

# **MECHANICAL VENTILATION**

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# Introduction

- In order to survive we have to be able to extract oxygen from the atmosphere and transport it to cells where it is utilized for essential metabolic processes.

# Negative Pressure

- When you breathe in, your diaphragm contracts (tightens) and moves downward. This increases the space in your chest cavity, into which your lungs expand. The intercostal muscles between your ribs also help enlarge the chest cavity. They contract to pull your rib cage both upward and outward. This creates a **NEGATIVE PRESSURE** ventilation and you inhale air.

# The Air We Breathe

- Air contains 79.02-percent nitrogen, 20.95-percent oxygen, 0.03-percent carbon dioxide and included in the nitrogen are small amounts of argon, neon, helium, krypton, hydrogen, and radon.

# 100% Oxygen

- We commonly have people on high  $FiO_2$  because they have some deficit in their ability to breathe for various reasons. Usually if someone is really in distress we start off at 100%  $O_2$  but try to wean this down as quickly as possible.

# Problems with breathing 100% Oxygen.

- Absorptive Atelectasis: Which occurs when high levels of O<sub>2</sub> "washout" the Nitrogen in the alveoli, leading to collapse of these sacs (alveolar collapse = atelectasis) and decreased perfusion space leading to lung shunting and airway collapse.
- Cardiac: Can lead to constriction of coronary arteries and lead to damage similar to a heart attack

# Nasal Cannulas are safe

- The Oxygen coming through a nasal cannula is 100% pure, but the percent that it actually increases the  $FiO_2$  is related to how fast the oxygen is flowing, with each liter per minute adding about 4%. So even at 10L per minute, which is about the fastest flow for nasal cannula, the total  $FiO_2$  gets to about 60% .

# Pressure Gradient

- In general, gases move from an area of high pressure to areas of low pressure known as the Pressure Gradient. (Diffusion)
- If there are a mixture of gases in a container, the pressure of each gas (partial pressure) is equal to the pressure that each gas would produce if it occupied the container alone.



# Partial Pressures

- The standard air pressure at sea level or (pAtm) is 760mm Hg. Since oxygen comprises about 21 percent of the air The PO<sub>2</sub> or partial pressure of oxygen is 160mm Hg. (760 x .21 percent = 160)

# Altitude Changes on Lungs

- The atmospheric pressure decrease at a 10,000-foot altitude which causes the air pressure to drop to 523mm Hg.
- This will result in a decrease in the hemoglobin saturation 87 percent and PaO<sub>2</sub> (partial pressure in Arterial blood) of 61mm Hg.

# Mountain sickness, Altitude Sickness

- At 15,000 feet air pressure drops to 429mm Hg and the hemoglobin saturation drops to 80 percent (we need 87-97 percent for normal functioning).
- Partial pressure arterial oxygen PaO<sub>2</sub> is 44mm Hg (the body requires 60-100mm Hg.).

# Dropping Pressures

- However by the time the inspired air reaches the trachea it has been warmed and humidified 100% by the upper respiratory tract. This warm wet air is absorbed by tissue and mixed with residual air in the lungs. By the time the oxygen has reached the alveoli the (partial pressure)  $PO_2$  has fallen to a pressure of about 100 mmHg

# PO<sub>2</sub>

- **PO<sub>2</sub> (Partial Pressure of Oxygen 160 mmHg at sea level)** reflects the amount of oxygen gas dissolved in the blood. It primarily measures the effectiveness of the lungs in pulling oxygen into the blood stream from the atmosphere.

# Arterial OXYGEN PRESSURE: PaO<sub>2</sub>

- Arterial partial pressure of oxygen -  
This measures the pressure of oxygen dissolved in the blood and how well oxygen is able to move from the airspace of the lungs into the blood.  
(PaO<sub>2</sub>) = 95 mm Hg

# Pulse Ox

- **(SpO<sub>2</sub>) values.** O<sub>2</sub> content measures the amount of oxygen in the blood. Oxygen saturation measures how much of the hemoglobin in the red blood cells is carrying oxygen (O<sub>2</sub>).

# PaO<sub>2</sub> and SaO<sub>2</sub>

- Think of PaO<sub>2</sub> (Partial Pressure of Oxygen in the Arteries) think of it as the driving pressure for oxygen molecules entering the red blood cell and chemically binding to hemoglobin; the higher the PaO<sub>2</sub>, the higher the SaO<sub>2</sub>.



# PaO<sub>2</sub> and SaO<sub>2</sub>

- Whatever the SaO<sub>2</sub>, its value is simply the percentage of total binding sites on arterial hemoglobin that are bound with oxygen, and can never be more than 100%.

# Hemoglobin

- The body requires hemoglobin saturations of 87-97 percent and this is registered by Pulse Ox reading.

# Carbon Dioxide (PaCO<sub>2</sub>).

- Partial pressure of carbon dioxide - This measures how much carbon dioxide is dissolved in the blood and how well carbon dioxide is able to move out of the body. **(PaCO<sub>2</sub>) = Target 35 mm Hg**

# What IF?

- No Co<sub>2</sub> in the Lungs?
- What would Happen?

# Blood Gases

	● ABG	● VBG
● PH	● 7.35-7.45	● 7.25-7.35
● PCO <sub>2</sub>	● 35-45	● 41-51
● PO <sub>2</sub>	● 80-100	● 35-40
● HCO <sub>3</sub>	● 22-26	● 22-26

# Hypoxemia

- **Hypoxemia** = low  $O_2$  in blood less than 60mmHg. is a deficiency in the concentration of dissolved oxygen in arterial blood.
- **Symptoms** = The main symptom of hypoxemia is shortness of breath, but depending on how quickly hypoxemia develops, you may experience a reduced capacity for exercise, fatigue and confusion.

# Hypercapnia

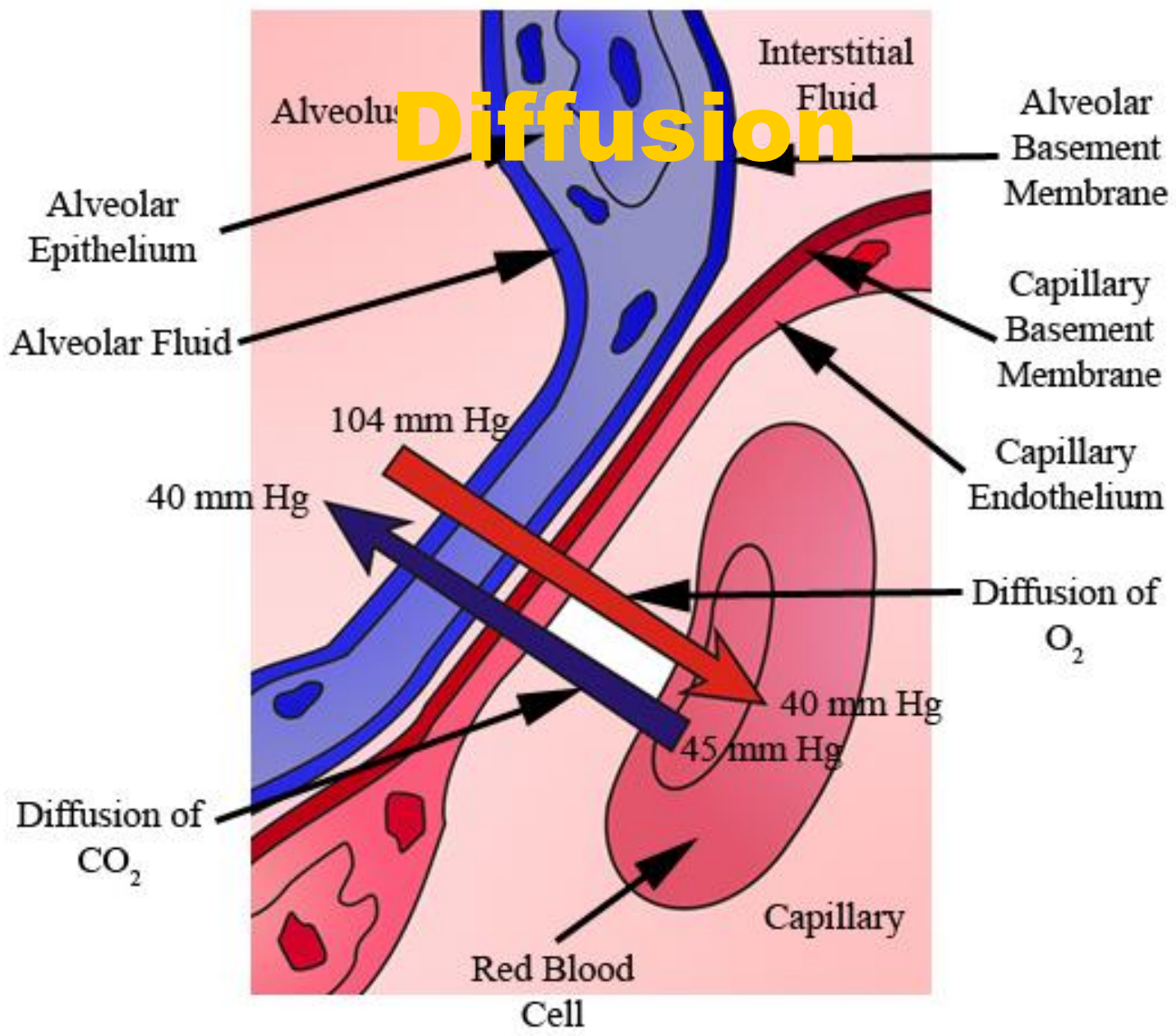
- **Hypercapnia** = also known as hypercarbia, is a condition where there is too much carbon dioxide (CO<sub>2</sub>) in the blood. Hypercapnia is generally caused by hypoventilation, lung disease, or diminished consciousness. It may also be caused by exposure to environments containing abnormally high concentrations of carbon dioxide or by rebreathing exhaled carbon dioxide.
- **Symptoms** = greater than 45 mmHg include flushed skin, full pulse, twitches, hand flaps, reduced neural activity, and possibly a raised blood pressure. In severe hypercapnia (generally PaCO<sub>2</sub> greater than 75 mmHg), symptomatology progresses to disorientation, panic, hyperventilation, convulsions, unconsciousness, and eventually death

# Diffusion

- Hemoglobin is the oxygen carrying agent of the blood. Oxygen must diffuse from a gaseous state to a dissolved state to combine with the hemoglobin.
- The oxygen diffuses across the alveolar membrane, through the interstitial fluid and capillary endothelium. Within this capillary, the dissolved oxygen diffuses through the plasma, the red blood cell membrane, and the intracellular fluid within the red cell to combine with the hemoglobin.
- The solubility of a gas, and its partial pressure, greatly influences its diffusion characteristics. Carbon dioxide is about 25 times more soluble than oxygen in pulmonary tissues and fluids and its capacity for diffusion is about 20 times greater than oxygen.



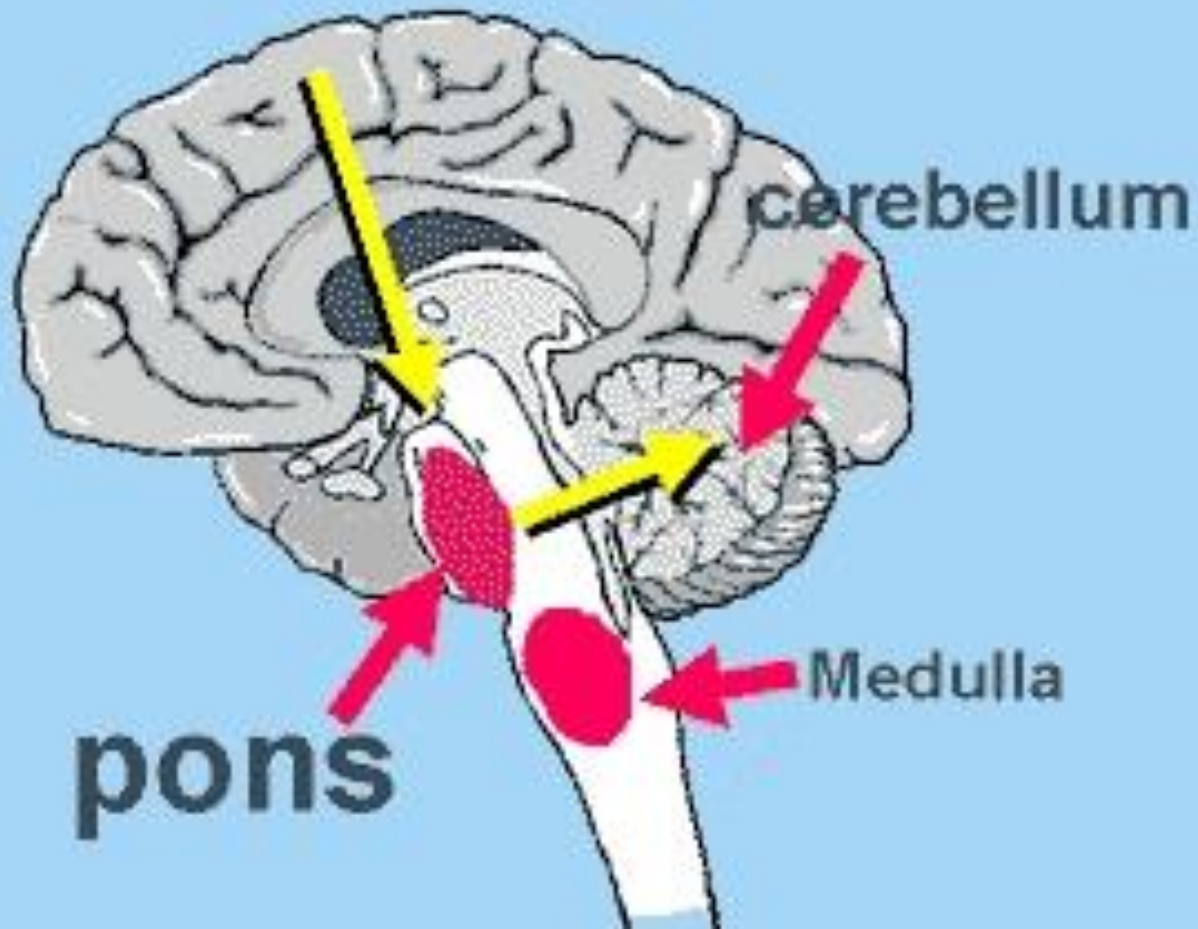
# Diffusion



- Diffusion of different gases from the blood into tissues or from tissues into blood depends on the difference in partial pressures of a gas on the two sides. e.g. the partial pressure of oxygen in the arterial blood is 95 mmHg and in the tissue spaces is 40 mmHg and therefore there is a net pressure of 55 mmHg that pushes oxygen from blood into the tissues. You may ask here why the oxygen is low in the tissues. This is because the tissues continuously consume oxygen so the oxygen partial pressure tends to fall whereas the blood in arteries has much oxygen as it is continuously oxygenated in the lungs. Similarly the carbon dioxide tends to diffuse out of the tissues into the blood because it is high in the tissues due to continuous production i.e. 45 mmHg and in the arterial blood it is 40 mmHg. Thus net pressure of 5 mmHg pushes the carbon dioxide out of the tissues into the blood.

- Mechanical ventilation is fundamentally different from normal breathing.
- During spontaneous breathing, the diaphragm contracts on inhalation, moving toward the abdomen, and the chest wall expands. The space inside the thorax enlarges and creates a vacuum that draws air into the lungs and helps to distribute the air evenly.

- You don't have to think about breathing because your body's **autonomic nervous system** controls it, as it does many other functions in your body. If you try to hold your breath, your body will override your action and force you to let out that breath and start breathing again. The respiratory centers that control your rate of breathing are in the brainstem or **medulla**. The nerve cells that live within these centers automatically send signals to the diaphragm and intercostal muscles to contract and relax at regular intervals.

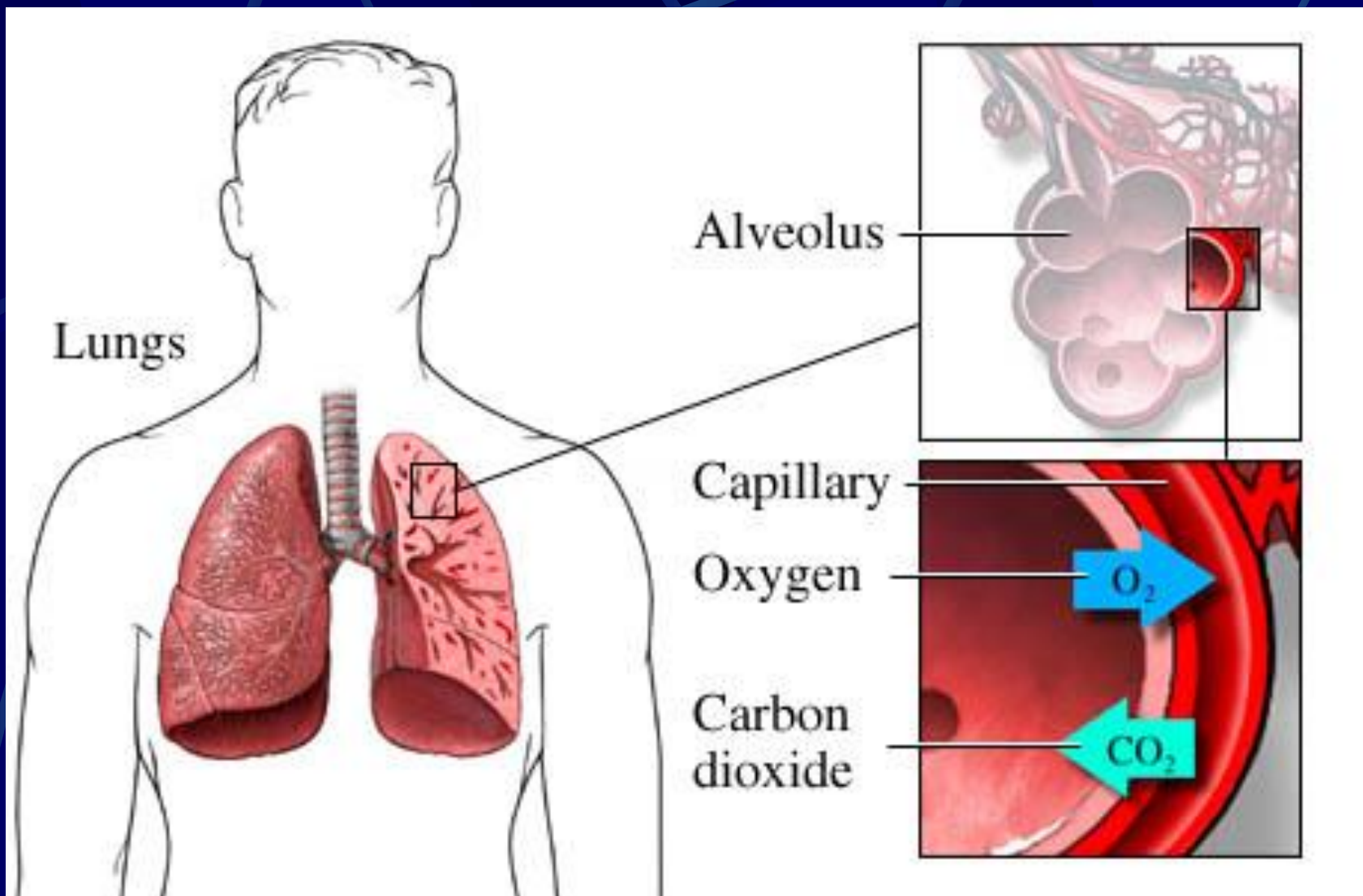


● However, the activity of the respiratory centers can be influenced by these factors:

- Oxygen
- Carbon dioxide
- Hydrogen ion (pH)
- Stretch
- Signals from higher brain centers
- Chemical irritants

# What Happens When the Air Gets There

- Within each air sac, the oxygen concentration is high, so oxygen passes or **diffuses** across the alveolar membrane into the **pulmonary capillary**. At the beginning of the pulmonary capillary, the hemoglobin in the red blood cells has carbon dioxide bound to it and very little oxygen. The oxygen binds to hemoglobin and the carbon dioxide is released. Carbon dioxide is also released from sodium bicarbonate dissolved in the blood of the pulmonary capillary. The concentration of carbon dioxide is high in the pulmonary capillary, so carbon dioxide leaves the blood and passes across the alveolar membrane into the air sac. This exchange of gases occurs rapidly (fractions of a second). The carbon dioxide then leaves the alveolus when you exhale and the oxygen-enriched blood returns to the heart. Thus, the purpose of breathing is to keep the oxygen concentration high and the carbon dioxide concentration low in the alveoli so this gas exchange can occur.





# When Lungs Fail

- There are many common conditions that can affect your lungs. We will describe some of the ones you hear about most often. Diseases or conditions of the lung fall mainly into two classes -- those that make breathing harder and those that damage the lungs' ability to exchange carbon dioxide for oxygen. **Diseases or conditions that influence the mechanics of breathing:**

# ● Diseases or conditions that influence the mechanics of breathing:

- Asthma
- Emphysema
- Bronchitis
- Pneumothorax
- Apnea
- Pulmonary edema
- Smoke inhalation
- Carbon monoxide poisoning

- Any of these that effect the gas exchange in the aveoli (avelous) requires us to support the patient by positive pressure ventilations.

# Total lung capacity (TLC)

- Average adult = 6 L or 6000 ml
- but only a small amount of this capacity is used during normal breathing.

# Tidal volume ( $V_t$ )

- The amount of air breathed in or out during normal respiration. The volume of air an individual is normally breathing in and out.
- Patients with normal lungs can tolerate a tidal volume of 12-15 cc/kg, whereas patients with restrictive lung disease may need a tidal volume of 5-8 cc/kg
- 500ml is our average for adult

# Functional residual capacity (FRC)

- The amount of air left in the lungs after a tidal breath out. The amount of air that stays in the lungs during normal breathing.
- 2.4 L is average in adults

# Our Goals

- Maintain adequate pulmonary gas exchange
- Minimize the risk of lung injury
- Reduce the patient's work of breathing
- Optimize patient comfort elevation of the head of the bed to 30 - 45 degrees

# Ventilator settings

1. Ventilator mode
2. Respiratory rate
3. Tidal volume or pressure settings
4. Inspiratory flow
5. I:E ratio
6. PEEP
7. FiO<sub>2</sub>
8. Inspiratory trigger



# FiO<sub>2</sub>

- FiO<sub>2</sub>=fractional concentration of oxygen in inspired gas = 0.21 breathing air

# Mechanical Ventilation

- Mechanical ventilation is used to treat patients with respiratory failure from inadequate ventilation or oxygenation (or both), as evidenced by hypoxemia with or without hypercapnia.

# 50/50 Rule

- The 50/50 rule states that mechanical ventilation is indicated if a patient's partial-pressure of oxygen ( $\text{PaO}_2$ ) falls below 50 mm Hg and her partial-pressure of carbon dioxide ( $\text{PaCO}_2$ ) rises above 50 mm Hg.

- Always remember, though, that the 50/50 rule is only a guideline.
- Many patients need ventilatory support before they reach these critical values. On the other hand, some patients with severe COPD may have those values at baseline.

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# Making sense of settings

- When a patient is put on a ventilator, numerous settings, including respiratory rate, fraction of inspired oxygen ( $F_iO_2$ )=.21-1, volume or pressure control, and ventilator mode, must be selected. In addition, two adjuncts—PEEP and pressure support—are sometimes used, depending on the patient's status and which ventilation mode is chosen. To properly care for your patient, it's important to understand each of these settings



- In patients at risk for alveolar collapse on exhalation, a small amount of pressure can be maintained in the alveoli to hold them open.
- This is called positive-end expiratory pressure (PEEP), and it can improve alveolar recruitment and increasing oxygenation

# ***Respiratory rate***

- This setting simply refers to the number of breaths per minute that the ventilator delivers. Eight to 12 bpm is a typical respiratory rate. Depending on the mode selected, the ventilator can provide all of the patient's ventilation, or the patient may be able to breathe spontaneously between ventilator breaths.

# ***FiO2***

- This indicates the amount of oxygen the ventilator delivers, expressed as a percentage or a number between zero and one. FiO<sub>2</sub> varies widely depending on the patient's condition; room air is 21% (0.21). While some patients might be adequately oxygenated with an FiO<sub>2</sub> of less than 40% (0.40), someone with severe hypoxemia, for example, might need an initial FiO<sub>2</sub> setting of 100% (1.00).<sup>2</sup> Arterial blood gases and pulse oximetry values will help determine FiO<sub>2</sub> settings.

# ***Volume control***

- Traditionally, mechanical ventilation is volume controlled. This setting means the ventilator is programmed to deliver a preset volume of oxygen and air, called the tidal volume ( $V_T$ ), regardless of the amount of pressure required to deliver the volume (a positive pressure alarm protects patients from dangerously high pressures).

## ***Pressure Control- Plateau Pressure***

- An alternative to volume control that's indicated for some patients, pressure control simply means that pressure is the endpoint rather than volume. Thus, inspiration ends when a preset pressure is reached, regardless of the volume delivered.
- The advantage of this mode is that it allows the volume to change in response to intrathoracic pressure. The goal is to increase mean airway pressure by prolonging inspiration, ideally recruiting more alveoli than volume control ventilation. By limiting pressure, there is less risk of pressure-related injury.

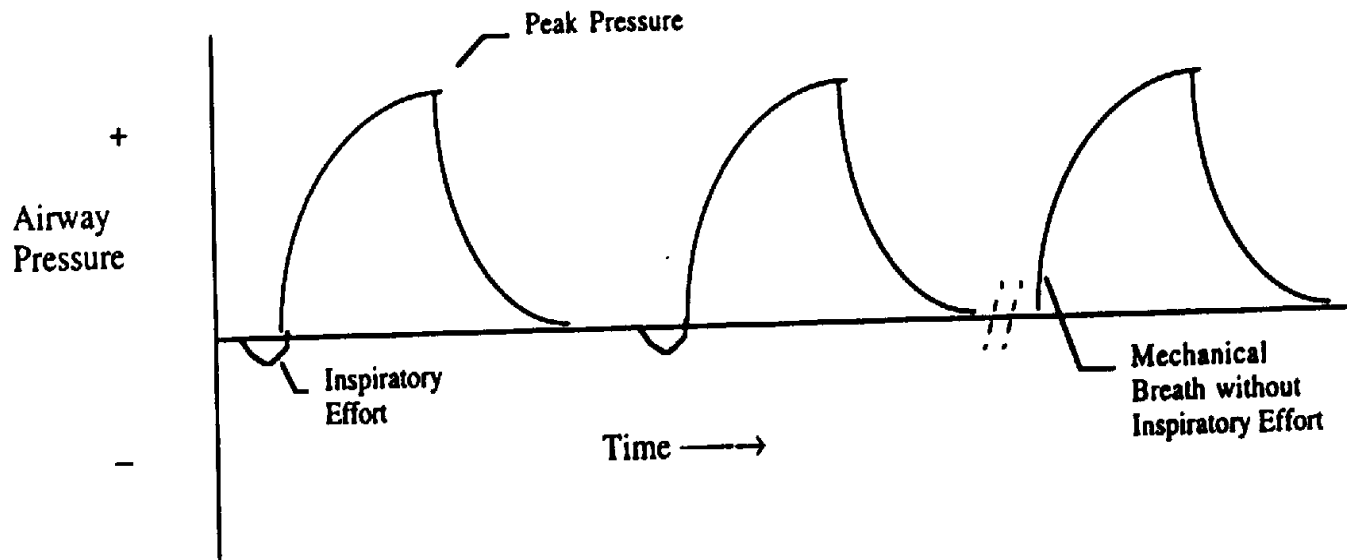
# ***Pressure-regulated volume control (PRVC)***

- This type of mechanical ventilation is an alternative to strict pressure control, representing an attempt to obtain the best of both volume and pressure control. PRVC automatically adapts to changing compliance of the lungs to adjust inspiratory time and pressure to maintain a preset tidal volume. **(we do not have this option)**

# ***Assist control (AC)***

- In this mode, the ventilator supports every breath, whether it's initiated by the patient or the ventilator. AC is often used to allow the patient to rest, because the ventilator does all the work. This high level of respiratory support is frequently required in patients who have been resuscitated, have acute respiratory distress syndrome (ARDS), or are paralyzed or sedated.
- Because AC mode results in the highest level of positive pressure in the chest, it increases the risk of barotrauma to the lungs. Anxious patients who frequently trigger the ventilator can easily hyperventilate

# A/CV

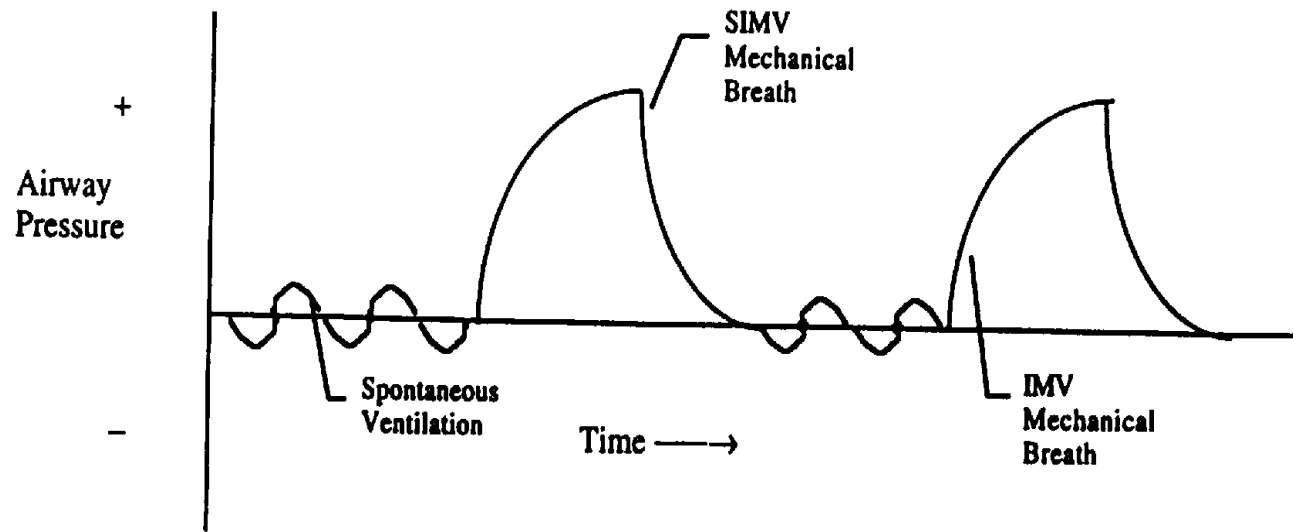




# ***Synchronized intermittent mandatory ventilation (SIMV)***

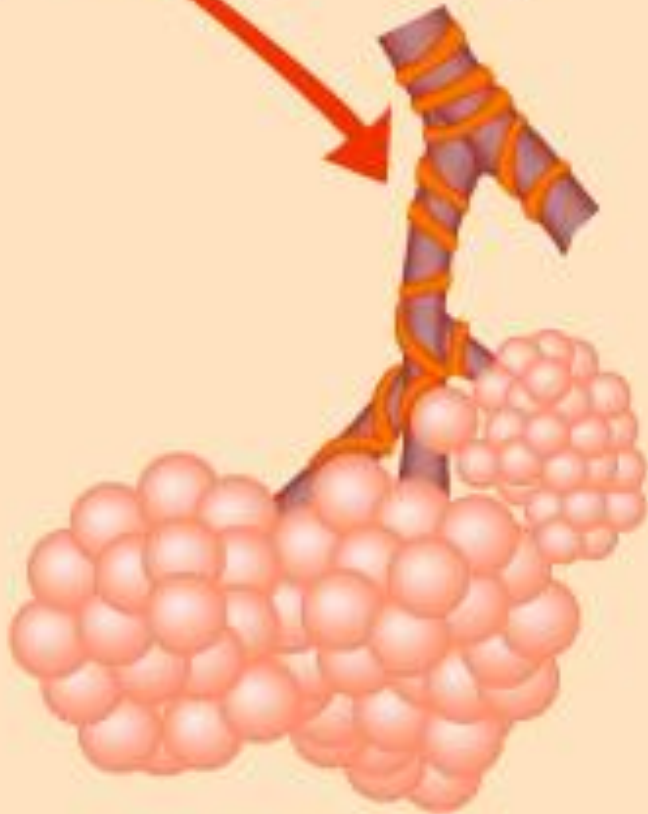
- In this mode, not all spontaneous breaths are assisted, leaving the patient to draw some breaths on their own. For example, if your patient's ventilator is set on SIMV mode with a respiratory rate of 10 bpm, they will receive a breath roughly once every six seconds. They can also breathe on their own in between the machine-assisted breaths.
- There are several advantages to this mode for patients who can tolerate it. SIMV helps preserve the strength of the respiratory musculature, decreases the risk of hyperventilation and barotrauma, and facilitates weaning. Weaning can be done by gradually decreasing the percentage of machine-assist ventilation.
- Patients who need short-term ventilation benefit most from SIMV.

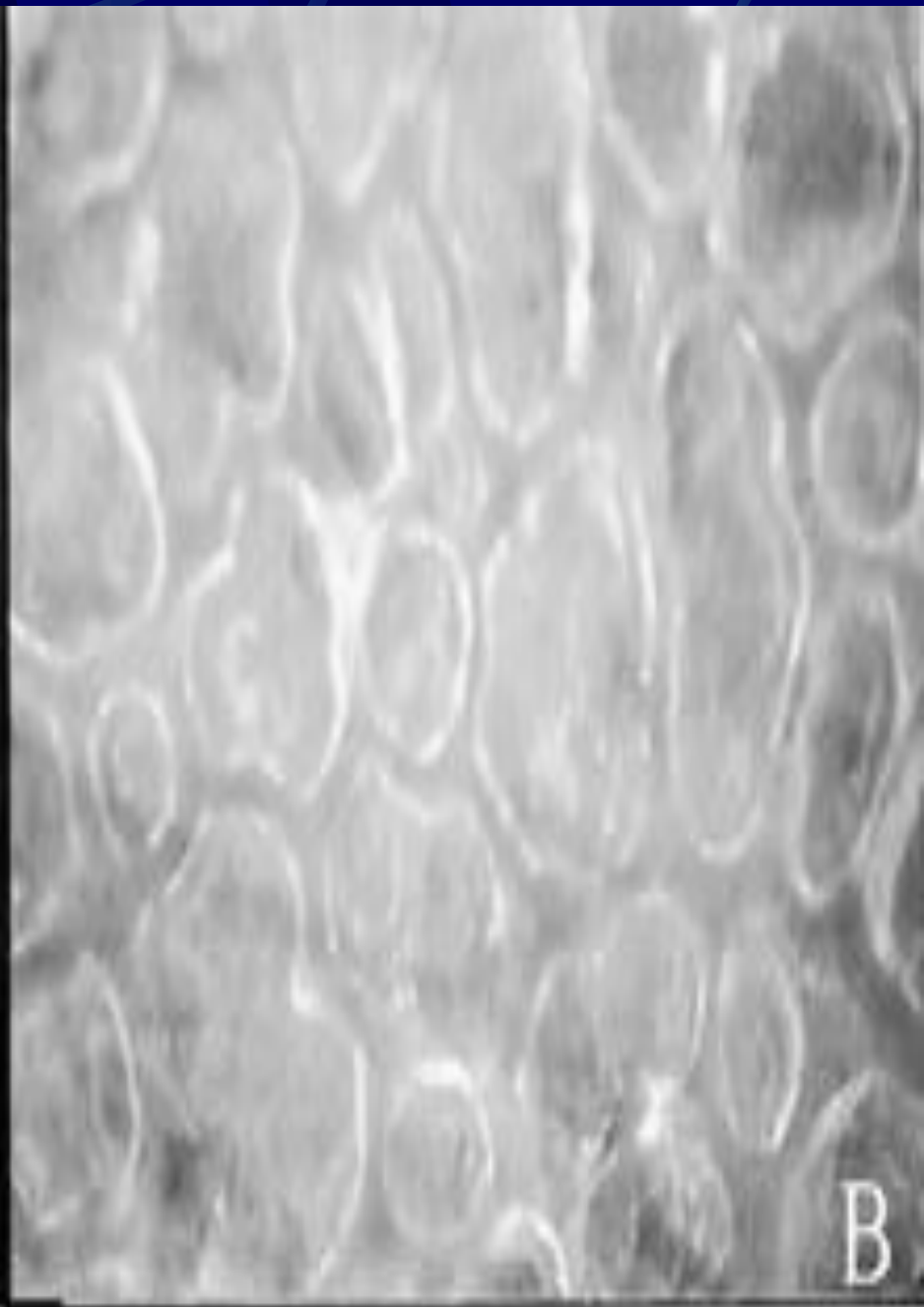
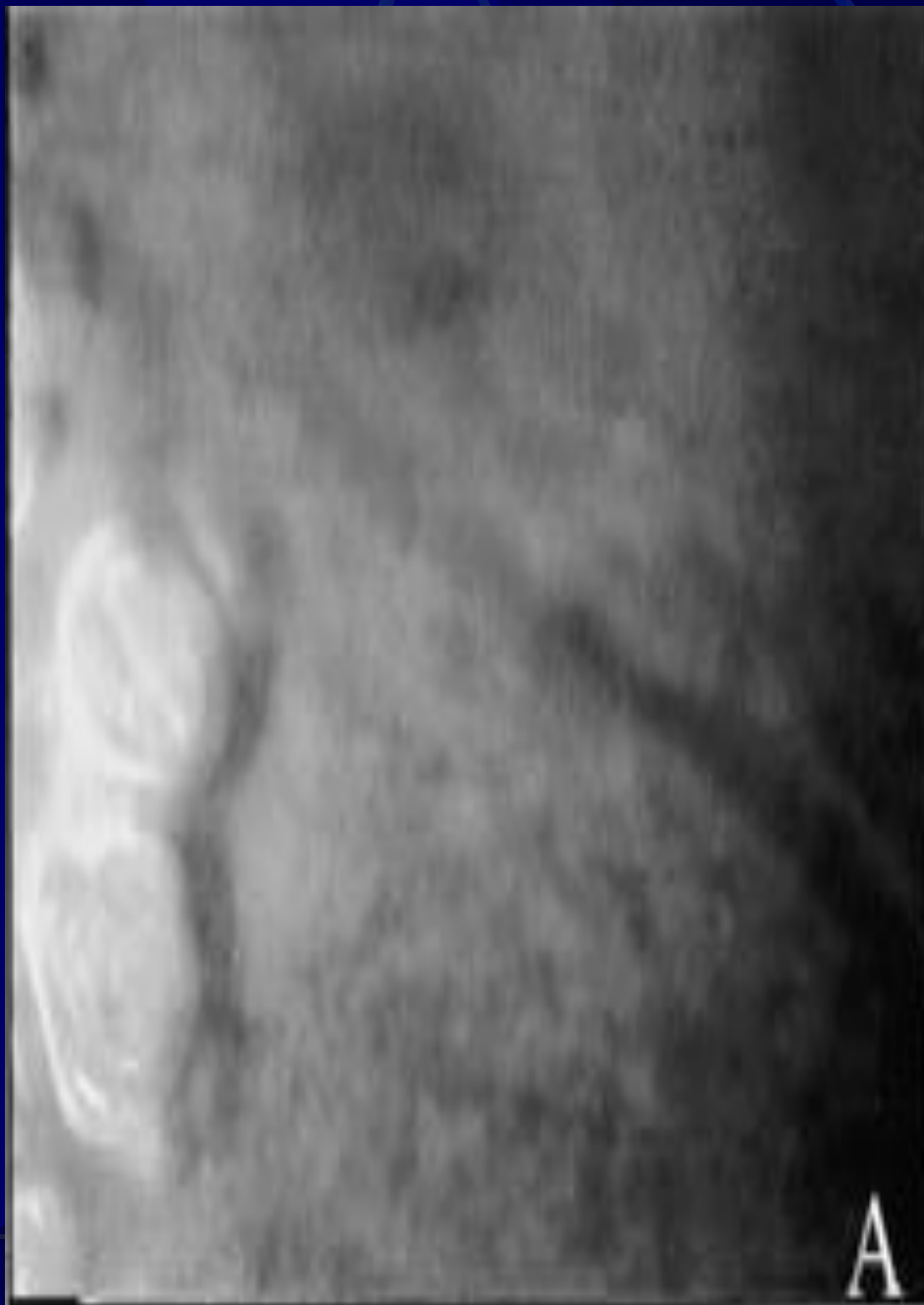
# SIMV



# ***Positive end-expiratory pressure (PEEP)***

- PEEP can be used to increase oxygenation in either AC or SIMV mode. The effect of PEEP on the lungs is similar to blowing up a balloon and not letting it completely deflate before blowing it up again.
- Most patients are started on 5 cm H<sub>2</sub>O of PEEP. Some patients, such as those with ARDS or other conditions that make lungs stiff, require higher levels of PEEP to keep **alveoli** from collapsing and to decrease intrapulmonary shunting. It's not unusual to use 8 - 12 cm H<sub>2</sub>O in these patients.
- But PEEP should not exceed 20 cm H<sub>2</sub>O; higher settings increase the risk of severe lung damage, subcutaneous emphysema, and pneumothorax.





# Positive End-expiratory Pressure (PEEP)

What is PEEP?

What is the goal of PEEP?

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

# 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 Indications
  - Barotrauma
  - Airway trauma
  - Hemodynamic instability
  - I.C.P.?
  - Bronchospasm?



# PEEP

- What PEEP do you want?
  - Usually, 5-10 cmH<sub>2</sub>O

# ***Pressure support***

- Added to SIMV, this provides a small amount of pressure during inspiration to help the patient draw in a **spontaneous breath**. Pressure support makes it easier for the patient to overcome the resistance of the ET tube and is often used during weaning because it reduces the work of breathing.
- It's not necessary during AC ventilation because in that setting, the ventilator supports all of the breaths.

- The presence of an endotracheal tube increases the resistance to inspiration, add to this a lung injury and the patient incurs a high workload to breathing. Pressure support offsets this work – it offloads the respiratory muscles in order to return the tidal volume to normal.
- A normal individual who is intubated and not attached to a ventilator will have a lower functional residual volume (FRC) – the lungs tend to collapse inwards – and a lower tidal volume

- Pressure support overcomes the resistance to inspiration and reduces the workload of that part of the ventilatory cycle.
- The term “pressure support ventilation” describes the combination of pressure support and PEEP.

# Reminder

- Pressure support works on the **SIMV mode only** and delivers pressure supported breaths during spontaneous respirations of the patient.

# Understanding

If a patient is on PEEP 5cmH<sub>2</sub>O and pressure support of 10cmH<sub>2</sub>O what is the peak/plateau press?

# Crossvent 3+



Spon



# Sigh Breath

- $V_{on} = 1.5$  times the tidal volume
  - This occurs once every 100 breaths or 7 minutes whichever comes first.
  - Tidal volume of 500 = sigh of 750
  - Remember this will increase peak pressure during the sigh breath



# Auto-PEEP or Intrinsic PEEP

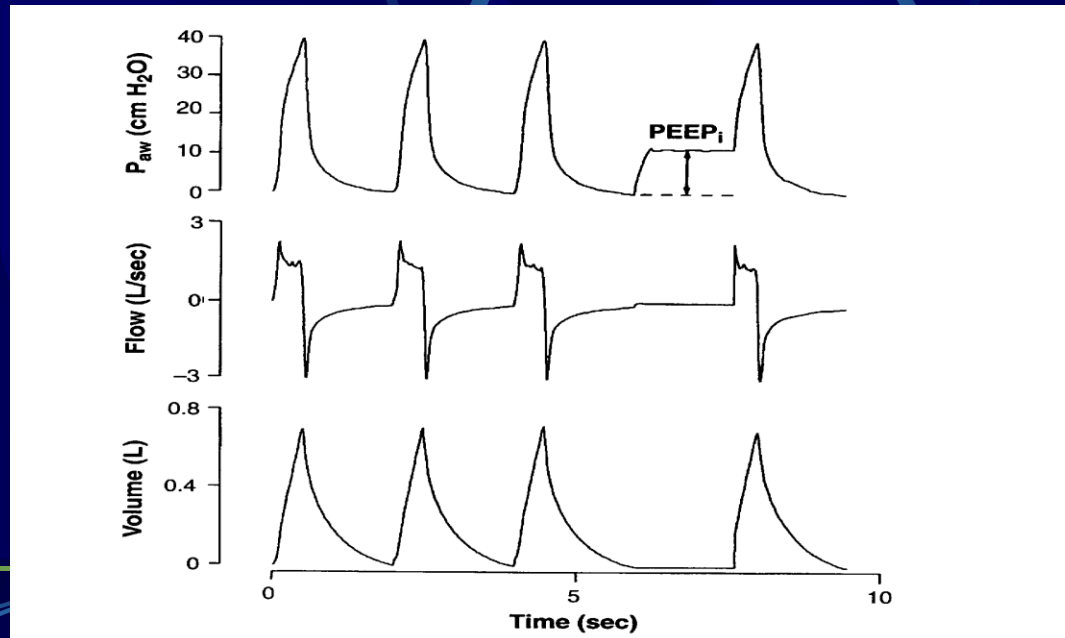
- What is Auto-PEEP?
  - Normally, at end expiration, the lung volume is equal to the Functional Residual Capacity.
  - When PEEPi occurs, the lung volume at end expiration is greater than the Functional Residual Capacity.

# 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  $V_t$ )
  - Expiratory muscle activity
  - Lesions that increase expiratory resistance

# 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

# Monitoring of the patient

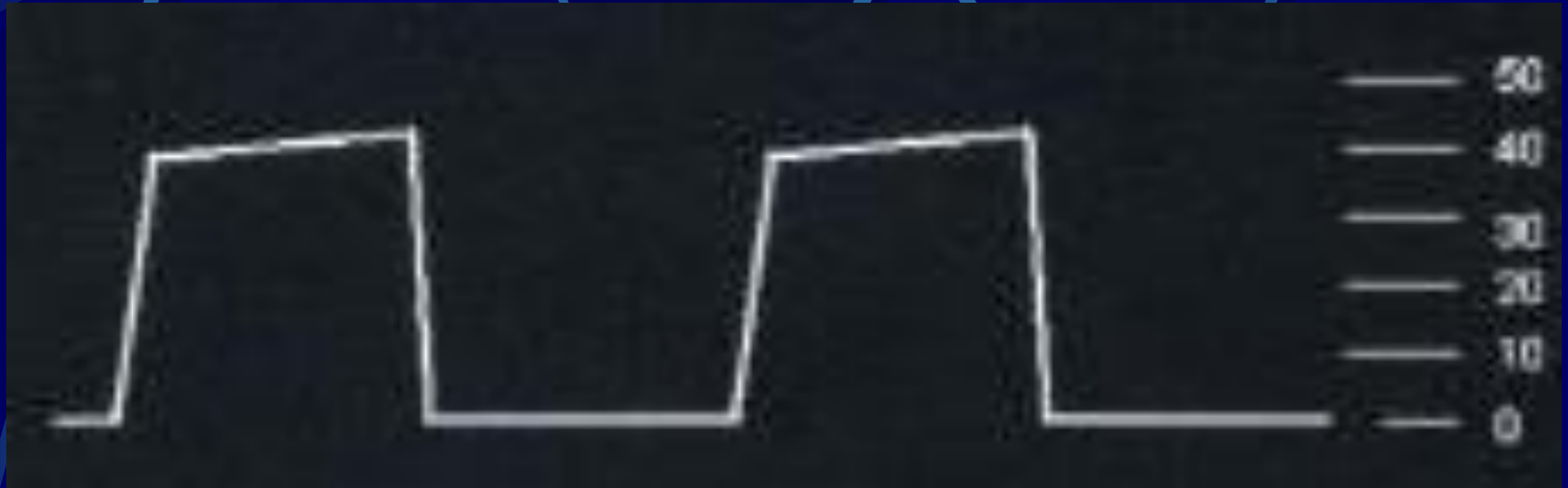


# Look at your patient

- Question your pt
- Examine your pt
- Monitor your pt
- Look at the synchronicity of your pt breathing

- Monitoring includes – patient's color, ease of inspirations, mental status, alertness, cap refill, cardiac, EtCo<sub>2</sub>, BP, HR, and Spo<sub>2</sub> if available.

# Normal Co2

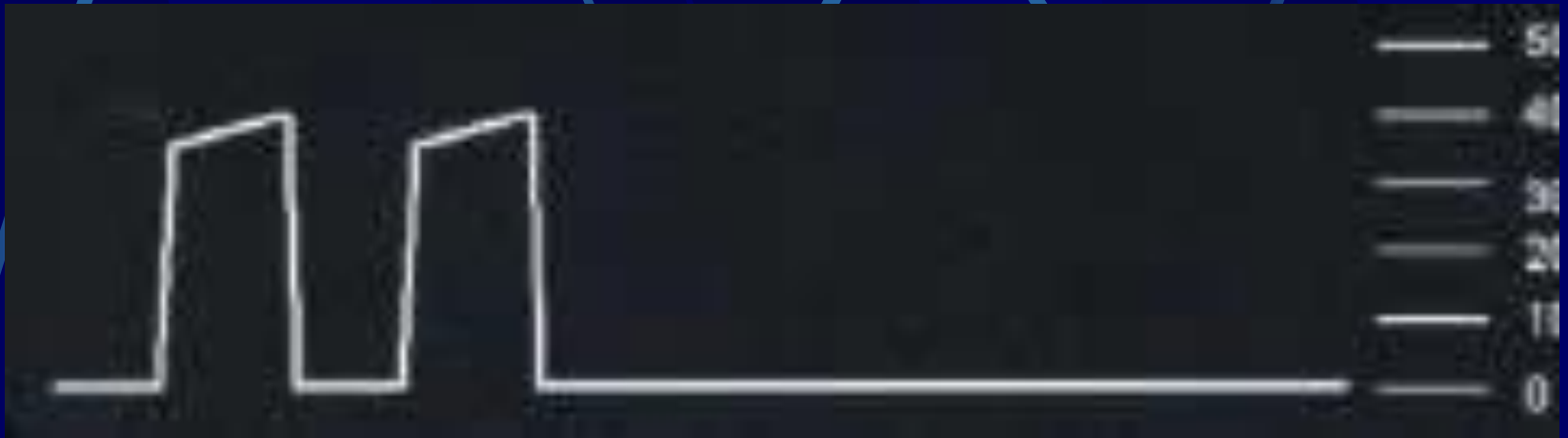




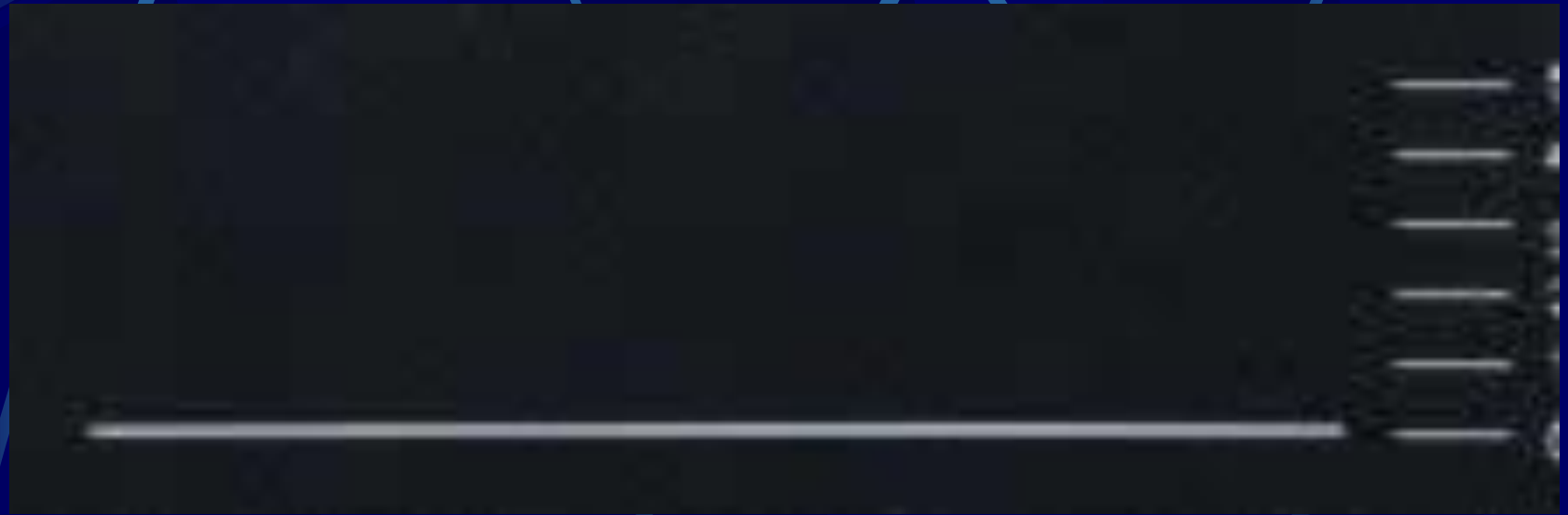
# Breath Around Broken Cuff or tube to small



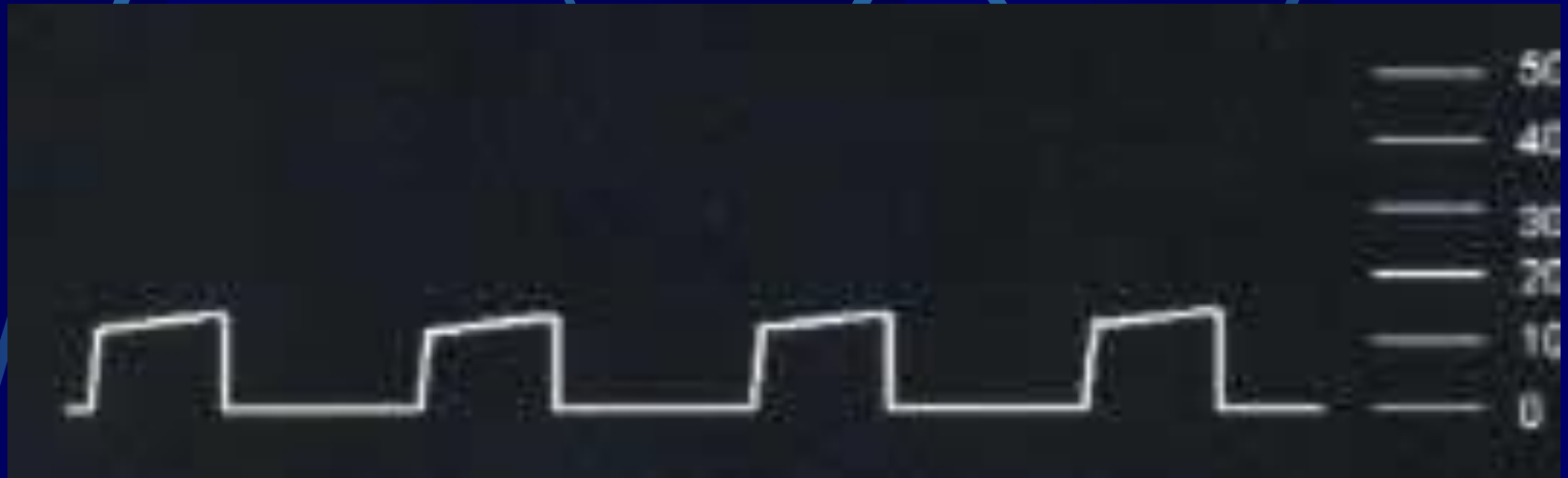
# Et Tube Dislodged



# ESOPHAGEAL INTUBATION



# Good CPR EtCo2



# CPR with return of Respirations



# Bronchospasm – “Sharkfin”

albuterol or atrovent



# Rise in Base Line

Rebreathing Co<sub>2</sub> need longer  
expiratory time



# Pressures

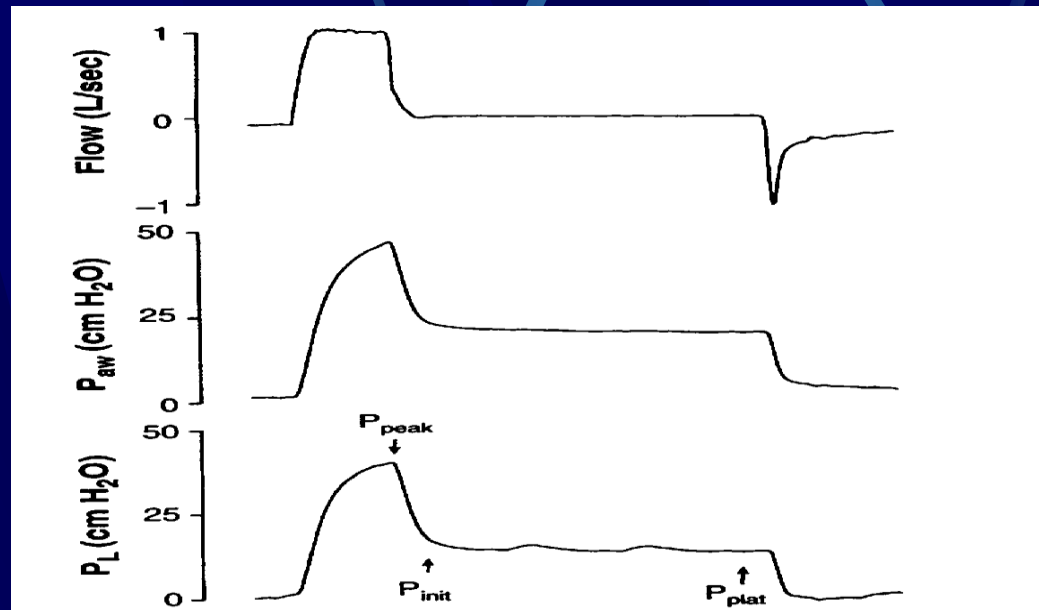


# Pressure

- 10-20 cm H<sub>2</sub>O above peak inspiratory pressure
- 
- maximum is 35 cm H<sub>2</sub>O

# P<sub>peak</sub>

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





# **Responding to Alarms**

# Stay Calm

- Since a ventilator is, in effect, merely an air pump, an alarm simply signals that there's something wrong with the pressure, volume, or rate of air being delivered. When an alarm sounds, your role is to immediately check the patient and the equipment and figure out—and fix—what's interfering with the function of the ventilator. If you can't immediately identify the problem, disconnect the patient from the ventilator, use a manual resuscitation bag.

# Check Connection

- Often, the problem is related to the tubing

- Low limit alarm –

- Tube has come loose
- Vent lower limit was set at improperly on alarm screen one
- Displaced ETT or trach tube
  
- The most common places for leaks are around the ET tube cuff, poorly secured connections, and drainage and access ports on the tubing.

## ● High limit Alarm –

- Coughed
- Alarm limit too low on alarm screen one
- Kink in vent tubing
- Patient biting on ETT
- Airway is blocked
- Tension pneumothorax

- Leak at ET tube – adjust pressure trigger to compensate for this problem. You will have to adjust the trigger to a higher number so that the vent does not auto trigger.



- Reason that the vent auto triggers -
  - leaks in ETT
  - pressure too sensitive raise to 1.0 – 2.0

- Why does the battery light flash red?
  - Because you do not have the ventilator plugged into AC power. You must always acknowledge the battery light or it will continue to alarm.

# Increased Respiratory Rate

- Patient anxiety or pain
  - Secretions in ETT/airway
  - Hypoxia
  - Hypercapnia
- 
- More commonly, though, water or kinks in the tubing trigger this alarm because air is pulsing through the tubing around the obstruction.

# Respiratory Acidosis

- $\text{CO}_2 > 50$
- Mechanical Ventilation (increase the respiratory rate and tidal volume).
- (Note: beware of Sodium Bicarbonate can overcompensate and cause Metabolic Alkalosis. Also, if pt has been hypoxic and this is a Lactic Acidosis-- $\text{NaHCO}_3$  can be dangerous)

# Respiratory Alkalosis

- $\text{CO}_2 < 35$
- - a. Sedatives or analgesics
  - b. Correction of hypoxia (possible diuretics, mechanical ventilation to also decrease respiratory rate and decrease the tidal volume)

# **Vigilance wards off complications**

- Infection, atelectasis ( a collapse of lung tissue) , barotrauma, and oxygen toxicity are all potential complications of mechanical ventilation. Good pulmonary hygiene as well as careful attention to the ventilator settings, monitor, and patient are the key to avoiding them.

- **Manometric units** are units such as *millimeters of mercury* or *centimeters of water* that depend on an assumed density of a fluid and an assumed acceleration of gravity. manometric units are used routinely in medicine and physiology, and they continue to be used in areas as diverse as weather reporting and scuba diving.
- The **millimeter of mercury** (symbol: **mmHg**) is defined as the pressure exerted at the base of a column of fluid exactly 1 mm high, when the density of the fluid is exactly 13.5951 g/cm<sup>3</sup>, at a place where the acceleration of gravity is exactly 9.80665 m/s<sup>2</sup>.
- There are several things to notice about this definition:
  - A fluid density of 13.5951 g/cm<sup>3</sup> was chosen for this definition because this is the approximate density of mercury at 0 °C. The definition, therefore, assumes a particular value for the density of mercury. The density can depend on temperature, exogenous pressure, and other similar variables, so those have to assume certain conventional, normal values as well.
  - The definition assumes a particular value for the acceleration of gravity: the standard gravity  $g_0 = 9.80665 \text{ m/s}^2$ . In theory, the precise acceleration would vary, and the measurement would have to be recalibrated against the local value; in weightless conditions, this kind of measurement would not even make sense. In practice, of course, measurements are made using local values, which vary little enough at the Earth's surface.