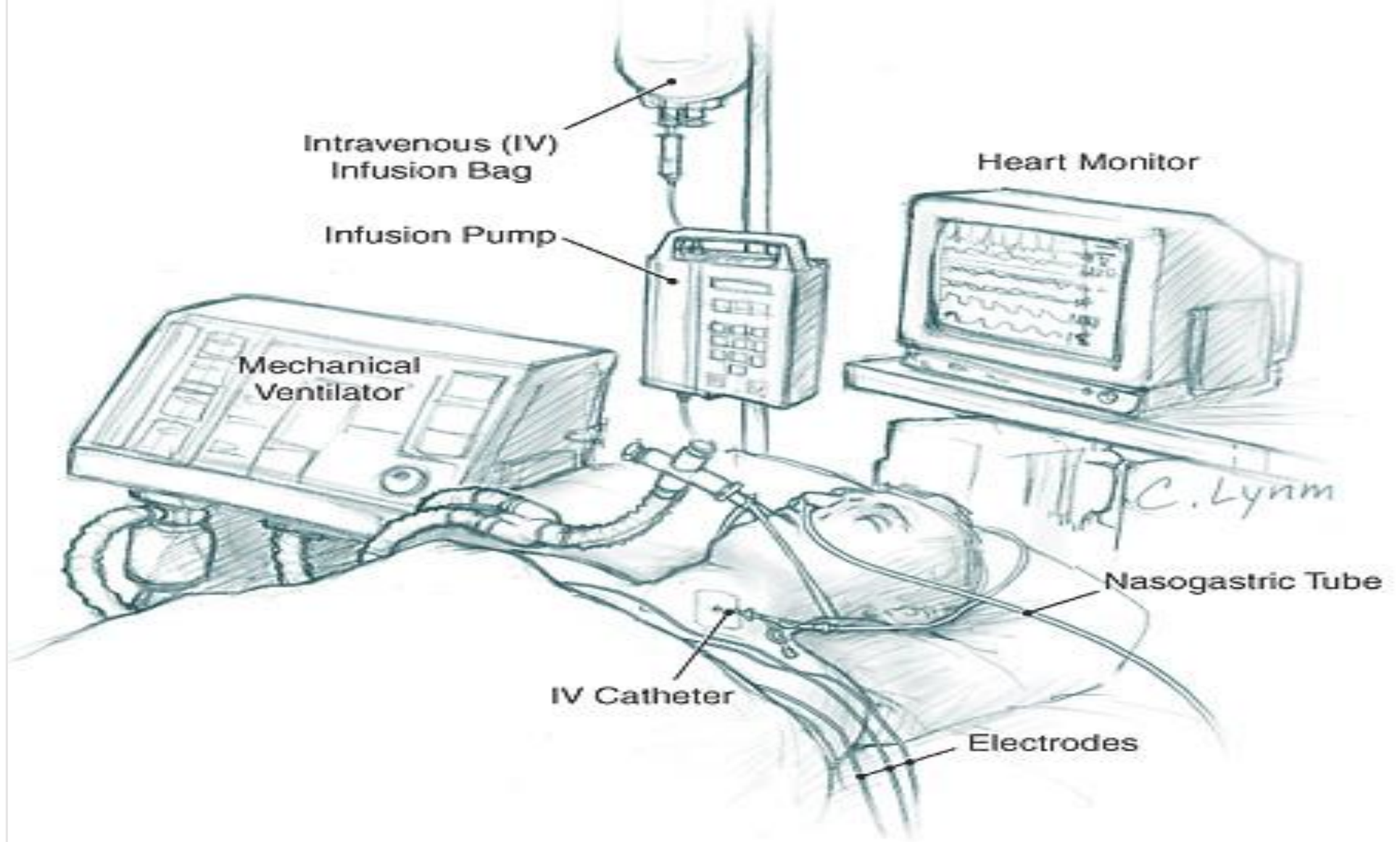
Fellowship in EBM (In training), Joanna Briggs Institute, University of Adelaide, AUSTRALIA

Fellowship in Trauma Critical Care and CPR, Vienna, Austria

Subspecialty in Intensive Care Medicine (ICM), TUOMS

**With tnx to Prof. Mahmoodpoor, My respected colleague, for sharing his slides**





Ventilate is derived from Latin word “ventus” meaning wind

## The Origin of Mechanical Ventilation

*“But that life may...be restored to the animal, an opening must be attempted in the trunk of the trachea, in which a tube of reed or cane should be put; you will then blow into this, so that the lung may rise again and the animal take in air. ...and as I do this, and take care that the lung is inflated in intervals, the motion of the heart and arteries does not stop...”*

Andreas Wesele Vesalius, 1543





Robert Hooke performed an experiment on October 24, 1667 where he connected a dog with open thorax to two bellows. Using one bellows only he demonstrated that the “the supply of fresh Air” can keep the dog alive for hours while “the bare Motion of the Lungs without fresh air contributes nothing to the life of the Animal”. Using the second bellows to produce a **positive pressure** through rapid pumping and then perforating the lungs he showed that the continuous flow of air alone is sufficient to keep the dog alive.

# Goal

- Maintain appropriate levels of partial pressure of O<sub>2</sub> and Co<sub>2</sub> in arterial blood (Adequate gas exchange)
- Unloading the ventilatory muscles
- Protecting lung from overdistension and recruitment – derecruitment injury.
- Reduce WOB
- Optimize patient comfort

# Goals of Mechanical Ventilation

| Goal                              | Target   |
|-----------------------------------|--|
| 1. Improve gas exchange           | Reverse hypoxemia<br>Relieve acute respiratory acidosis                      |
| 2. Relieve respiratory distress   | Reduce oxygen cost of breathing<br>Reverse respiratory muscle fatigue        |
| 3. Improve pulmonary mechanics    | Prevent and reverse atelectasis<br>Improve compliance<br>Prevent lung injury |
| 4. Permit lung and airway healing | Maintain lung and airway functions   |
| 5. Avoid complications            | Protect lung and airway<br>Prevent disuse respiratory muscle dystrophy       |

# Why ventilate?

- Improve oxygenation
- Increase/maintain minute ventilation and help CO<sub>2</sub> clearance
- Decrease work of breathing
- Protect airway



# Who needs a ventilator?

- Can't oxygenate (low PaO<sub>2</sub>/SPO<sub>2</sub>)
- Can't ventilate (high PaCO<sub>2</sub>)
- Can't participate or protect airway (low GCS)
- If you're not sure whether or not the patient needs a ventilator, the patient needs a ventilator.

# Objectives of Mechanical Ventilation

## Improve pulmonary gas exchange

Reverse hypoxemia and Relieve acute respiratory acidosis

## Relieve respiratory Distress

Decrease oxygen cost of breathing and reverse respiratory muscle fatigue

## Alter pressure-volume relations

Prevent and reverse atelectasis

Improve Compliance

Prevent further injury

## Permit lung and airway healing

## Avoid complications

# Common indications for ventilation

- Hypoxemic respiratory failure – 66%
- Acute exacerbation of COPD – 13%
- Neuromuscular disorders - 10%
- Coma - 10%



Ventilation

Parameters

Protocols

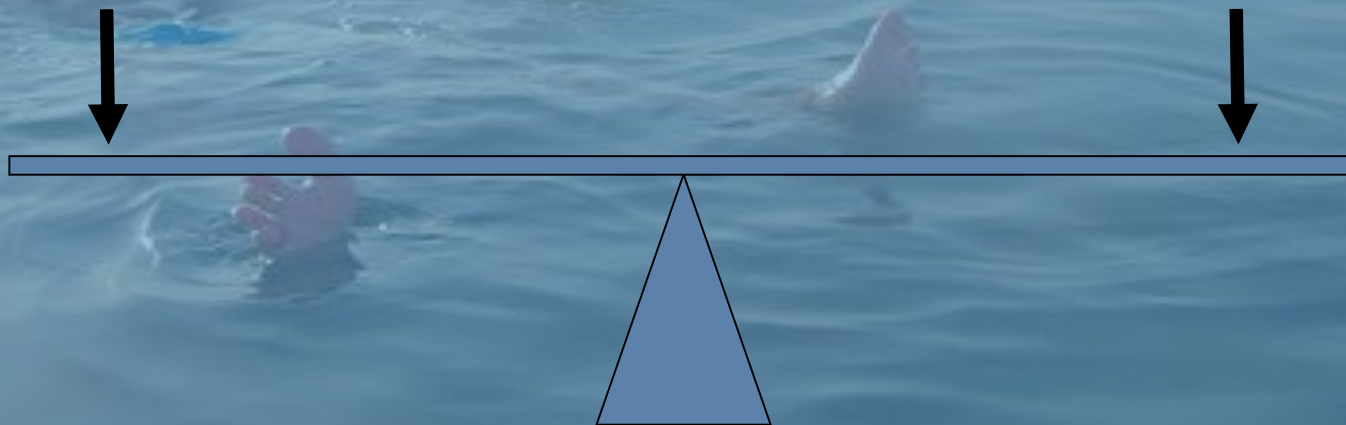
# Balance of Ventilation



I need 2 Volunteers !!

WOB

Energy Cost



# Balance of Ventilation

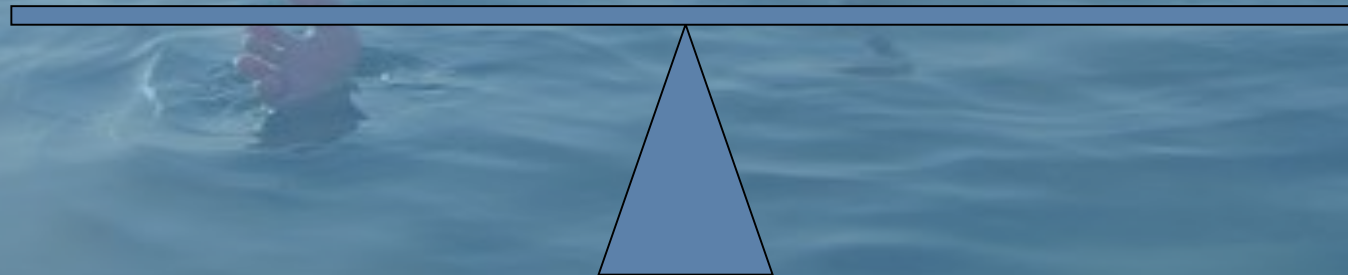
WOB  
Resistance  
Compliance

(Disease States)



Energy  
Muscle Strength  
Endurance

(Healthy States)



# Balance of Ventilation

WOB  
Resistance  
Compliance

(Disease States)

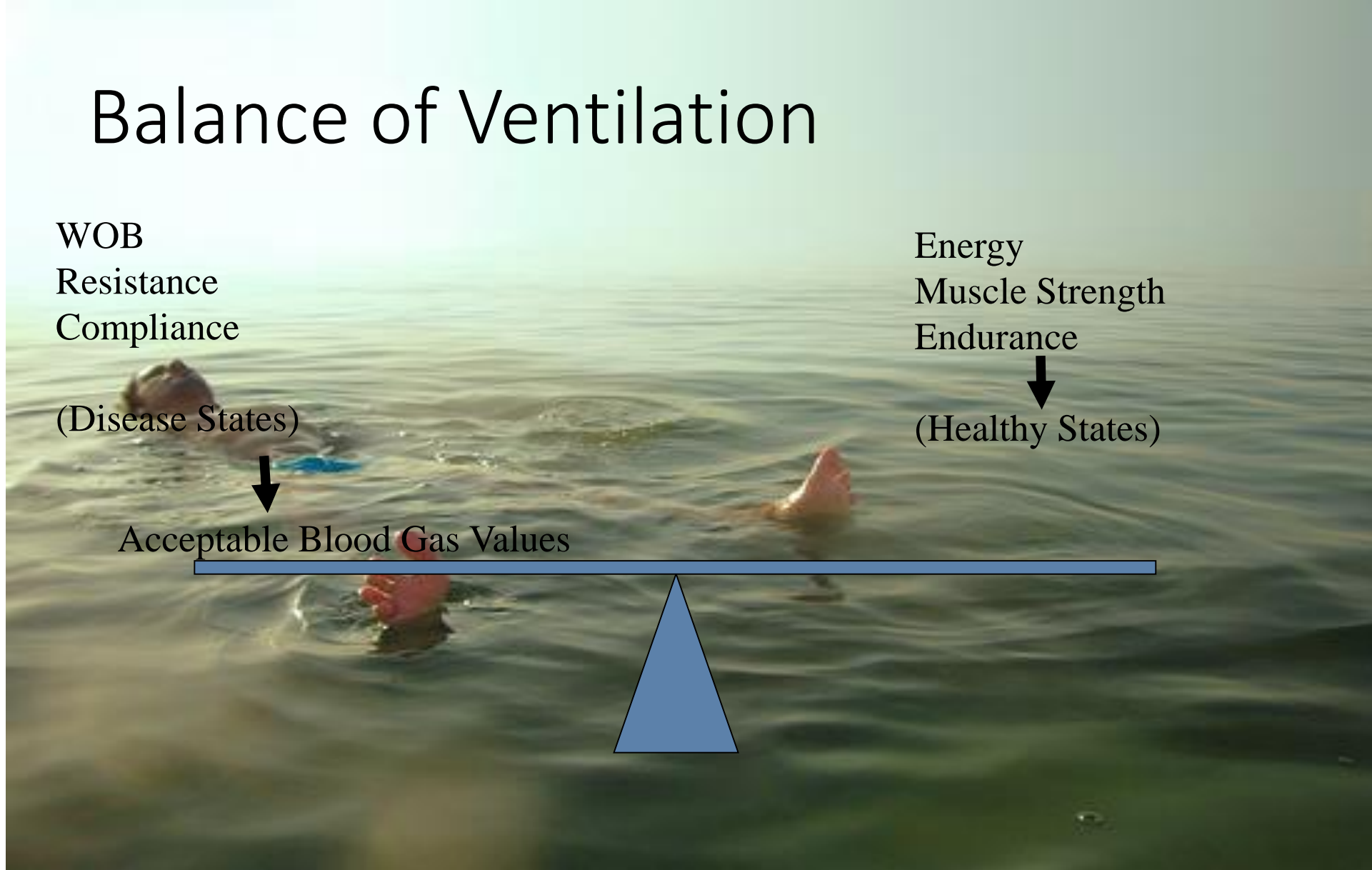
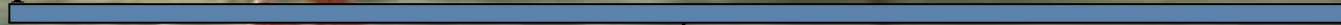


Acceptable Blood Gas Values

Energy  
Muscle Strength  
Endurance



(Healthy States)





# Balance of Ventilation



What do we do when out of Balance ?



We have to find the correct level of support



We have to find the correct level of support



We have to find the correct style of support



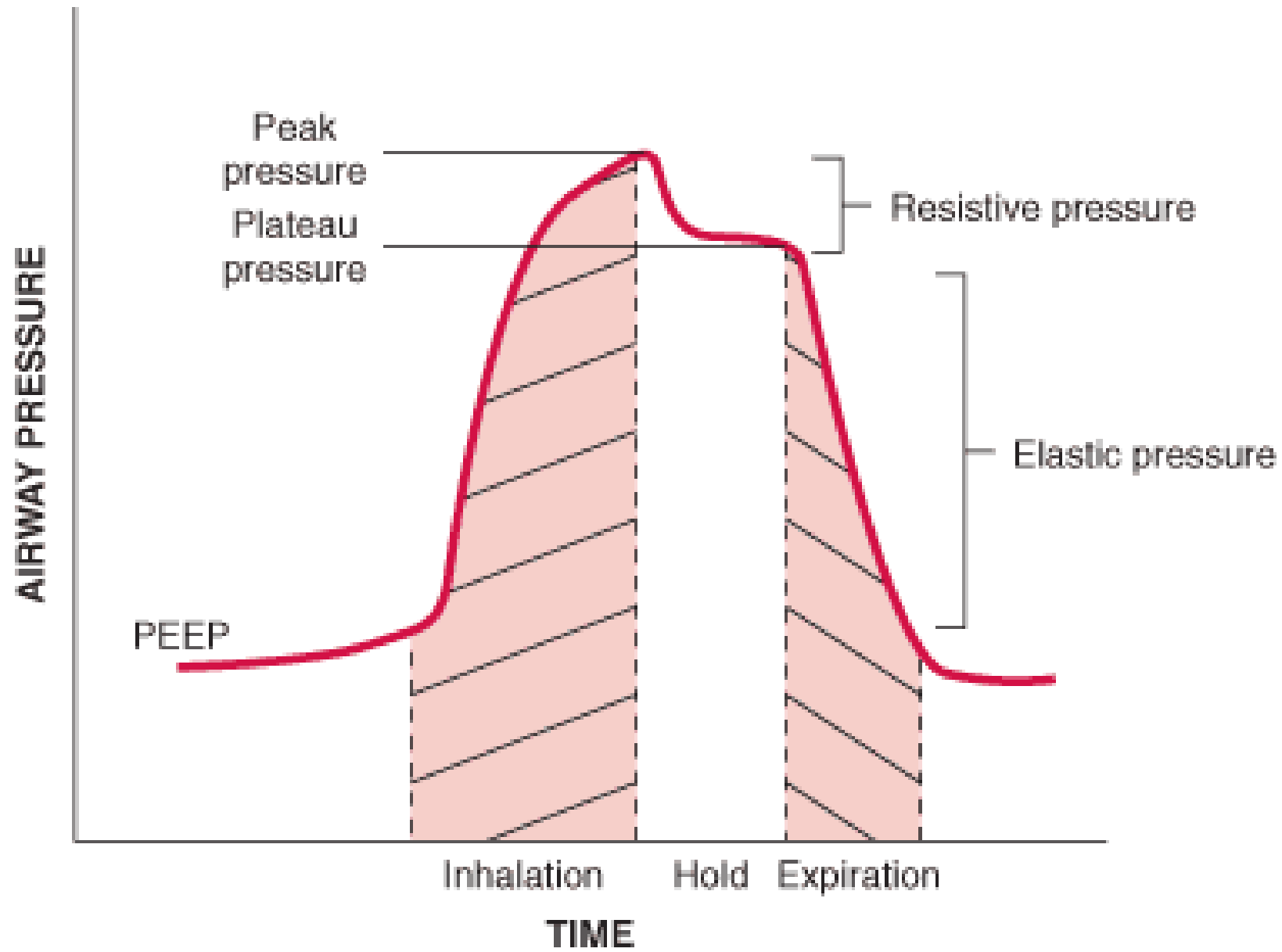
# Equation of motion

- $P_{\text{muscle}} = P_{\text{elastic}} + P_{\text{resistive}}$

**Equation of Motion**

**ventilation pressure** = **resistive pressure** + **elastic pressure**  
(to deliver tidal volume) (to make air flow through the airways) (to inflate lungs and chest wall)

$$P = P_{\text{resistive}} + P_{\text{elastance}}$$
$$P = R \times V + E \times V$$



There are three considerations in which mechanical ventilation should be **terminated** or **should not be started**

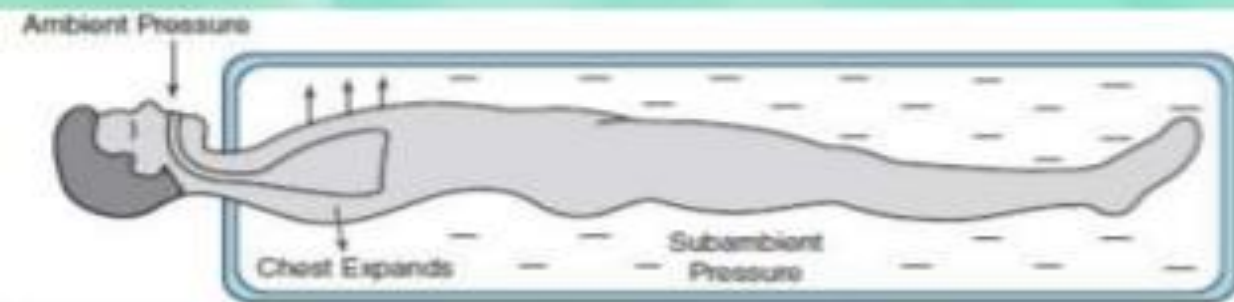
They are based on

- (1) patient's informed request,
- (2) medical futility (A condition in which medical interventions are useless based on past experience),
- (3) reduction or termination of patient pain and suffering.

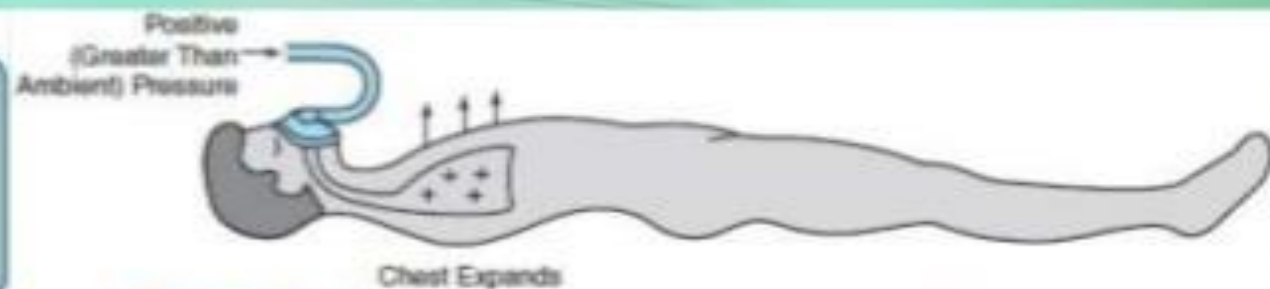


# Types of Ventilation

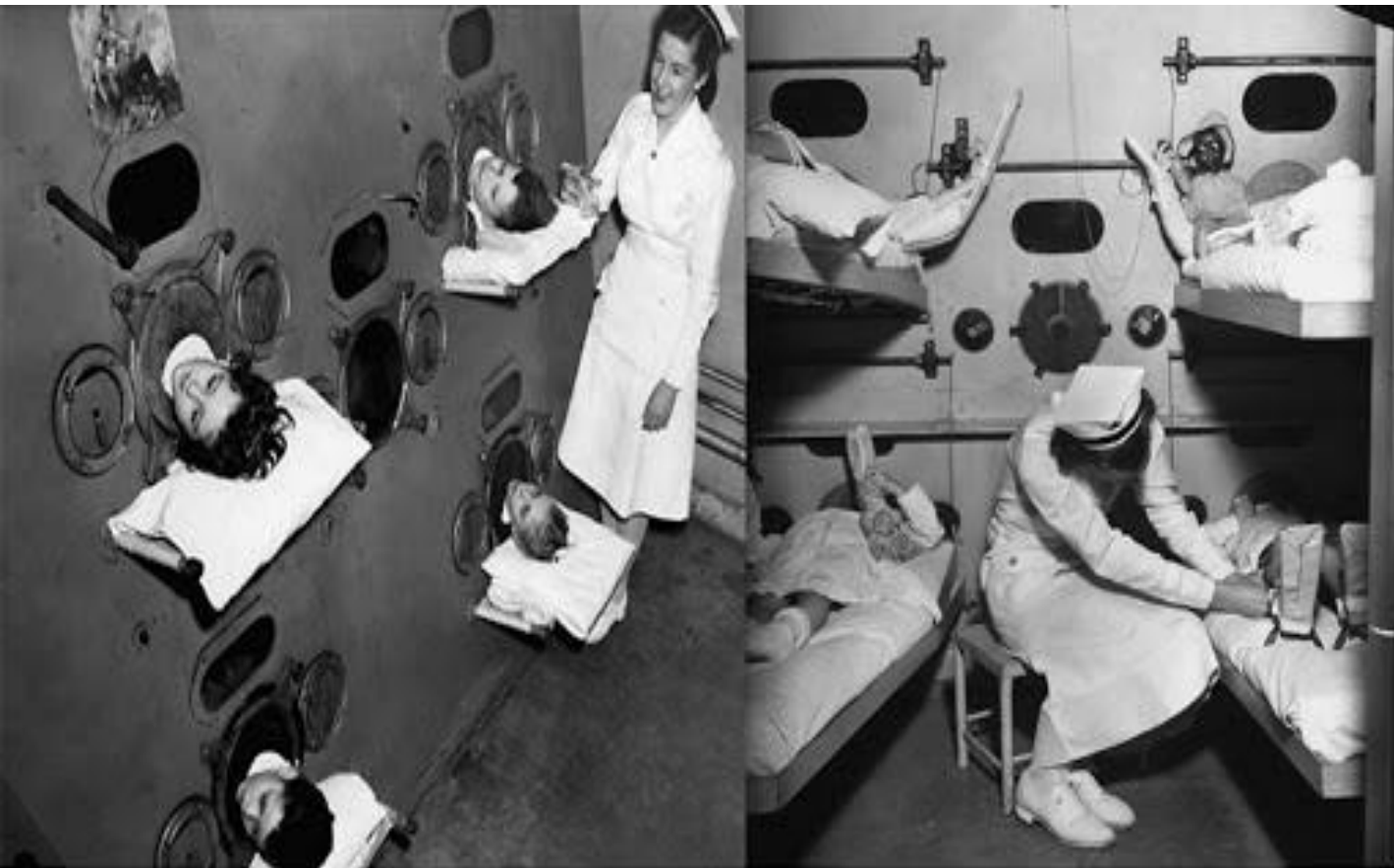
- Negative pressure ventilation
- Positive pressure ventilation
  - Simple pneumatic system
  - New generation microprocessor controlled systems.



**FIGURE 3-8** A schematic illustrating negative pressure ventilation.



**FIGURE 3-7** A schematic illustrating positive pressure ventilation.





GERDA  
PETERICH

# Basic Ventilator Parameters

- Mode
- Tidal volume
- Frequency or back up rate
- FiO<sub>2</sub>
- PEEP
- Flow rate
- I:E Ratio
- Triggers

# Tidal Volume

- initial tidal volume is usually set between **6 and 8 mL/kg** of predicted body weight.
- Tidal volumes  $\leq$  **6 mL per kg** of predicted body weight have been recommended for **ARDS** patients

**TABLE 8-7** Conditions That May Require Lower Tidal Volumes

| Condition                               | Examples                |
|---|-------------------------|
| Increase of airway pressure requirement | ARDS<br>Pulmonary edema |
| Increase of lung compliance             | Emphysema               |
| Decrease of lung volumes                | Pneumonectomy           |

Dr. Shumaylaaslam@gmail.com

IBW = Ideal body weight:

Males:  $IBW = 50 \text{ kg} + 2.3 \text{ kg}$  for each inch over 5 feet

Females:  $IBW = 45.5 \text{ kg} + 2.3 \text{ kg}$  for each inch over 5 feet

AjBW = adjusted body weight:

$AjBW = IBW + 0.4(ABW - IBW)$

### **Ideal Body Weight (IBW) (kg)**

•  $IBW \text{ (male)} = 50 + 2.3 (H - 60)$  مردان

•  $IBW \text{ (female)} = 45.5 + 2.3 (H - 60)$  زنان

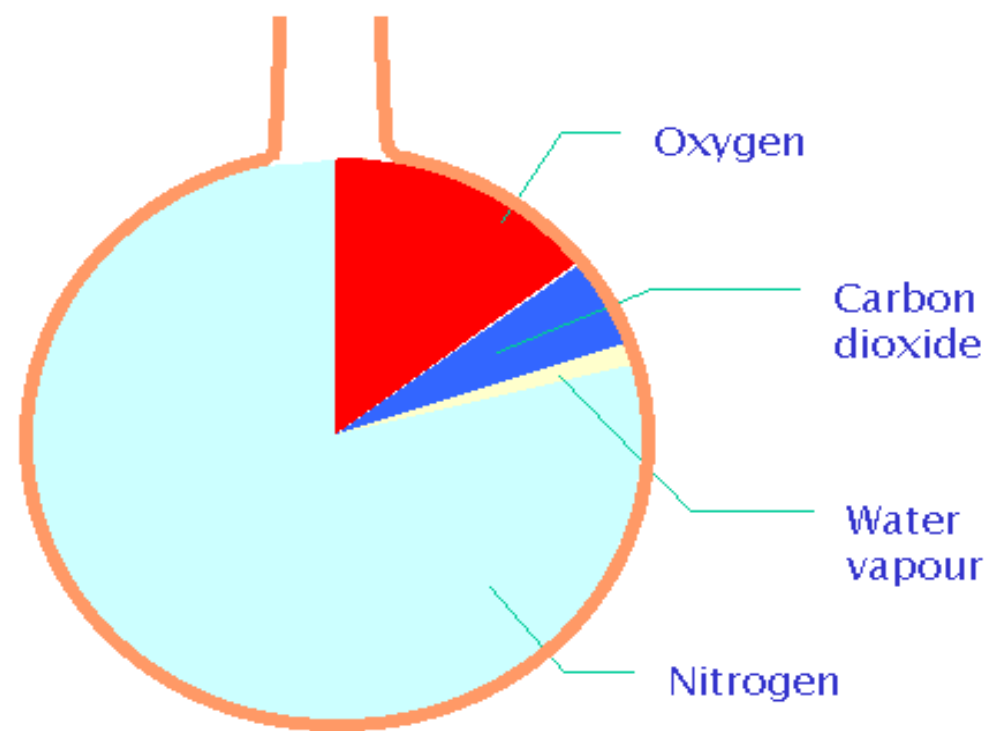
# Frequency (Back Up Rate)

- the number of **breaths per minute** that is intended to provide eucapneic ventilation (PaCO<sub>2</sub> at patient's normal)
- The initial frequency is usually set between **12 and 16/min.**
- Frequencies of 20/min or higher are associated with auto-PEEP and should be avoided.
  - high ventilator frequency, inadequate inspiratory flow and air trapping contribute to the development of auto-PEEP.

# FIO2

- Fraction of inspired Oxygen
  - The initial FIO2 may be set at 100%.
  - should be evaluated by means of ABG after stabilization of the patient.
- should be adjusted accordingly to maintain a PaO2 between 80 and 100 mm Hg.
- After stabilization of the patient, the FIO2 is best kept below 50% to avoid oxygen induced lung injuries
- Can be assed by SpO2, maintaing  $\geq 96\%$





$$\text{Alveolar pressure} = P_{\text{A}}\text{O}_2 + P_{\text{A}}\text{CO}_2 + P_{\text{A}}\text{H}_2\text{O} + P_{\text{A}}\text{N}_2$$

# Hyperoxia

- Oxygen toxicity is cellular injury of the lung parenchyma and airway epithelium due to release of cytotoxic, free oxygen radicals.
- Very similar to the ARDS
- FIO<sub>2</sub> 100% ▶ 12h, FIO<sub>2</sub> 80% ▶ 24h, FIO<sub>2</sub> 60% ▶ 36h
- Administration of FIO<sub>2</sub> 0.5 for long term usually does NOT result in toxicity.
- Retrolental Fibroplasia in prematurity (less than 1kg in both weight and 28 weeks gestation )
- Suppress of ventilation
- Convulsion (> 2ATA) ➡ the most acute toxic effect of O<sub>2</sub>

## Oxygenation Using FiO2 and PEEP

$$\text{Desired FiO}_2 = \frac{\text{PaO}_2 \text{ (desired)} \times \text{FiO}_2 \text{ (known)}}{\text{PaO}_2 \text{ (known)}}$$

$$\text{Desired FiO}_2 = \frac{(60 \text{ mm Hg}) (0.50 \text{ FiO}_2)}{40 \text{ mm Hg}}$$

$$\text{Desired FiO}_2 = 0.75$$

# Improving Ventilation / Oxygenation

## ◆ Oxygenation Using FiO<sub>2</sub> and PEEP

### ■ Adjusting FiO<sub>2</sub>

- ◆ Because of the linear correlation between PaO<sub>2</sub> and FiO<sub>2</sub> the following equation can be used to select the desired FiO<sub>2</sub> to achieve a desired PaO<sub>2</sub>:

$$\text{Desired FiO}_2 = \frac{\text{PaO}_2 (\text{desired}) \times \text{FiO}_2 (\text{known})}{\text{PaO}_2 (\text{known})}$$

# Achieving correct PaO<sub>2</sub>

$$\frac{\text{Desired PaO}_2 \times \text{FiO}_2}{\text{Current PaO}_2}$$

**Example:** A patient is currently hypoxic with a PaO<sub>2</sub> Of 60 on an FiO<sub>2</sub> of .45. The physician orders to maintain A PaO<sub>2</sub> of at least 80 mmHg and asks you to adjust the Ventilator accordingly

$$\frac{80 \text{ mmHg} \times .45}{60 \text{ mmHg}} \longrightarrow .60$$

*Increase the FiO<sub>2</sub> to .60 to achieve a PaO<sub>2</sub> Of 80 mmHg*

# Trigger

There are two ways to initiate a ventilator-delivered breath:

## 1. pressure triggering

- initiated if the demand valve senses a negative airway pressure deflection (generated by the patient trying to initiate a breath) greater than the trigger sensitivity.
- A trigger sensitivity of -1 to -3 cm H<sub>2</sub>O is typically set

## 2. flow-by triggering

- initiated when the return flow is less than the delivered flow, a consequence of the patient's effort to initiate a breath
- the trigger sensitivity is usually set at 2 L/min

# Phase Variables

**Trigger** (start)

begins inspiratory flow

**Limit/Control/Target** (continue)

places a maximum value on a “control variable”  
pressure, volume, flow, Time

**Cycling** (end)- ends inspiratory flow

# Triggering

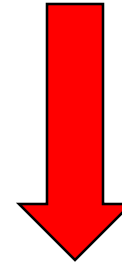
- **Time**: the ventilator cycles at a set frequency as determined by the controlled rate.
- **Pressure**: the ventilator senses the patient's inspiratory effort by way of a decrease in the baseline pressure.
- **Flow**: modern ventilators deliver a constant flow around the circuit throughout the respiratory cycle (flow-by). A deflection in this flow by patient inspiration, is monitored by the ventilator and it delivers a breath. This mechanism requires less work by the patient than pressure triggering.



# Inspiratory Trigger

- Normally set automatically
- 2 modes:
  - Airway pressure
  - Flow triggering

How does the ventilator know when to give a breath? (Trigger)



| A/C                       |   | PC             |  | P-TRIG                                      | 45 kg |
|---------------------------|---|----------------|--|---|-------|
| f                         | P <sub>i</sub>                            | T <sub>i</sub> | P <sub>TRIG</sub>                          | O <sub>2</sub>                              |       |
| 16 $\frac{1}{\text{min}}$ | 20 $\frac{\text{cm}}{\text{H}_2\text{O}}$ | 0.95           | 2.0 $\frac{\text{cm}}{\text{H}_2\text{O}}$ | 40 %  |       |
| $\sqrt{\text{I}}$         |   |                |  | PEEP  |       |
| 50 %                      |   |                |  | 10.0 $\frac{\text{cm}}{\text{H}_2\text{O}}$ |       |

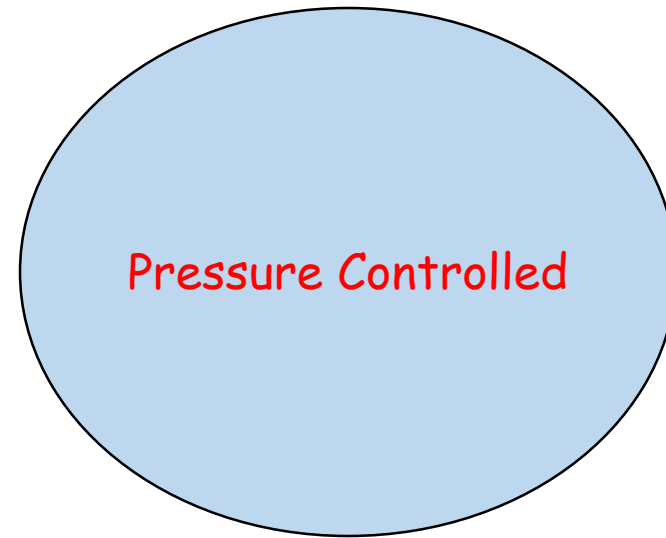
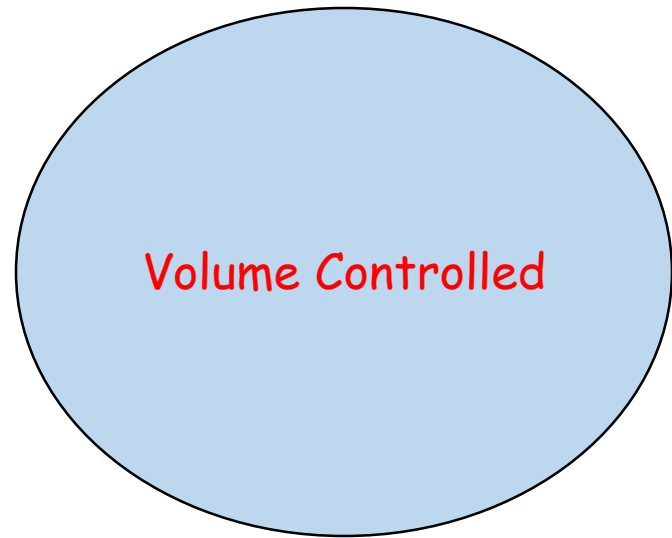
# Control

- **Volume Controlled** (volume limited, volume targeted) and Pressure Variable
- **Pressure Controlled** (pressure limited, pressure targeted) and Volume Variable
- **Dual Controlled** (volume targeted (guaranteed) pressure limited)

# End of Insp...cycle mechanisms

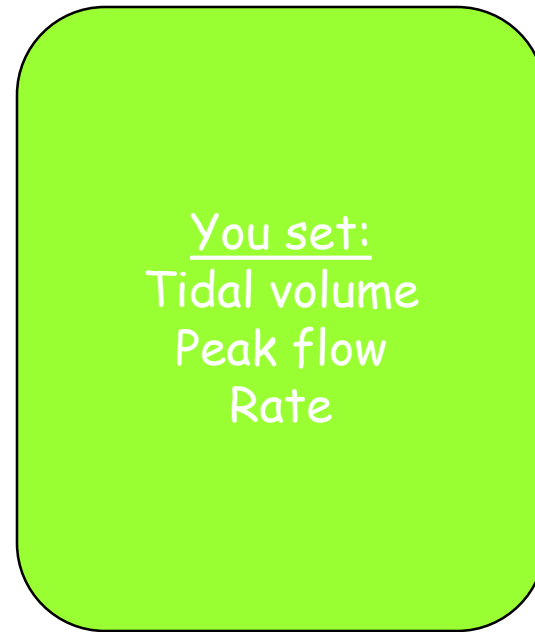
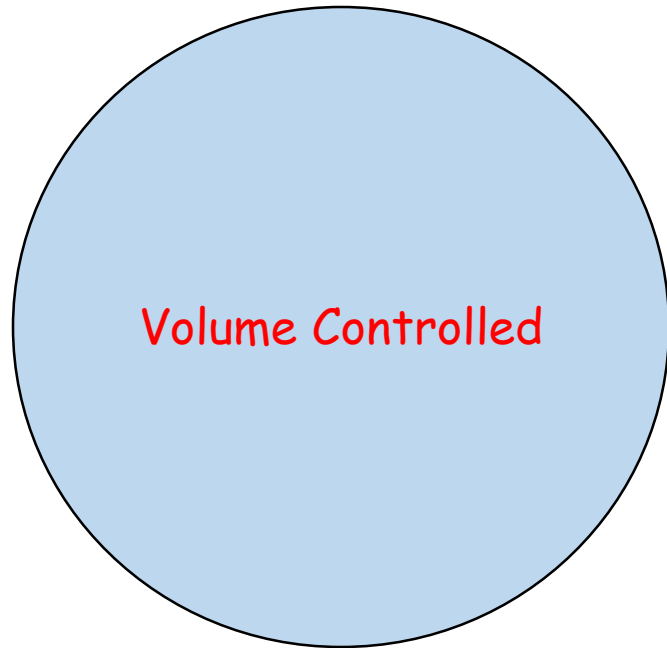
- The phase variable used to terminate inspiration-
  - Volume
  - Pressure
  - Flow
  - Time

There are two ways to give a breath

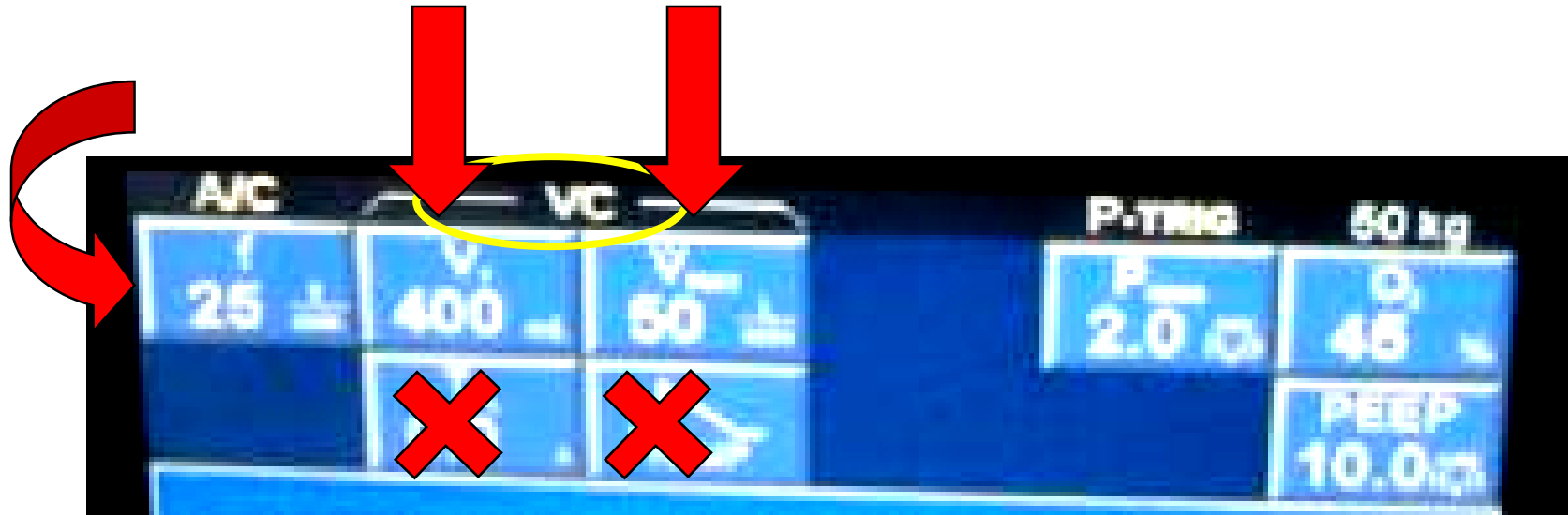


EITHER CAN BE USED WITH A/C OR SIMV!

# What do you set?



# Where are those?



- Tidal volume ( $V_t$ ) – volume to be given with each breath (usually in mL)
  - ?Normal  $V_t$
- Peak flow (VMAX) – rate at which volume is delivered (in L/min)
- Rate - Breaths/minute

# What do you set in PC?

Pressure Controlled

You set:  
Pressure limit  
Time spent in  
inspiration (Itime)  
Rate

You set:  
Pressure limit  
I:E ratio  
Rate

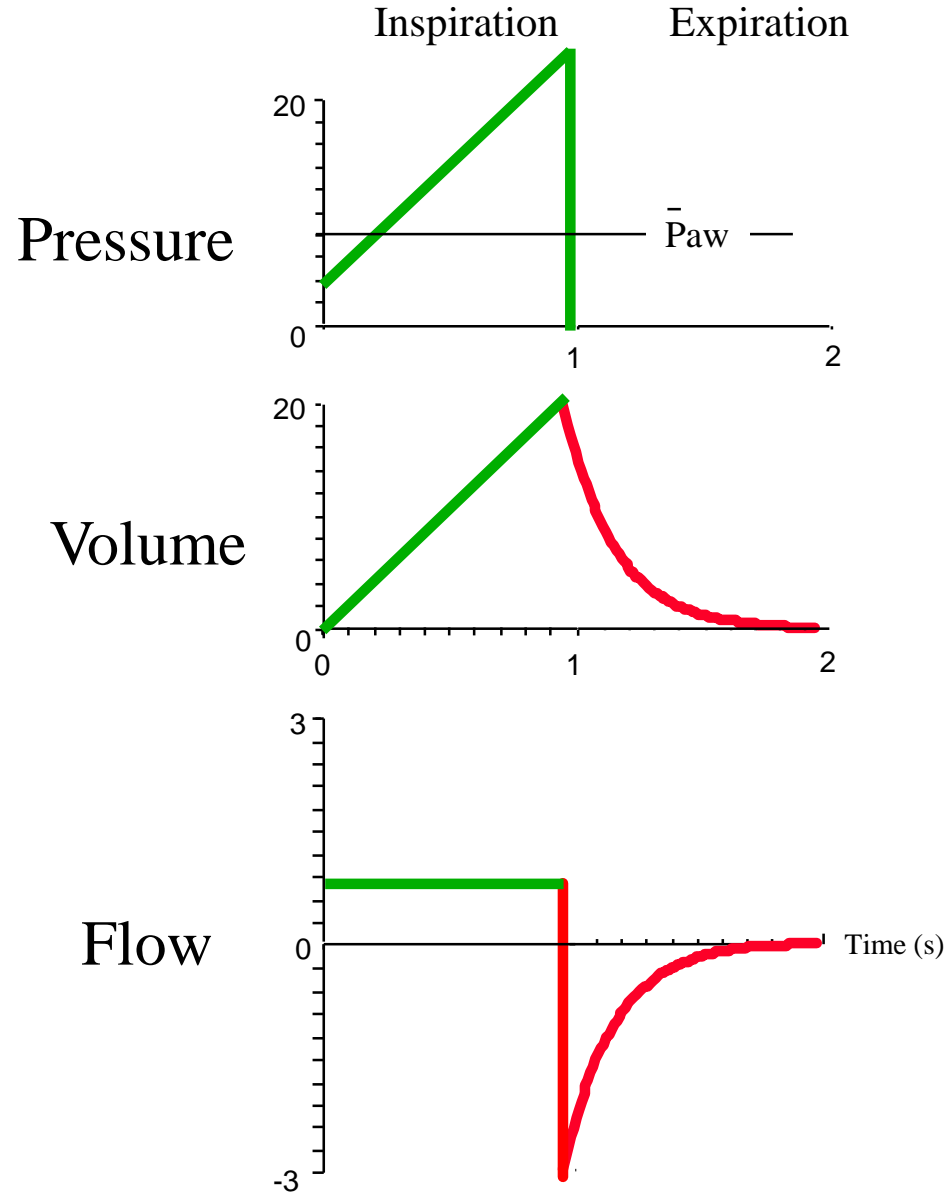


# Where are those?

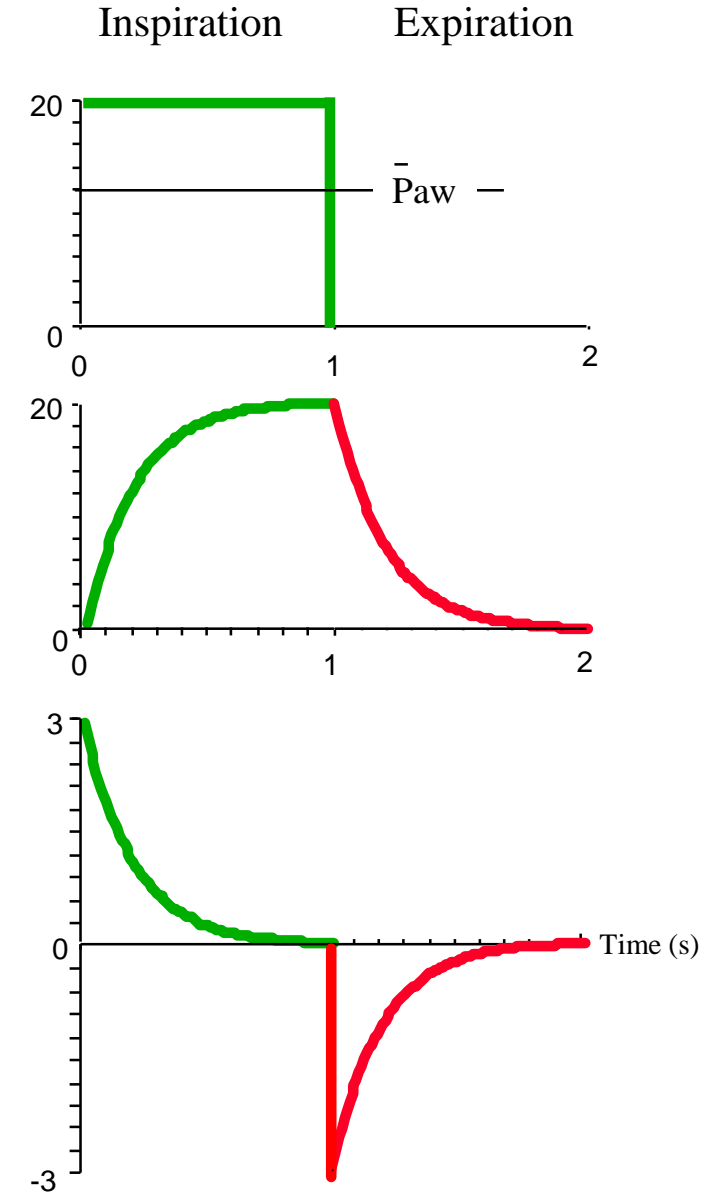


- Pi = Inspiratory pressure above PEEP = (Pressure limit = Pi + PEEP)
  - Ti = time for inspiration
  - Rate – Breaths/minute
    - 16 breaths/minute = 3.75s/breath = 0.95/(3.75 – 0.95) = I:E = 1:2.9
- \*\*Different ventilators do PCV set-up differently\*\***

# Volume/Flow Control



# Pressure Control



## Volume control

## Pressure control

### *Settings*

- TV, inspiratory flow, I:E ratio

- Peak inspiratory pressure, inspiratory time,

### *Constant*

- Tidal volume

- Maximum inspiratory pressure

### *Variable*

- Airway pressure

- Tidal volume

# PEEP

- Positive end-expiratory pressure (PEEP)
  - PEEP reinflates collapsed alveoli and supports and maintains alveolar inflation during exhalation.
    - increases the functional residual capacity
    - useful to treat refractory hypoxemia.
  - The initial PEEP level may be set at 5 cm H<sub>2</sub>O
  - Auto-PEEP is present when the end-expiratory pressure does not return to baseline pressure at the end of expiration.

PEEP



Decreases the pressure threshold for alveolar inflation



Increases FRC



Improves ventilation



- (1) Increases  $V/Q$
- (2) Improves oxygenation
- (3) Decreases work of breathing

- Complications of PEEP

- (1) decreased venous return and cardiac output,
- (2) barotrauma,
- (3) increased intracranial pressure, and
- (4) alterations of renal functions and water metabolism.

# Positive End-expiratory Pressure (PEEP)

What is PEEP?

What is the goal of PEEP?

- Improve oxygenation
- Diminish the work of breathing
- Different potential effects

# Positive end-expiratory pressure

- Alveolar pressure at end-expiration is above atmospheric pressure : PEEP
- Extrinsic PEEP
- Auto PEEP





- Physiologic
- Optimal
- Best
- Best PEEP: Monitor Cardiac Output

Another measure: Venous Oxygen Saturation

If VOS decreases after PEEP applied= Drop CO

Swan-Ganz catheter may be indicated in most patients on PEEP

Internal PEEP

External PEEP

## Positive end-expiratory pressure

- CLINICAL USES:

- Reduce toxic levels of FiO<sub>2</sub> (ARDS not pneumonia)
- Low-volume ventilation
- Obstructive lung disease (Extrinsic=Occult PEEP)

### CLINICAL MISUSES:

- Reducing Lung Edema
- Routine PEEP
- Mediastinal Bleeding after CABG

# PEEP



- What are the secondary effects of PEEP?
  - Barotrauma
  - Diminish cardiac output
  - Regional hypoperfusion
  - NaCl retention
  - Augmentation of I.C.P.?
  - Paradoxal hypoxemia

# PEEP



- Contraindication:
  - No absolute CI
  - Barotrauma
  - Airway trauma
  - Hemodynamic instability
  - I.C.P.?
  - Bronchospasm?

# Auto-PEEP or Intrinsic PEEP

- What is Auto-PEEP?
  - Normally, at end expiration, the lung volume is equal to the FRC
  - When PEEPi occurs, the lung volume at end expiration is greater than the FRC

# Auto-PEEP or Intrinsic PEEP

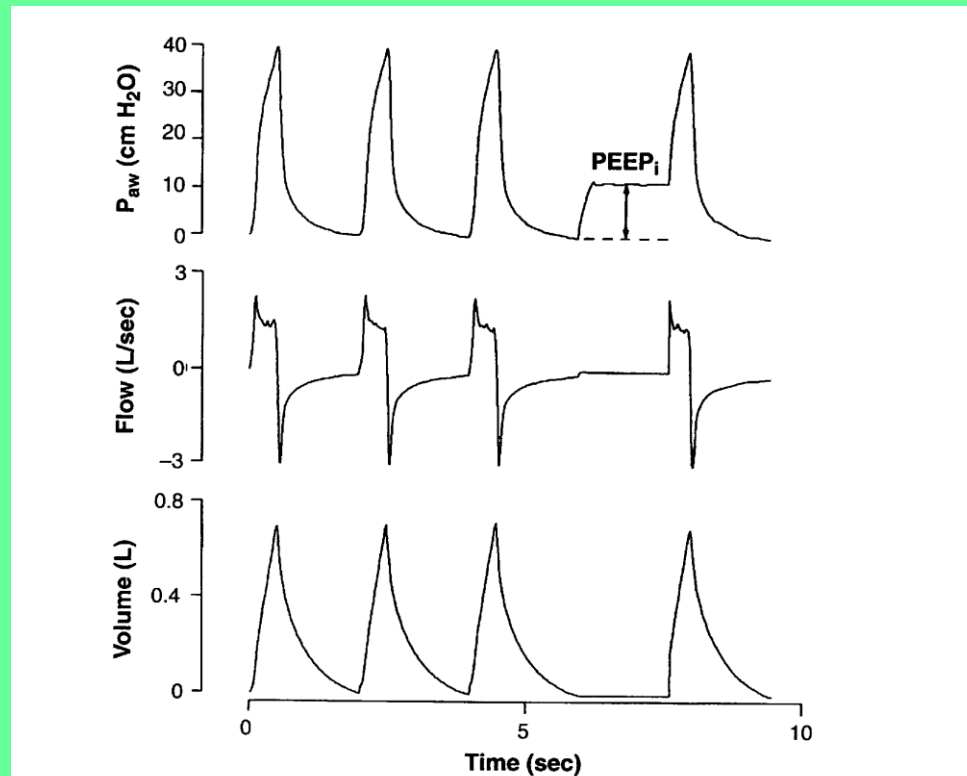
- Why does hyperinflation occur?
  - Airflow limitation because of dynamic collapse
  - No time to expire all the lung volume (high RR or Vt)
  - Expiratory muscle activity
  - Lesions that increase expiratory resistance

## Occult PEEP

- Intrinsic or Auto-PEEP or Hyperinflation
- Incomplete alveolar emptying during expiration
- Ventilator Factors: High inflation volumes, rapid rate, low exhalation time
- Disease factors: Asthma, COPD
- Consequences: Decreased CO/EMD, Alveolar rupture, Underestimation of thoracic compliance, increased work of breathing.
- If extrinsic PEEP does not increase  $P_k$ , then occult PEEP is present

# Auto-PEEP or Intrinsic PEEP

- Auto-PEEP is measured in a relaxed pt with an end-expiratory hold maneuver on a mechanical ventilator immediately before the onset of the next breath

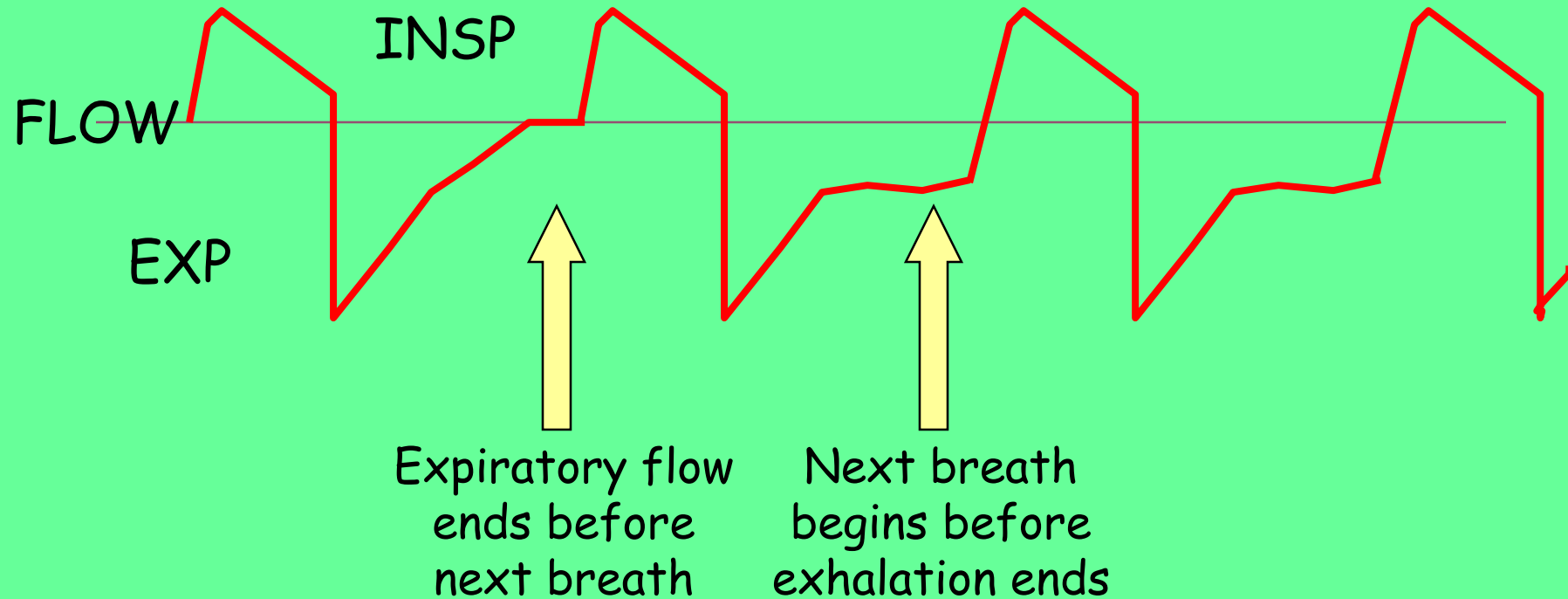




# Auto-PEEP or Intrinsic PEEP

- Adverse effects:
  - Predisposes to barotrauma
  - Predisposes hemodynamic compromises
  - Diminishes the efficiency of the force generated by respiratory muscles
  - Augments the work of breathing
  - Augments the effort to trigger the ventilator

# What is "Auto-Peep"?

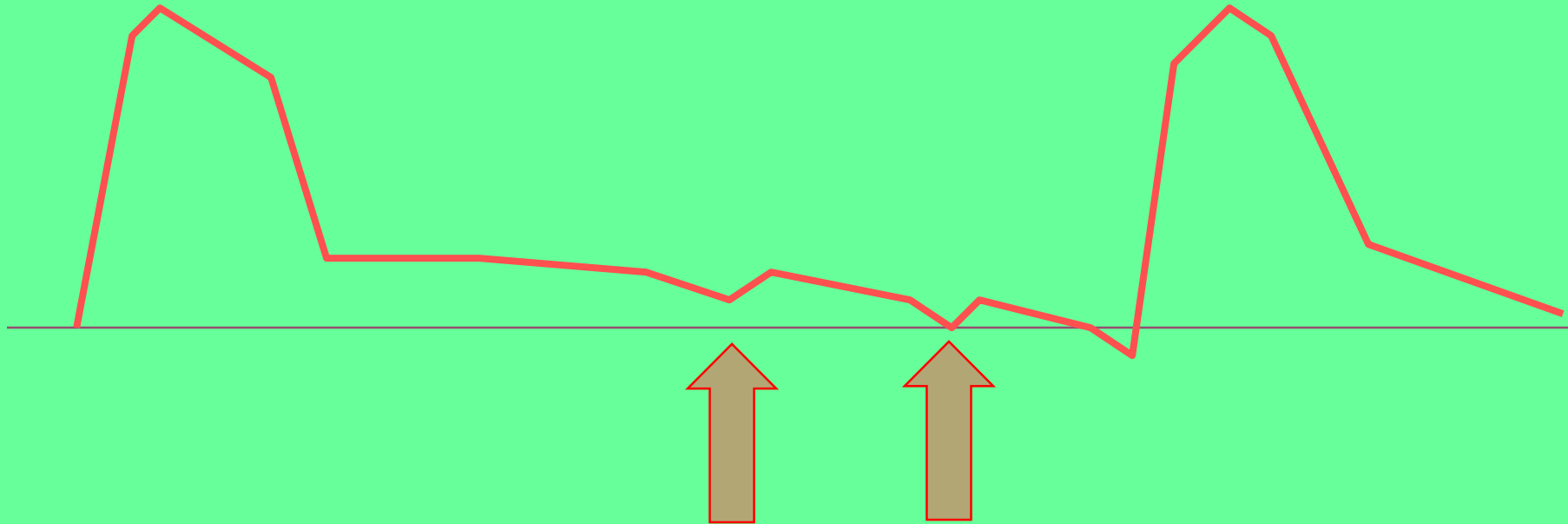


Obstructive lung disease (pursed lip)  
Rapid breathing (breath stacking)  
Forced exhalation (anxiety)

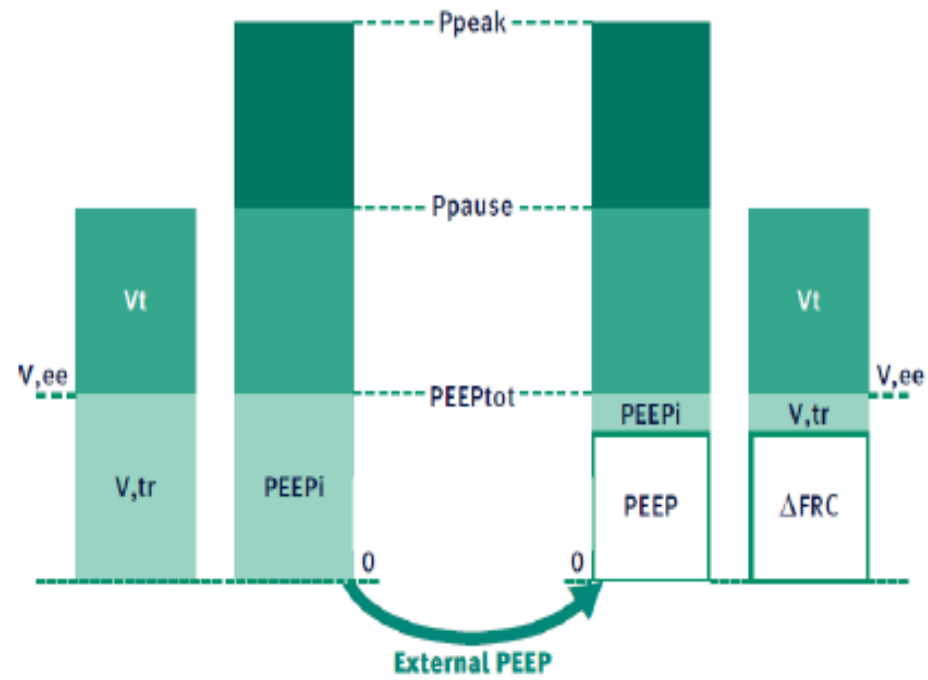
# What is "Auto-Peep"?



## Another clue to Auto-PEEP



Failed Inspiratory Efforts



A COPD patient with dynamic hyperinflation and air-trapping due to bronchial collapse: Effects of external PEEP on ventilation pressures and lung volumes.

# Flow rate

- The peak flow rate is the maximum flow delivered by the ventilator during inspiration.
- The inspiratory flow needs to be sufficient to overcome pulmonary and ventilator impedance otherwise the work of breathing is increased.
- Peak flow rates of 60 L per minute may be sufficient,
- higher rates are frequently necessary in patients with bronchoconstriction.

- An insufficient peak flow rate is characterized by
  - dyspnea,
  - spuriously low peak inspiratory pressures,
  - scalloping of the inspiratory pressure tracing

# I:E Ratio

- The I:E ratio is the ratio of inspiratory time to expiratory time.
- It is usually kept in the range between 1:2 and 1:4
- A larger I:E ratio
  - possibility of air trapping
  - auto-PEEP
- Inverse I:E ratio
  - correct refractory hypoxemia in ARDS patients



- I:E ratio may be altered by manipulating any one or a combination of the following controls:
  - (1) flow rate,
  - (2) inspiratory time,
  - (3) inspiratory time %,
  - (4) frequency, and
  - (5) minute volume (tidal volume and frequency).

**TABLE 8-9** Effects of Flow Rate Change on I Time, E Time, and I:E Ratio

| Parameter Change   | I Time   | E Time   | I:E Ratio |
|--------------------|----------|----------|-----------|
| Increase flow rate | Decrease | Increase | Increase  |
| Decrease flow rate | Increase | Decrease | Decrease  |

**TABLE 8-10** Effects of  $V_T$  Change on I Time, E Time, and I:E Ratio

| Parameter Change      | I Time   | E Time   | I:E Ratio |
|-----------------------|----------|----------|-----------|
| Increase tidal volume | Increase | Decrease | Decrease  |
| Decrease tidal volume | Decrease | Increase | Increase  |

**TABLE 8-11** Effects of Frequency Change on I Time, E Time, and I:E Ratio

| Parameter Change | I Time         | E Time   | I:E Ratio |
|------------------|----------------|----------|-----------|
| Increase $f$     | Minimal change | Decrease | Decrease  |
| Decrease $f$     | Minimal change | Increase | Increase  |

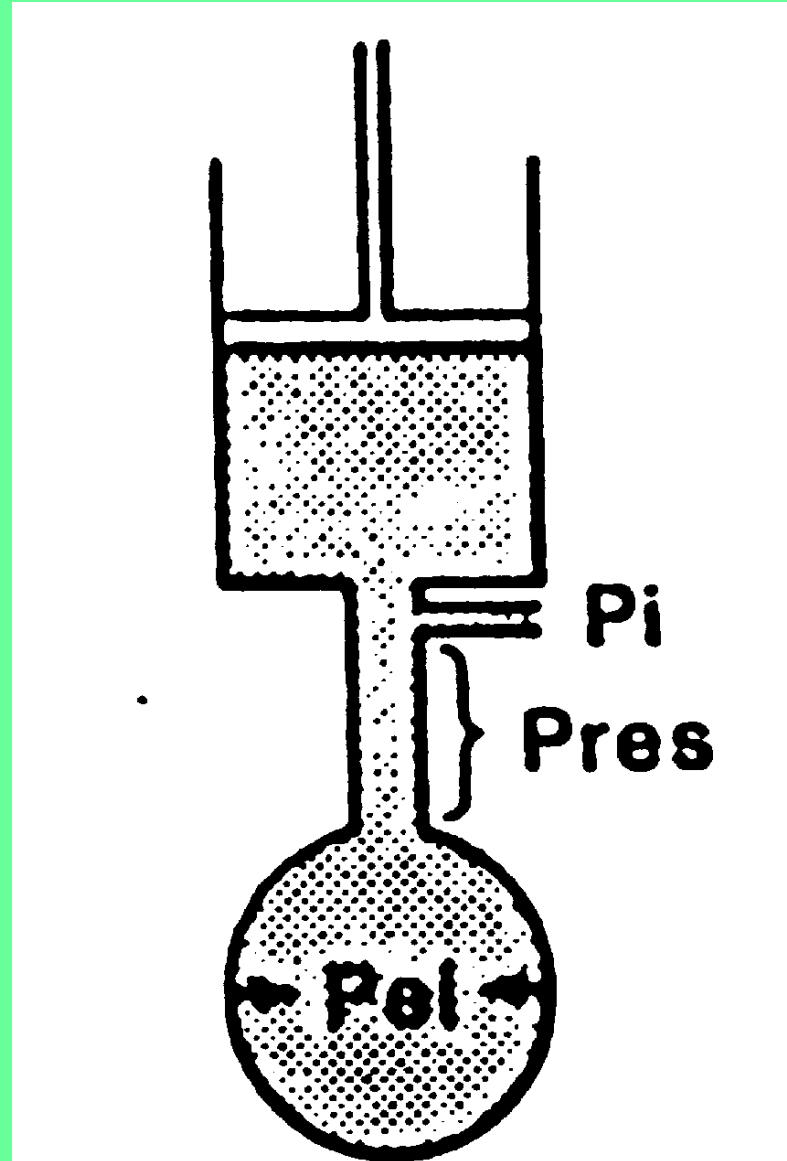
# CPAP

- Definition
  - Continuous positive airway pressure
  - Application of constant positive pressure throughout the spontaneous ventilatory cycle
- No mechanical inspiratory assistance is provided
  - Requires active spontaneous respiratory drive
- Same physiologic effects as PEEP

Monitoring of the patient

Monitoring of the patient

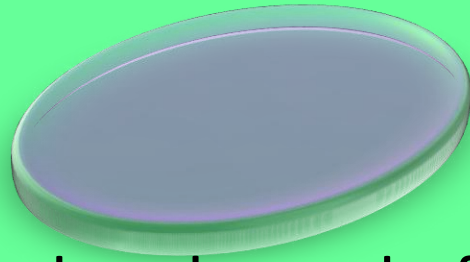
# Pressures



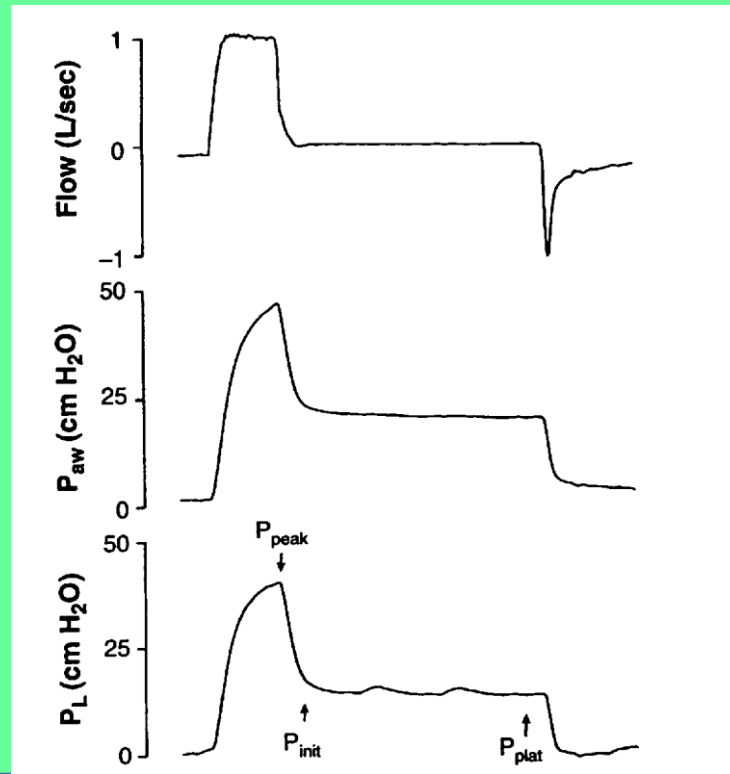
# Peak Pressure ( $P_{peak}$ )

- $P_{peak} = P_{plat} + P_{res}$

Where  $P_{res}$  reflects the resistive element of the respiratory system (ET tube and airway)



- Pressure measured at the end of inspiration
- Should not exceed 50cmH<sub>2</sub>O?





# Compliance pressure ( $P_{plat}$ )

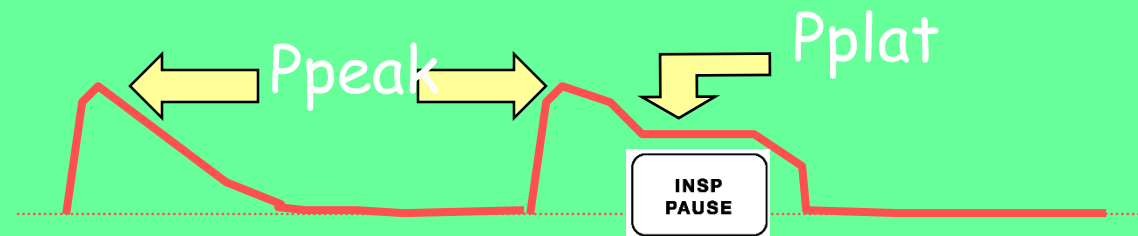
- Represent the static end inspiratory recoil pressure of the respiratory system, lung and chest wall respectively
- Measures the static compliance or elastance
- End inspiratory hold, important in lung protective strategy

# Plateau Airway Pressure

- Normally  $P_{plat} = P_{peak} - 5\text{ to }10\text{ mmHg}$ 
  - In what situations isn't that the case?
- Why are we more interested clinically in  $P_{plat}$ ?

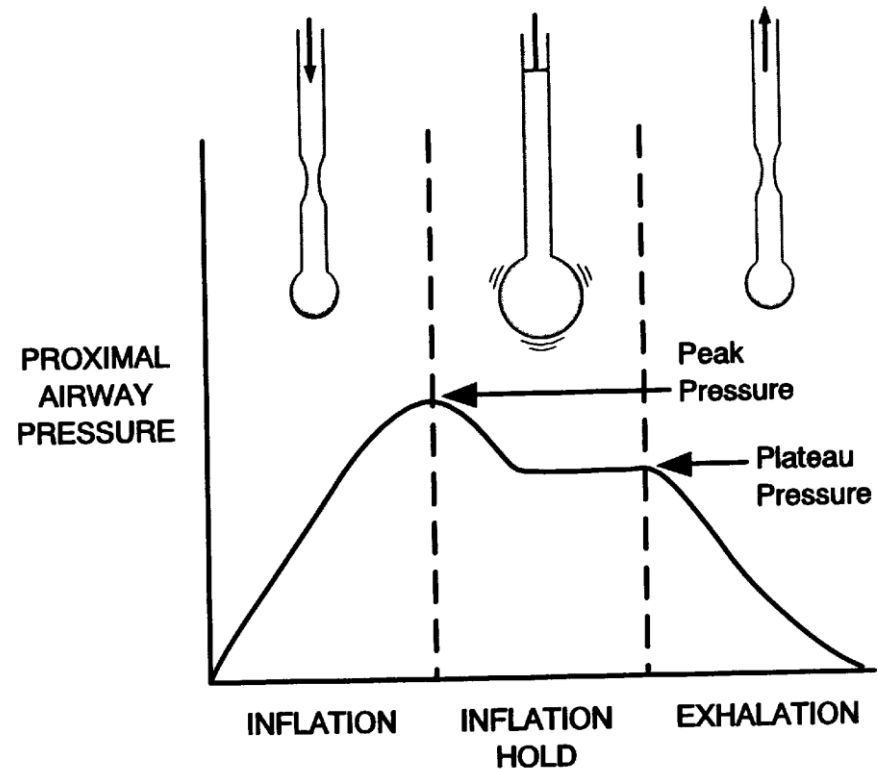
**INSP  
PAUSE**

Puts a pause in the  
inspiratory cycle -  
no flow - measures  
pressure



# Pplat

- Measured by occluding the ventilator 3-5 sec at the end of inspiration
- Should not exceed 30 cmH<sub>2</sub>O



# T plat

The time that lung is in inspiratory hold at end inspiration.

T plat > 0.5 seconds improves oxygenation, but it may require patient sedation and leads to hemodynamic instability( because of longer duration of T insp)

# Monitoring Lung Mechanics

## Proximal Airway Pressures (end-inspiratory)

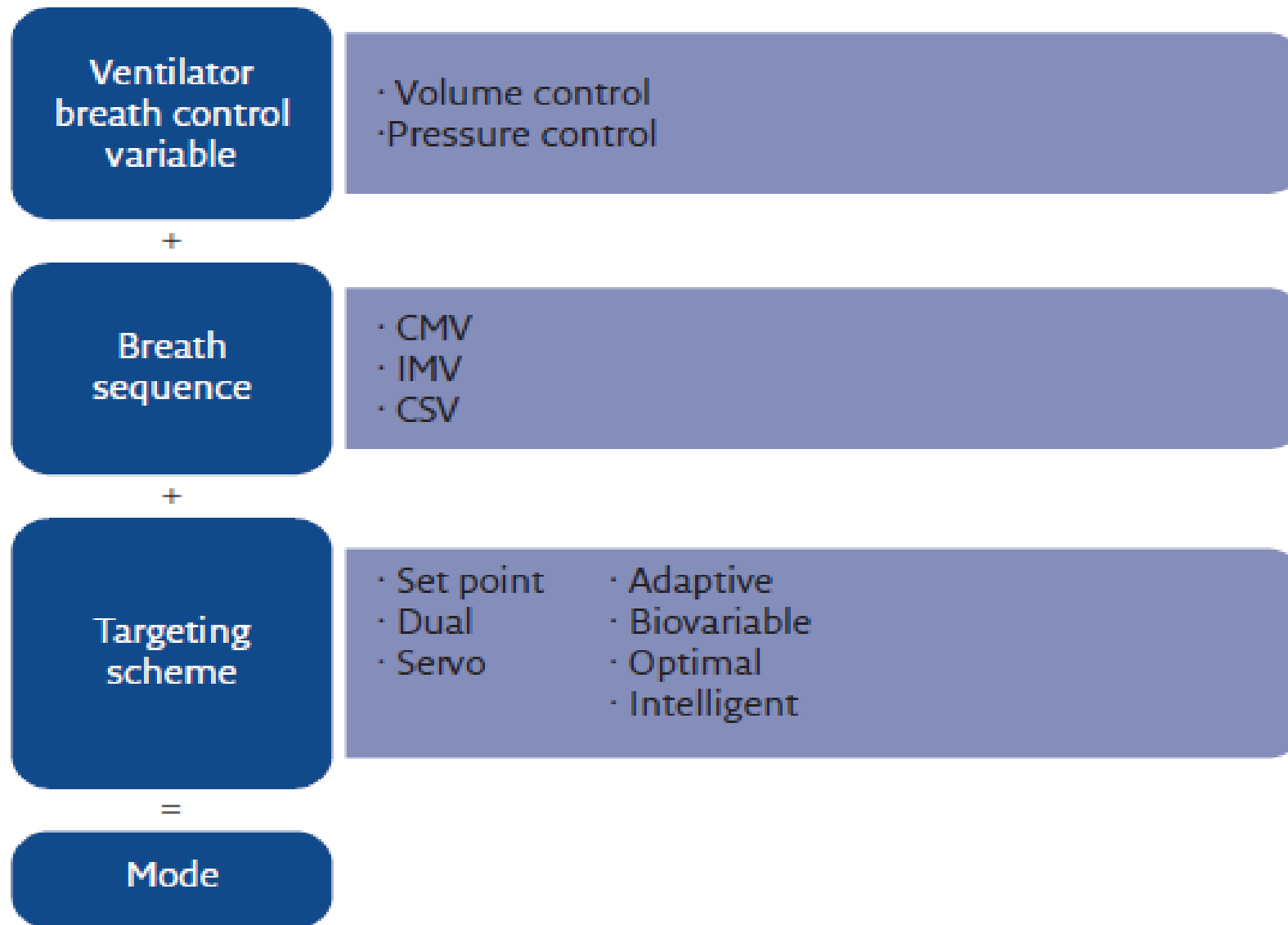
### 1. Peak Pressure $P_k$

Function of: Inflation volume, recoil force of lungs and chest wall, airway resistance

### 2. Plateau Pressure $P_l$

Occlude expiratory tubing at end-inspiration

Function of elastance alone



**Figure 5** Construction of the ventilation mode taxonomy suggested by Chatburn. The name of a ventilation mode results from three elements. CMV: continuous mandatory ventilation; IMV: intermittent mandatory ventilation; CSV: continuous spontaneous ventilation. Reproduced and modified from [31] with permission from the publisher.

# Use of Airway Pressures

## **Pk increased PI unchanged**

Tracheal tube obstruction

Airway obstruction from secretions

Acute bronchospasm

Rx: Suctioning and Bronchodilators

# Use of Airway Pressures

## **Pk and PI are both increased**

Pneumothorax

Lobar atelectasis

Acute pulmonary edema

Worsening pneumonia

ARDS

COPD with tachypnea and Auto-PEEP

Increased abdominal pressure

Asynchronous breathing



# Use of Airway Pressures

## Decreased Pk

System air leak: Tubing disconnection, cuff leak

Rx: Manual inflation, listen for leak

Hyperventilation: Enough negative intrathoracic pressure to pull air into lungs may drop Pk.

# Compliance

Lung Compliance, Chest Wall Compliance  
Total Compliance

$$C_T \text{ (L/cm H}_2\text{O)} = \Delta V \text{ (L)} / \Delta P \text{ (cm H}_2\text{O)} \quad (1)$$

The  $C_T$  of lung plus chest wall is related to the individual compliance of the lungs ( $C_L$ ) and chest wall ( $C_{CW}$ ) according to the following expression:

$$\begin{aligned} 1/C_T &= 1/C_L + 1/C_{CW} \\ \text{[or } C_T &= (C_L)(C_{CW}) / C_L + C_{CW}] \end{aligned} \quad (2)$$

# Compliance

## **Static Compliance (Cstat)**

Distensibility of Lungs and Chest wall

$$\underline{C_{stat} = V_t/P_l}$$

Normal C stat: 50-80 ml/cm of water

Provides objective measure of severity of illness in a pulmonary disorder

## **Dynamic Compliance**

$$\underline{C_{dyn}: V_t/P_k}$$

\*Subtract PEEP from  $P_l$  or  $P_k$  for compliance measurement

Use Exhaled tidal volume for calculations

- To determine

$C_l$ :  $dV$ , transpulmonary pressure gradient ( $P_A - P_{pl}$ )

$C_{cw}$ :  $dV$ , transmural pressure gradient ( $P_{pl} - P_{ambient}$ )

$C_t$ :  $dV$ , transthoracic pressure gradient ( $P_A - P_{ambient}$ ),  
which can be done dynamically or statically.

The peak transthoracic pressure value is due to the pressure required to overcome both elastic and airway resistance.

Plateau pressure is due to pressure required to gas distribution from stiff to more compliant alveoli (so it is less than peak pressure)

Static compliance

$$V_t / P_{\text{plat-PEEP}}$$

Dynamic compliance

$$V_t / P_{\text{peak-PEEP}}$$

Therefore C static is greater than C dynamic

# Resistance

## Airway Resistance

For air to flow into the lungs,  $\Delta P$  (pressure gradient) must also be developed to overcome the nonelastic airway resistance of the lungs to airflow. The relationship between  $\Delta P$  and the rate of airflow ( $\dot{V}$ ) is known as airway resistance (R):

$$R \text{ (cm H}_2\text{O / L / sec)} = \frac{\Delta P \text{ (cm H}_2\text{O)}}{\Delta \dot{V} \text{ (L / sec)}} \quad (4)$$

# Flow Patterns

- Laminar: with flow less than critical velocity
- Turbulant: with flow more than critical velocity
- Orifice :at severe constriction such as a nearly closed larynx or a kinked endotracheal tube



# Types of flow

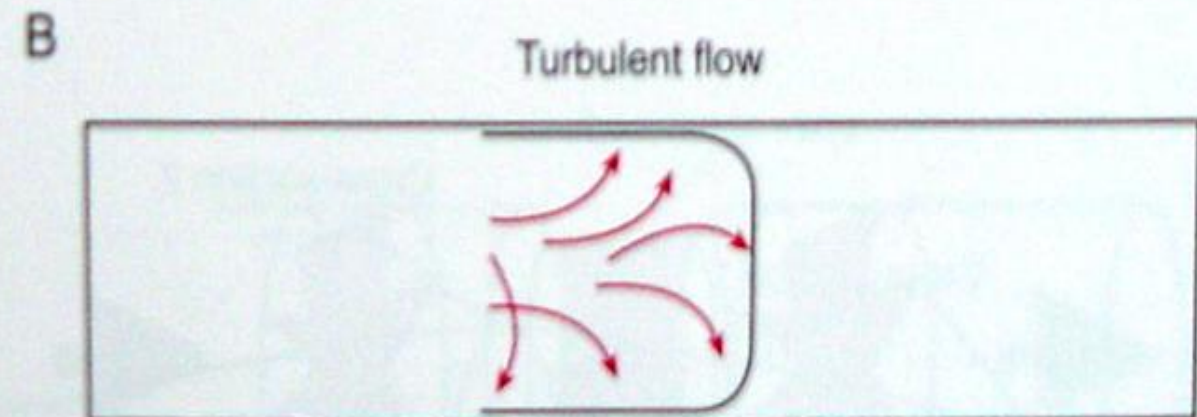
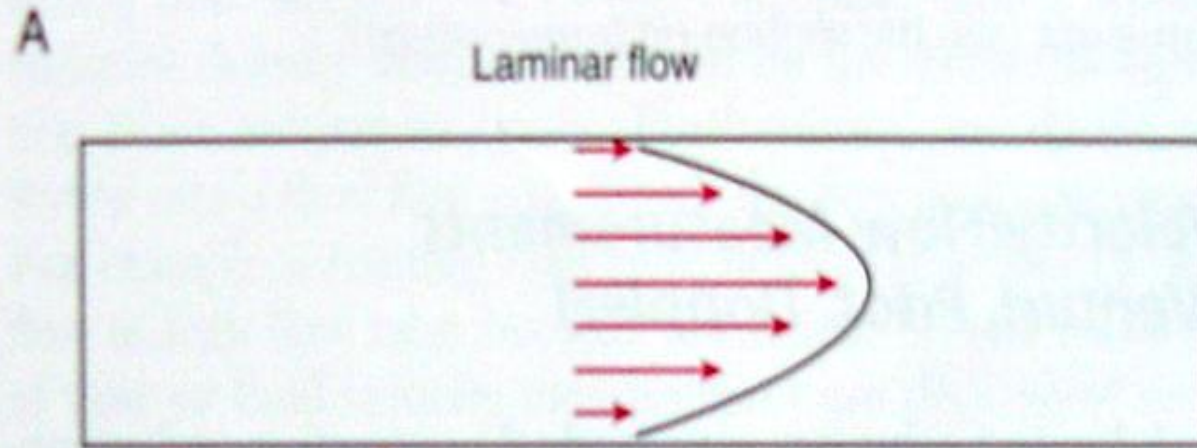
1-Laminar

$$Q = \frac{\pi r^4 \Delta p}{8 \eta l}$$

Hagen-poiseuille

2-Turbulent

$$Q^2 = \frac{4 \pi^2 r^5 \Delta p}{\rho f l}$$



# Mode

- Volume-Controlled Ventilation
  - set volume delivered with each breath
  - volume delivery fixed, pressure will vary, depending upon pulmonary compliance and airway resistance.
  - The advantage of volume control is the ability to regulate both tidal volume and minute ventilation (tidal volume x BUR)

- **Pressure-Controlled Ventilation**

- peak inspiratory pressure for each mechanical breath.
- pressure remains constant, volume and minute ventilation will vary with changes in the patient's pulmonary compliance or airway resistance
- The advantage of the pressure-controlled mode is that the lungs can be protected from excessive pressures, preventing ventilator-induced lung injury (VILI)

- Dual control mode
  - is a combined mode between two control variables
  - When VCV and PCV are combined, the patient receives **mandatory breaths that are volume-targeted, pressure-limited, and time-cycled**

# Pressure Support

- used to augment a patient's breathing effort by **reducing the airflow resistance during spontaneous breathing** (the artificial airway, ventilator circuit, and secretions)
- Pressure support is available in modes of ventilation that allows spontaneous breathing (e.g., SIMV, PSV).
- PS level must be adjusted on an as-needed basis depending on the changing conditions that alter the PIP and Pplat

# CONTROLLED MANDATORY VENTILATION (CMV)

- continuous mandatory ventilation or **control mode**, the ventilator delivers the preset tidal volume at a time-triggered frequency

**TABLE 4-2** Characteristics of the Control Mode

| Characteristic       | Description   |
|----------------------|---|
| Type of breath       | Each breath delivers a mechanical tidal volume.                                     |
| Triggering mechanism | Every breath in the control mode is time-triggered.                                 |
| Cycling mechanism    | Inspiration is terminated by the delivery of a preset tidal volume (volume-cycled). |

© Cengage Learning 2014

dr.shumayy@islam@gmail.co

29

- Indications for Control Mode
  - (1) tetanus or other seizure activities that interrupt the delivery of mechanical ventilation
  - (2) complete rest for the patient typically for a period of 24 hours
  - (3) patients with a crushed chest injury in which spontaneous inspiratory efforts produce significant paradoxical chest wall movement

- **Complication of CMV**

- In a sedated or apneic patient, potential for apnea and hypoxia if the patient should become disconnected from the ventilator or the ventilator should fail to operate.
- rapid disuse atrophy of diaphragm fibers
- prolonged mechanical ventilation leads to diaphragmatic oxidative injury, elevated proteolysis, and reduced function of the diaphragm

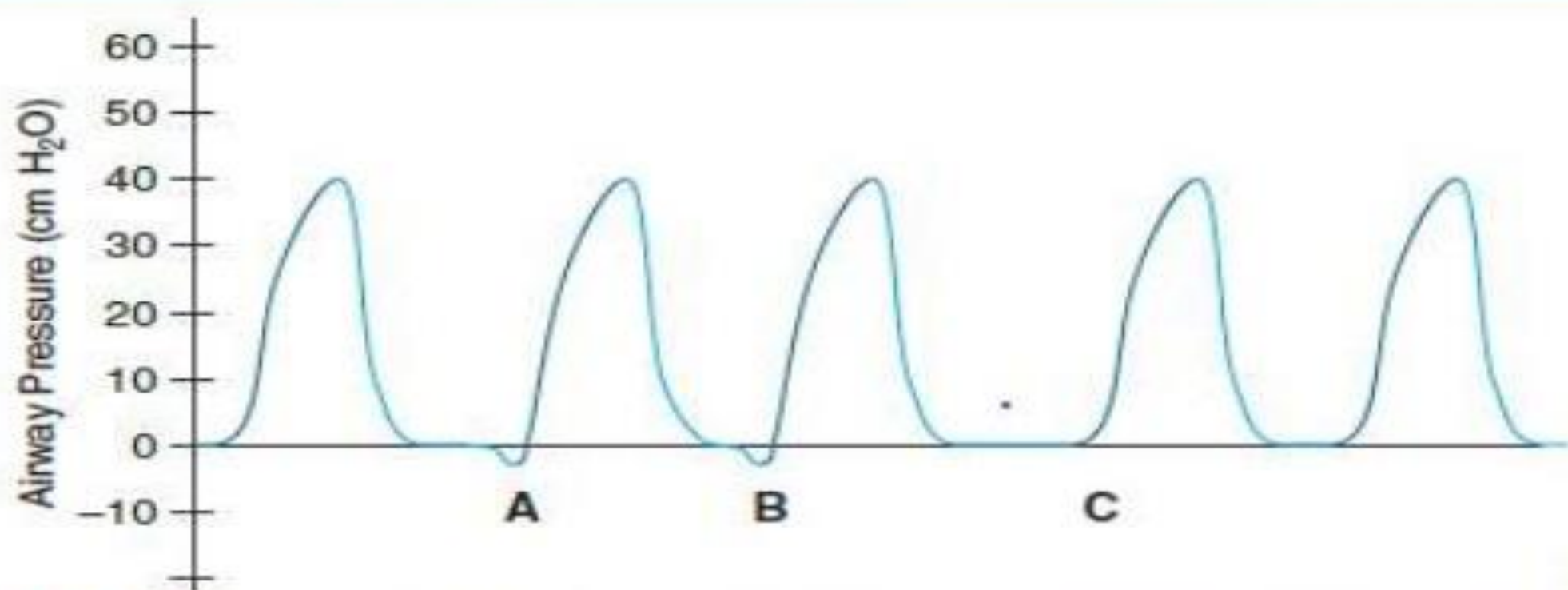


# How to set (Inputs)

- Mode: CMV
- TV: 360ml
  - Given weight: 60kg
- BUR: 16 breaths/ min
- Minute ventilation:  $TV \times BUR$
- Peak flow: 60
- FiO<sub>2</sub>: 100% initially

# ASSIST/CONTROL (AC)

- The mandatory mechanical breaths may be either patient-triggered by the patient's spontaneous inspiratory efforts (assist) or time-triggered by a preset frequency
- Inspiration in the AC mode is terminated by volume cycling. When the preset tidal volume is delivered, the ventilator is cycled to expiration.
- provide full ventilatory support for patients when they are first placed on mechanical ventilation



© Cengage Learning 2014

**FIGURE 4-5** Assist/control mode pressure tracing. Each assisted or controlled breath triggers a mechanical tidal volume. (A) An assisted breath; note the negative deflection at the beginning of inspiration. (B) Another assisted breath that is initiated by the patient sooner than (A). (C) A controlled breath; note the absence of a negative deflection at the beginning of inspiration.

## Indications for AC Mode

- patients with stable respiratory drive and can therefore trigger the ventilator into inspiration.

## Advantages of AC Mode

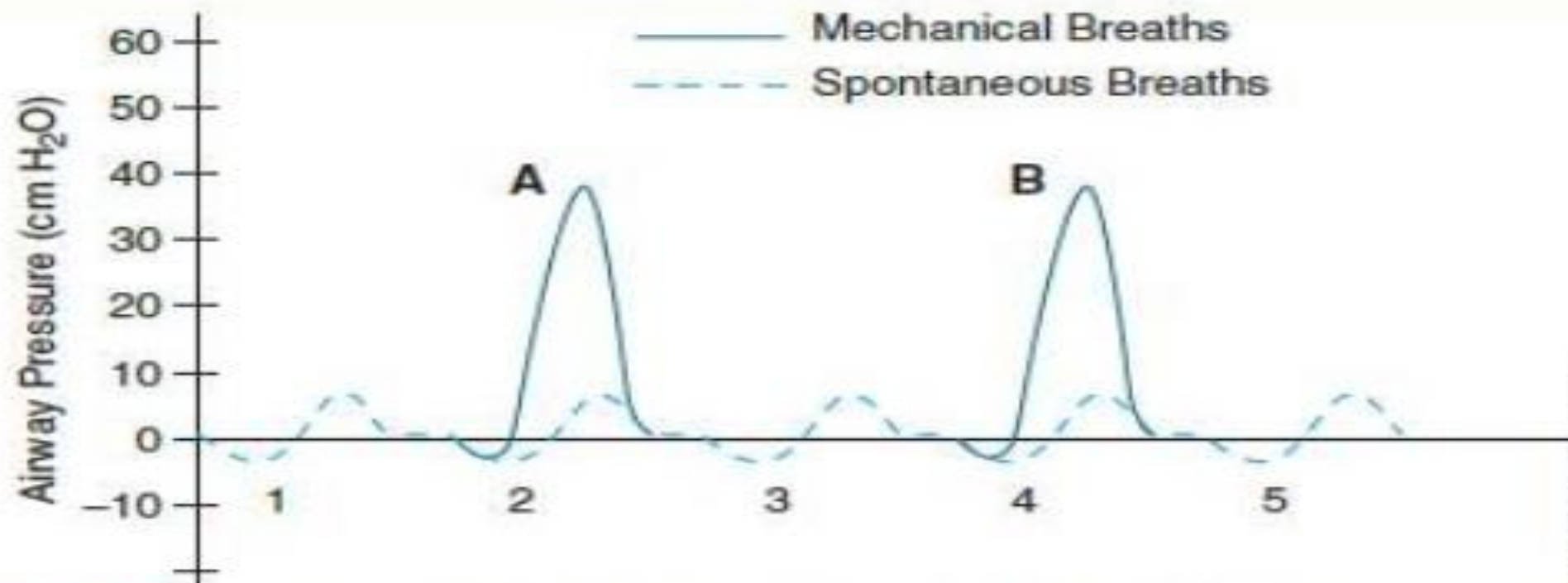
- patient's work of breathing requirement is very small
- allows the patient to control the frequency and therefore the minute volume required to normalize the patient's PaCO<sub>2</sub>

## Complications of AC Mode

- alveolar hyperventilation (respiratory alkalosis).

# SYNCHRONIZED INTERMITTENT MANDATORY VENTILATION (SIMV)

- ventilator delivers either assisted breaths to the patient at the beginning of a spontaneous breath or time-triggered mandatory breaths
- mandatory breaths are synchronized with the patient's spontaneous breathing efforts so as to avoid breath stacking
- Spontaneous frequency and tidal volume taken by the patient in the SIMV mode are totally dependent on the patient's breathing effort.



© Cengage Learning 2014

**FIGURE 4-7** Synchronized intermittent mandatory ventilation (SIMV) pressure tracing with two mandatory breaths and five anticipated spontaneous breaths (only three active). SIMV mode does not cause breath stacking since the mandatory breaths are delivered slightly sooner or later than the preset time interval but within a time window. Mandatory breaths (A) and (B) occur during a spontaneous inspiratory effort. The anticipated spontaneous breaths #2 and #4 did not occur as they turned into mechanical breaths during the mandatory cycle.

## Indications for SIMV Mode

- The primary indication for SIMV is to provide partial ventilatory support to the patient.

## Advantages of SIMV Mode

- (1) maintains respiratory muscle strength/avoids muscle atrophy,
- (2) reduces ventilation to perfusion mismatch,
- (3) decreases mean airway pressure, and
- (4) facilitates weaning.

## Complications of SIMV Mode

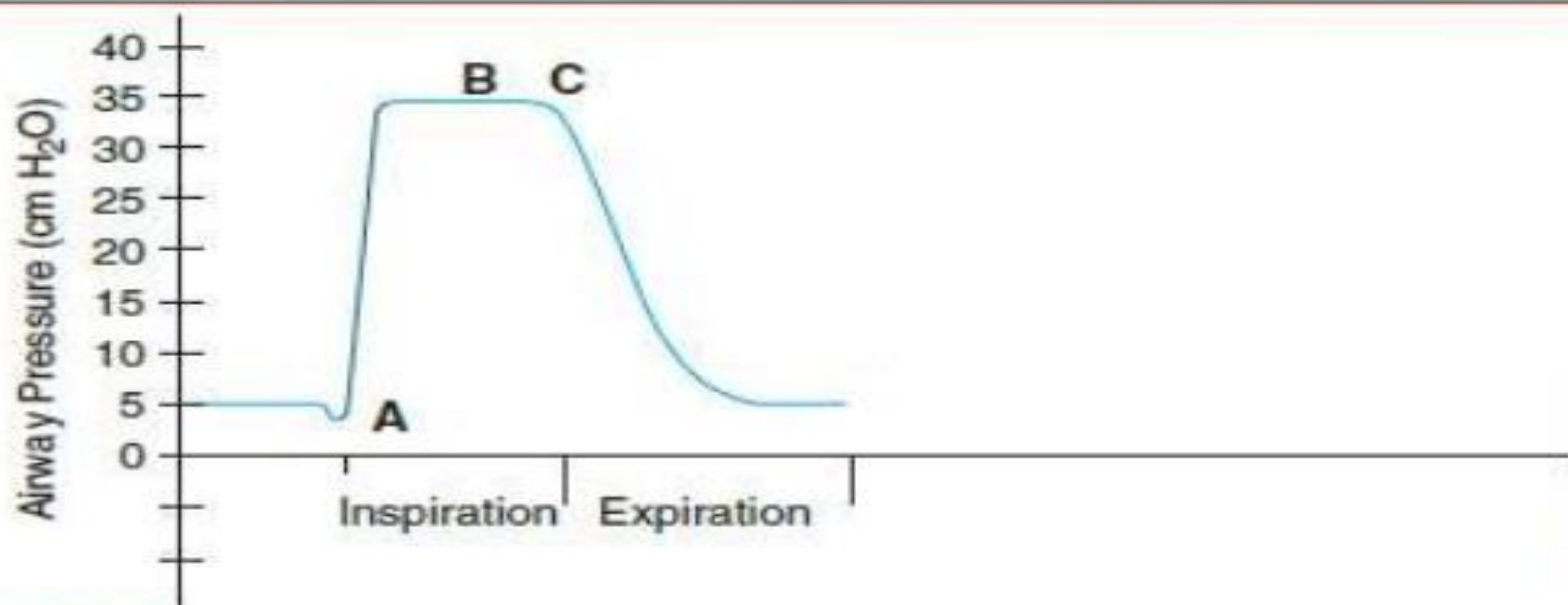
- The desire to wean the patient too rapidly, leading first to a high work of spontaneous breathing and ultimately to muscle fatigue and weaning failure



# PRESSURE SUPPORT VENTILATION (PSV)

- lower the work of spontaneous breathing and augment a patient's spontaneous tidal volume
- patient-triggered, pressure-limited, and flow-cycled.
- PSV + SIMV, significantly lowers the oxygen consumption requirement presumably due to the reduced work of breathing
  - (1) increases the patient's spontaneous tidal volume,
  - (2) decreases the patient's spontaneous frequency

- Pressure-supported breaths are considered spontaneous because
  - (1) they are patient-triggered,
  - (2) the tidal volume varies with the patient's inspiratory flow demand,
  - (3) inspiration lasts only for as long as the patient actively inspires, and
  - (4) inspiration is terminated when the patient's inspiratory flow demand decreases to a preset minimal value.



© Cengage Learning 2014

**FIGURE 4-8** Pressure support ventilation (PSV) with PEEP of 5 cm H<sub>2</sub>O. (A) Inspiratory effort; (B) Pressure support plateau of 30 cm H<sub>2</sub>O (peak inspiratory pressure of 35 cm H<sub>2</sub>O, PEEP of 5 cm H<sub>2</sub>O); (C) Beginning expiratory phase when the inspiratory flow drops to 25% (or other predetermined %) of its peak flow.

## **Indication for PSV**

- weaning from mechanical ventilation

## **Disadvantages**

- Each breath must be initiated by the patient. Central apnea may occur if the respiratory drive is depressed due to sedatives, critical illness, or hypocapnia due to excessive ventilation
- PSV is associated with poorer sleep than AC
- Relatively high levels of pressure support (>20 cm H<sub>2</sub>O) are required to prevent alveolar collapse (which can lead to cyclic atelectasis and ventilator-associated lung injury)

# CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)

- delivery of a continuous level of positive airway pressure.
- It is functionally similar to PEEP.
- The ventilator does not cycle during CPAP, no additional pressure above the level of CPAP is provided, and patients must initiate all breaths.
- most commonly used in the management of
  - sleep related breathing disorders,
  - cardiogenic pulmonary edema, and
  - obesity hypoventilation syndrome
- CPAP may be given via a face mask, nasal mask, or endotracheal tube.

# Summary

## Modes of mechanical ventilation

| Mode              | Breath strategy (target)            | Trigger    |         | Cycle (breath termination) | Types of breaths |          |             |
|-------------------|-------------------------------------|------------|---------|----------------------------|------------------|----------|-------------|
|                   |                                     | Ventilator | Patient |                            | Mandatory        | Assisted | Spontaneous |
| CMV               | Volume-limited                      | Yes        | No      | Volume                     | Yes              | No       | No          |
|                   | Pressure-limited                    | Yes        | No      | Time                       | Yes              | No       | No          |
| AC                | Volume-limited                      | Yes        | Yes     | Volume                     | Yes              | Yes      | No          |
|                   | Pressure-limited                    | Yes        | Yes     | Time                       | Yes              | Yes      | No          |
| IMV               | Volume-limited                      | Yes        | Yes     | Volume                     | Yes              | Yes*     | Yes*        |
|                   | Pressure-limited (also called APRV) | Yes        | Yes     | Time                       | Yes              | Yes*     | Yes*        |
| PSV               | Pressure-limited                    | No         | Yes     | Flow, pressure, or time    | No               | Yes      | No          |
| CPAP              |                                     | No         | No      | Flow                       | No               | No       | Yes         |
| Tube compensation |                                     | No         | Yes     | Flow                       | No               | No       | Yes         |













