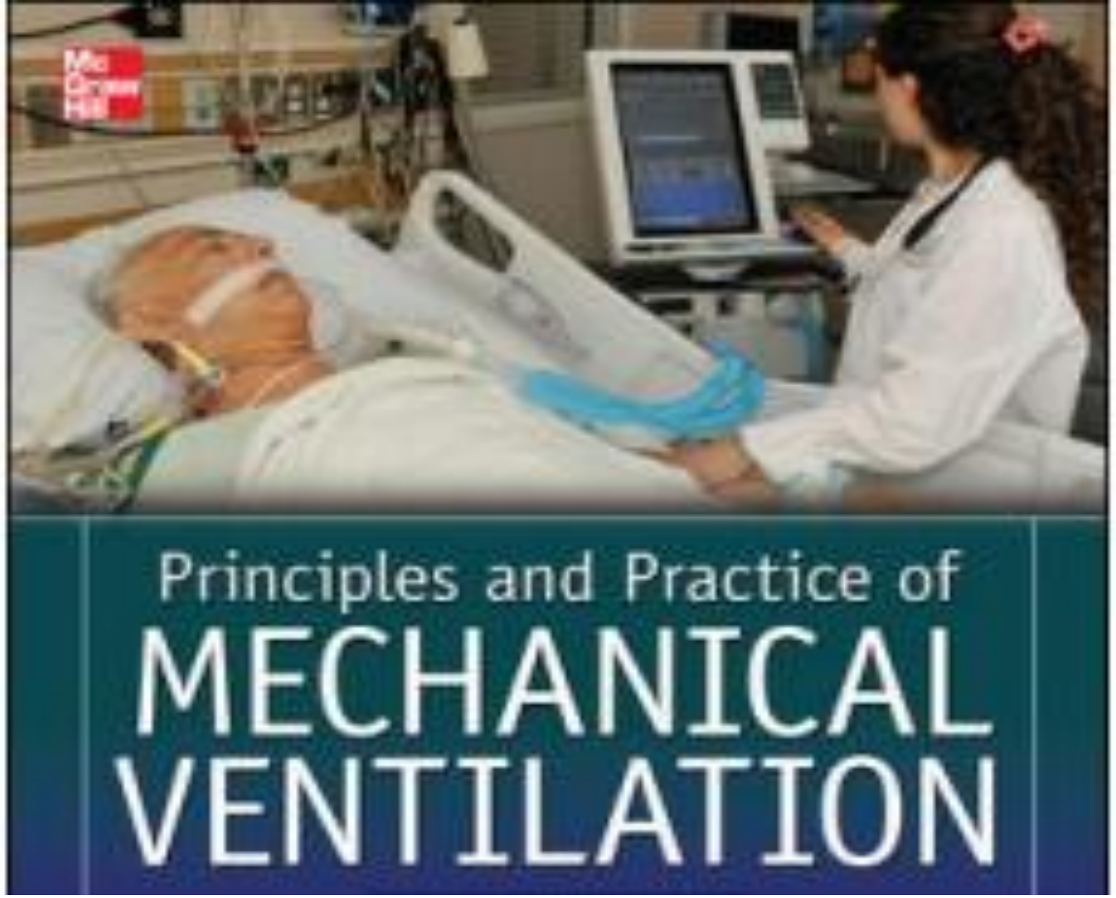

Hassan Soleimanpour

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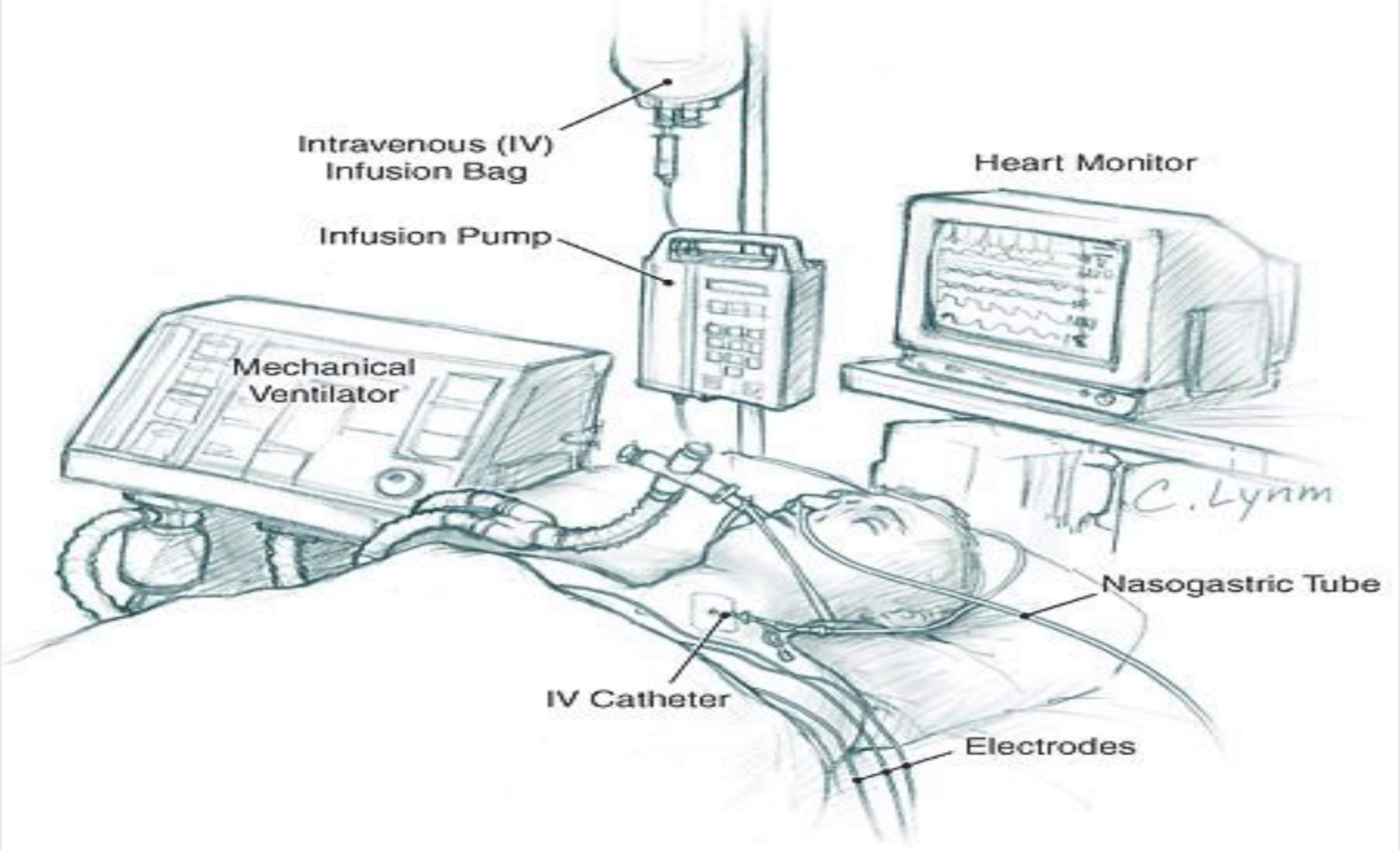
With tnx to Prof. Mahmoodpoor, My respected colleague, for sharing his slides

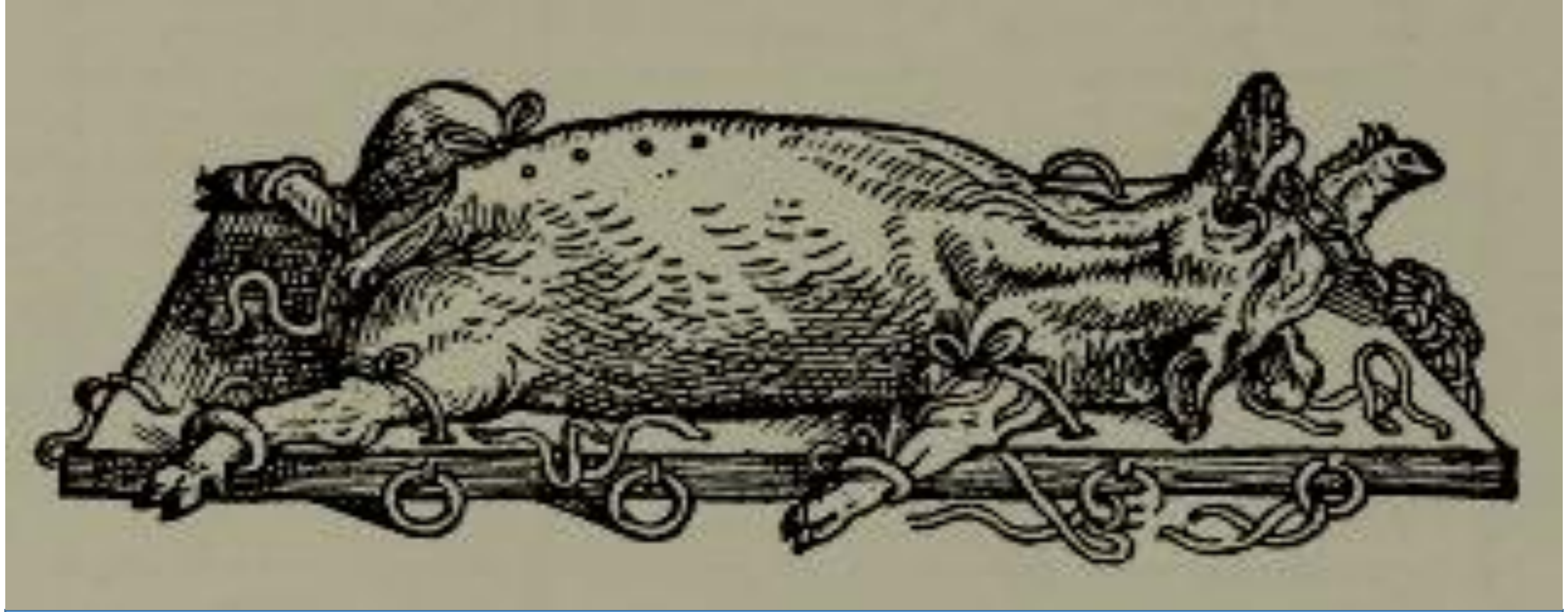


Ventilate is derived from
Latin word “ventus” meaning wind

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 O2 and Co2 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 Relieve acute respiratory acidosis
2. Relieve respiratory distress	Reduce oxygen cost of breathing Reverse respiratory muscle fatigue
3. Improve pulmonary mechanics	Prevent and reverse atelectasis Improve compliance Prevent lung injury
4. Permit lung and airway healing	Maintain lung and airway functions
5. Avoid complications	Protect lung and airway Prevent disuse respiratory muscle dystrophy

Clinical Application of Mechanical Ventilation, Fourth Edition by *David W. Chang*

Why ventilate?

- Improve oxygenation
- Increase/maintain minute ventilation and help CO_2 clearance
- Decrease work of breathing
- Protect airway

Who needs a ventilator?

- Can’t oxygenate (low PaO2/SPO2)
- Can’t ventilate (high PaCO2)
- 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%

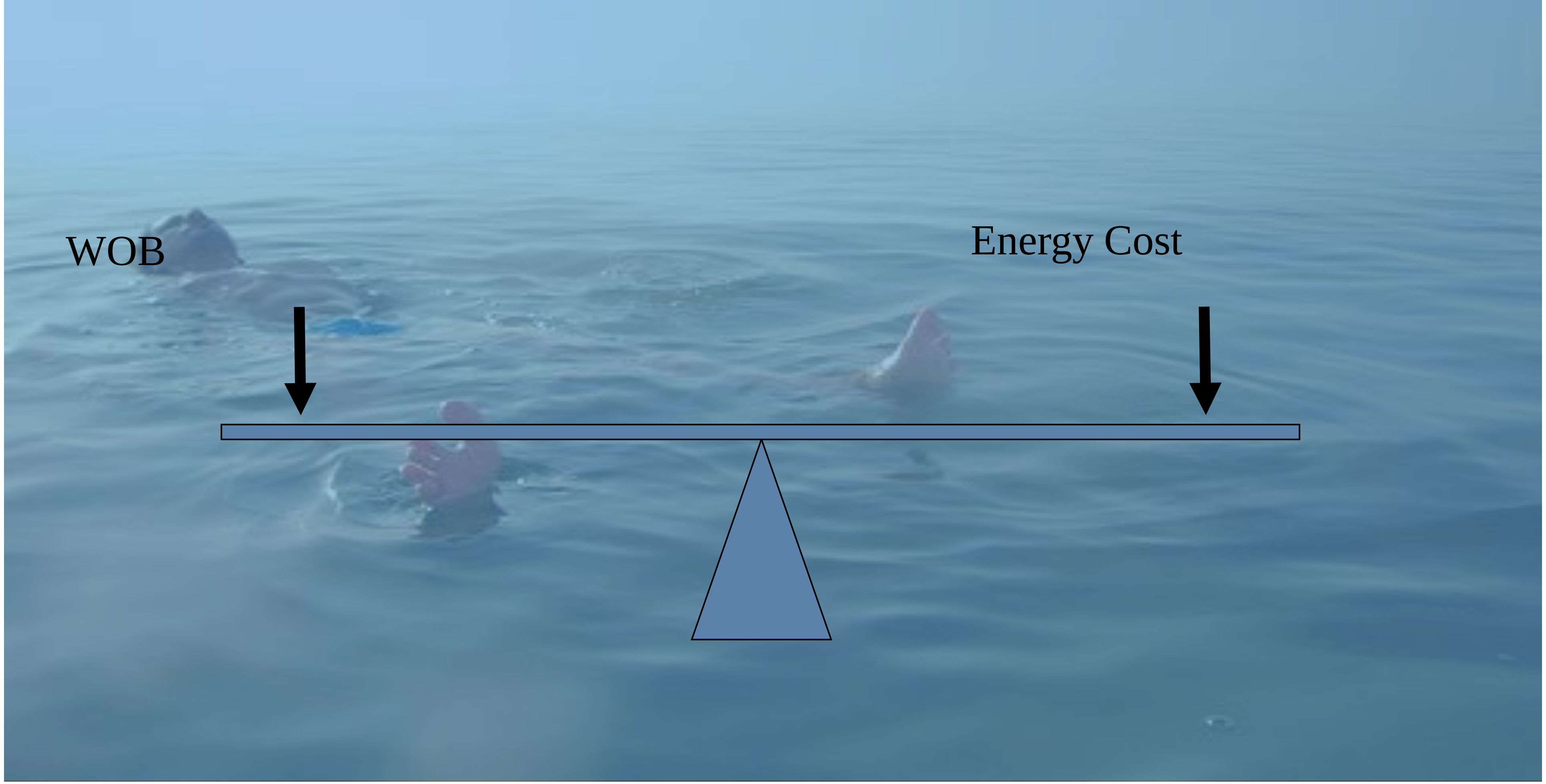
Ventilation

Parameters

Protocols

Balance of Ventilation

I need 2 Volunteers !!



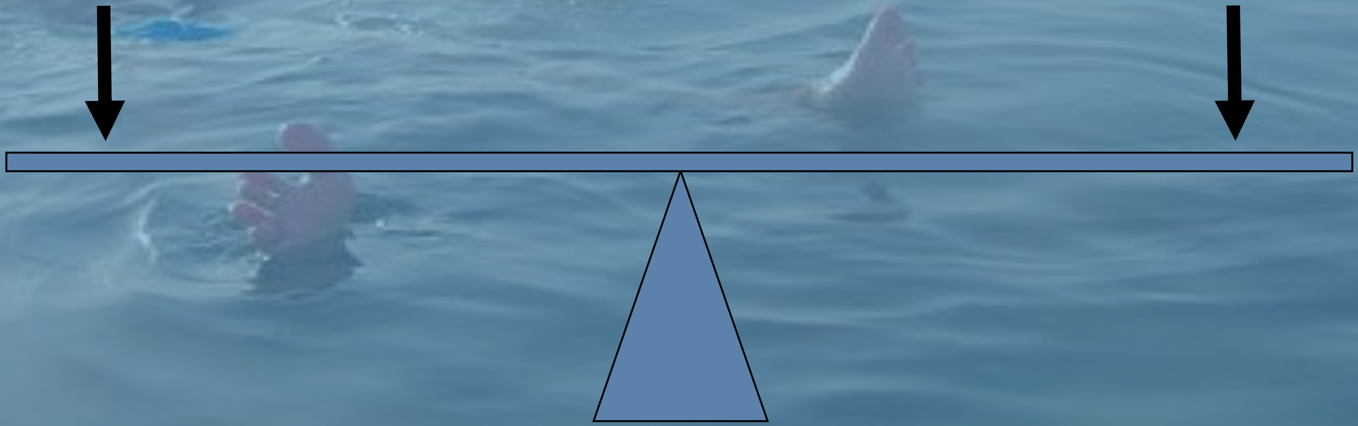
Balance of Ventilation

WOB
Resistance
Compliance

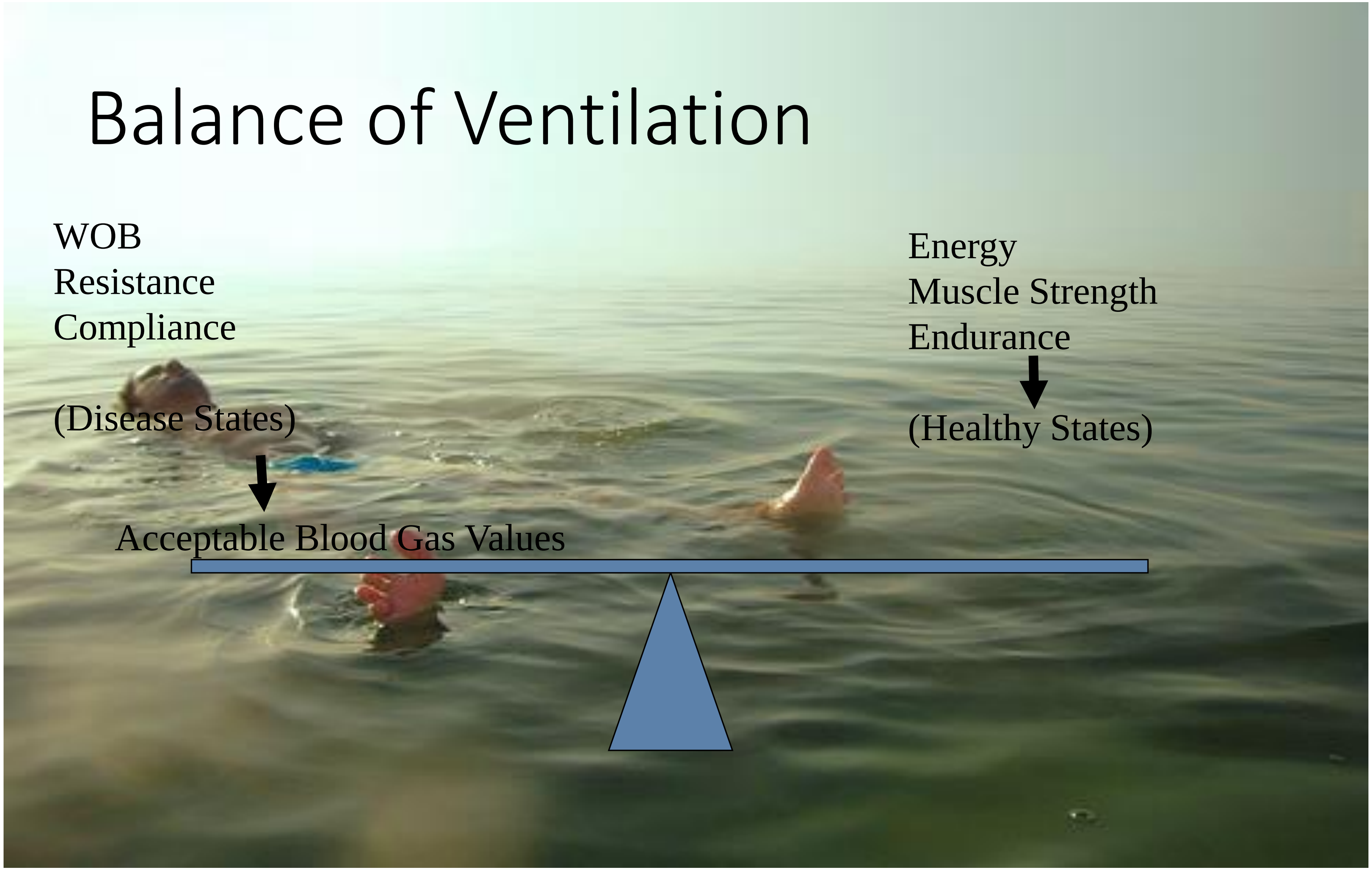
(Disease States)

Energy
Muscle Strength
Endurance

(Healthy States)



Balance of Ventilation



Balance of Ventilation

What do we do when out of Balance ?

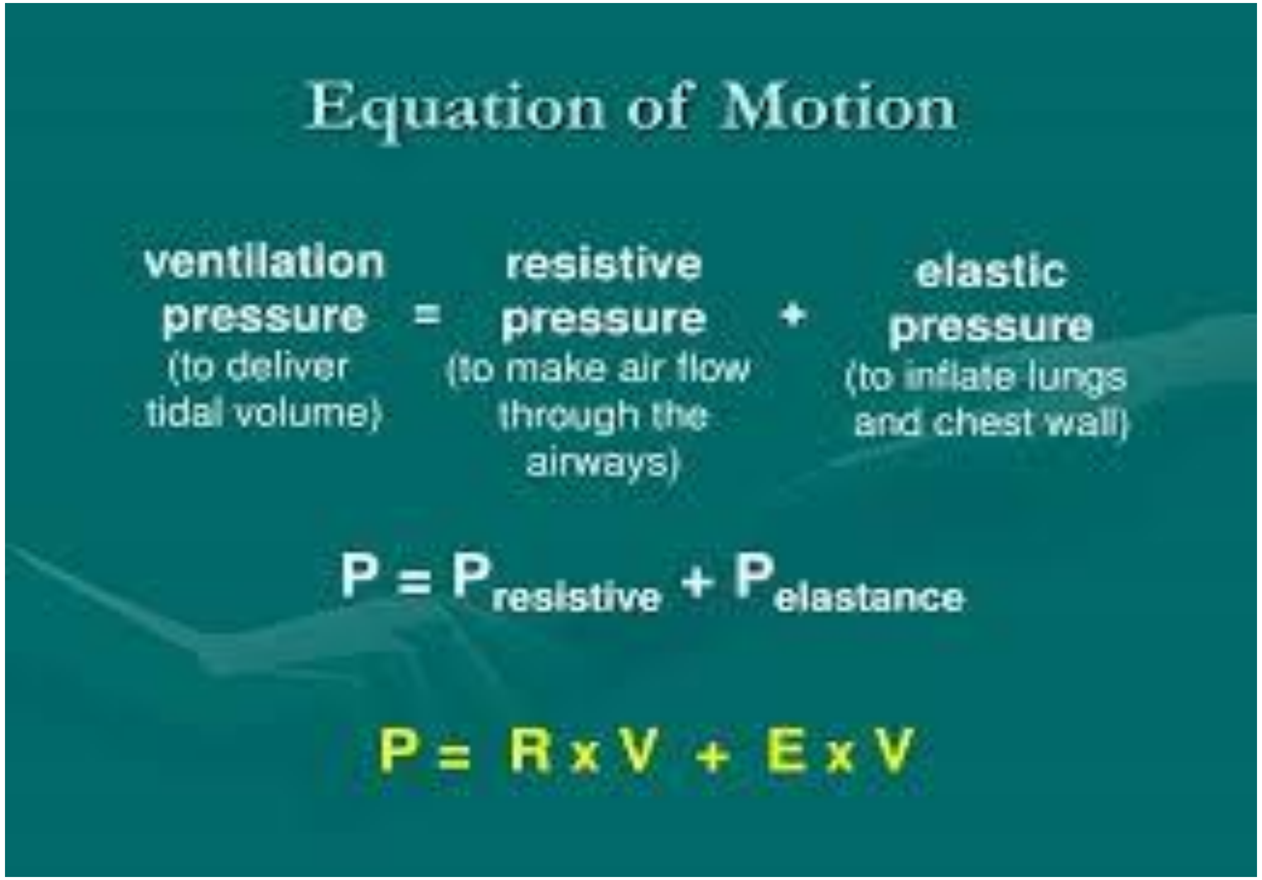
We have to find the correct level of support

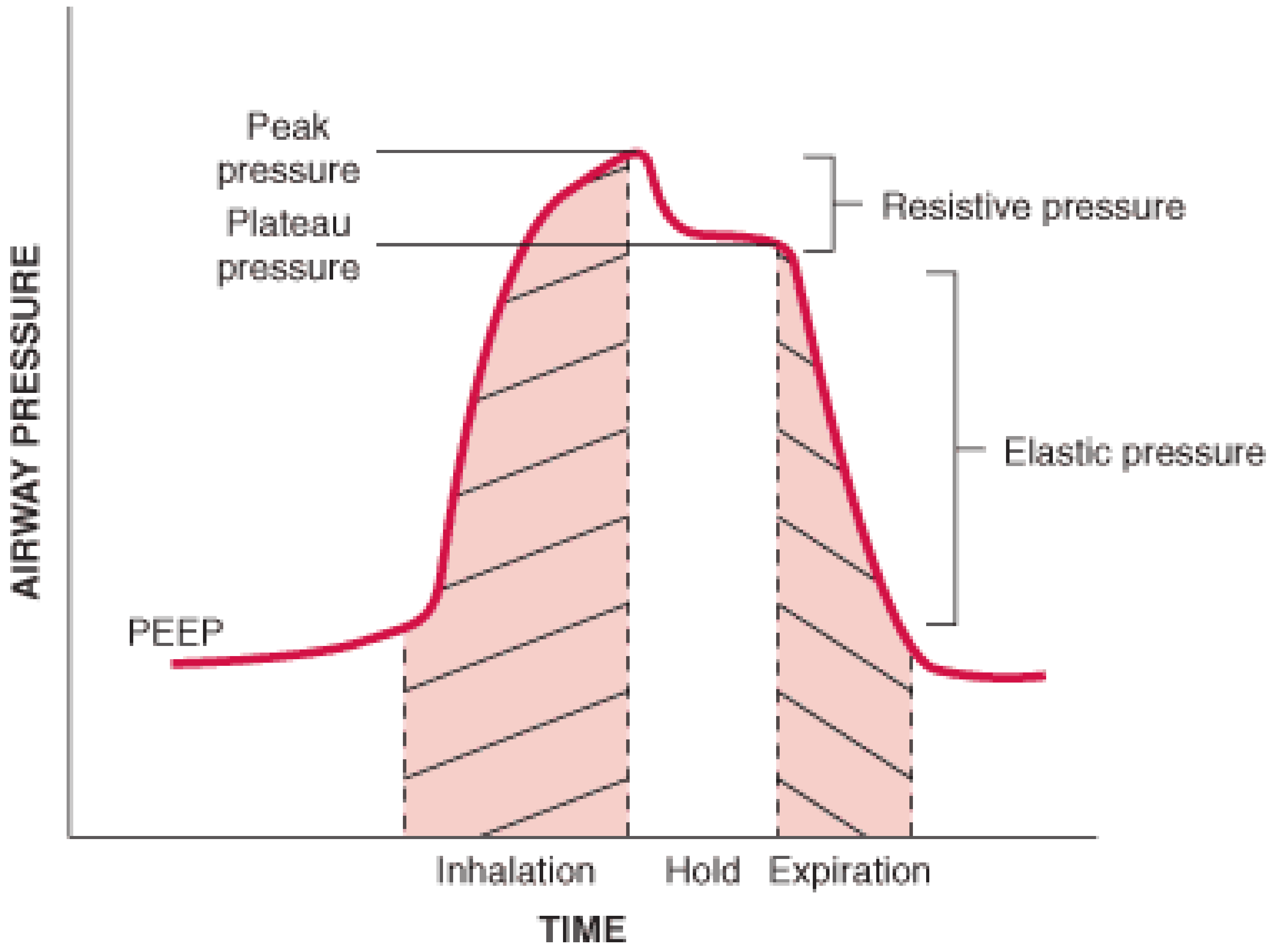
We have to find the correct level of support

We have to find the correct style of support

Equation of motion

- P muscle = P elastic + P resistive




Peak
pressure
Plateau
pressure
Resistive pressure
Elastic pressure
AIRWAY PRESSURE
PEEP
Inhalation
Hold
Expiration
TIME

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.

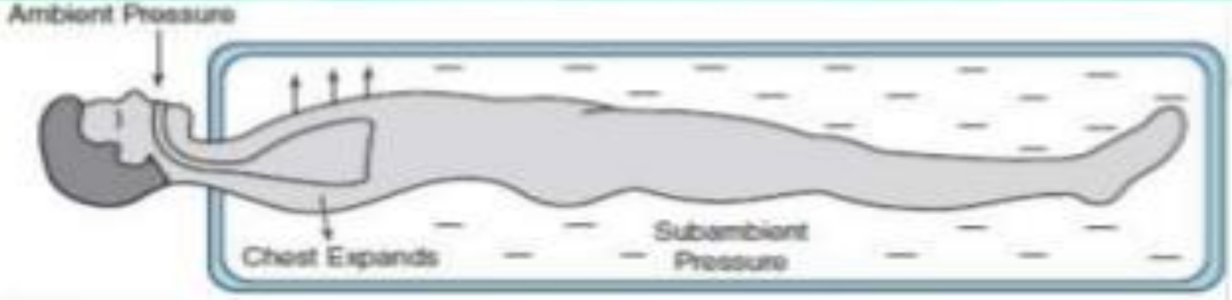


FIGURE 3-8 A schematic illustrating negative pressure ventilation.

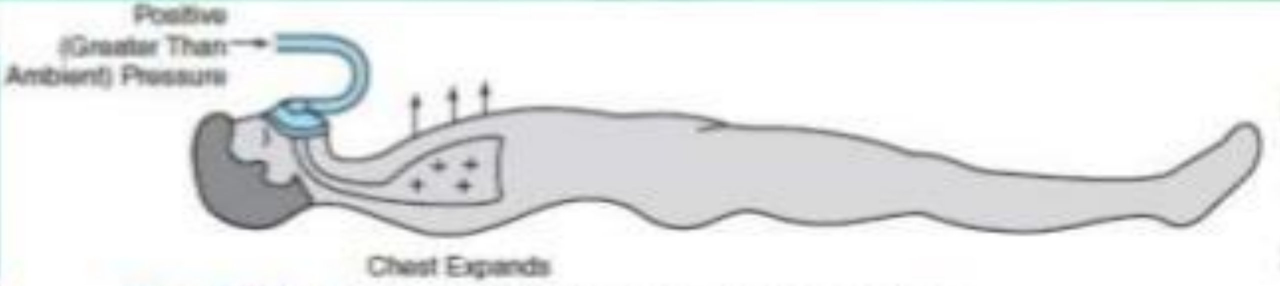


FIGURE 3-7 A schematic illustrating positive pressure ventilation.


GERDA
PETERICH

Basic Ventilator Parameters

- Mode
- Tidal volume
- Frequency or back up rate
- FiO2
- 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 </= **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 Pulmonary edema
Increase of lung compliance	Emphysema
Decrease of lung volumes	Pneumonectomy

IBW = Ideal body weight:

Males: IBW = 50 kg + 2.3 kg for each inch over 5 feet

Females: IBW = 45.5 kg + 2.3 kg for each inch over 5 feet

AjBW = adjusted body weight:

AjBW = IBW + 0.4(ABW - IBW)

Ideal Body Weight (IBW) (kg)

- IBW (male) = 50 + 2.3 (H – 60)مردان
- IBW (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 (PaCO2 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.

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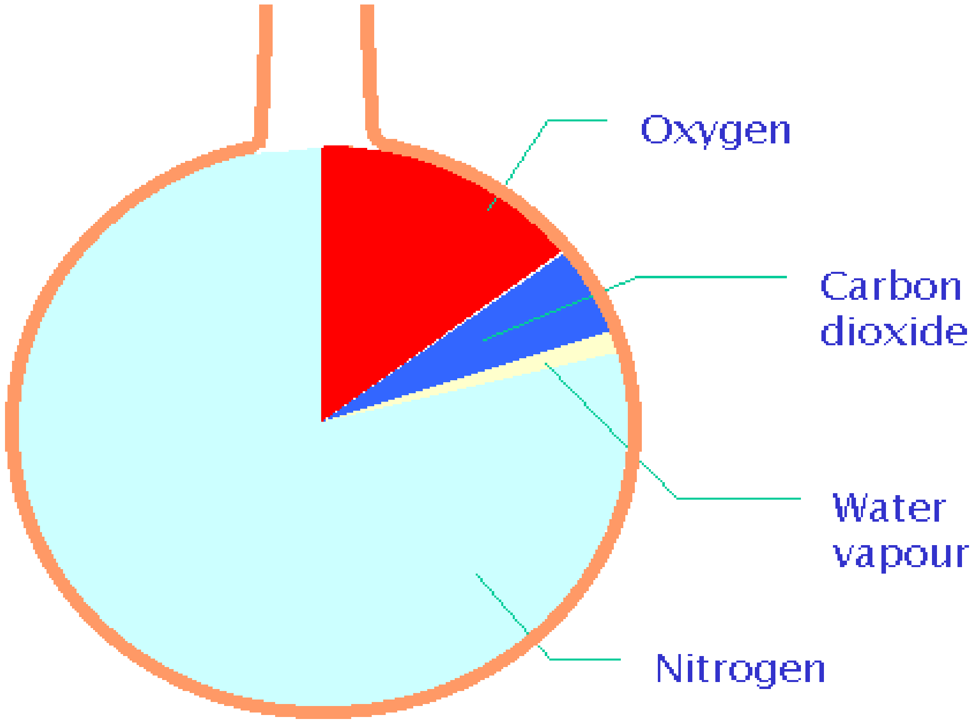
FIO2

- 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 >/= 96%



Alveolar pressure = $P_AO_2 + P_ACO_2 + P_AH_2O + P_AN_2$

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

- FIO2 **100%** ▶| **12h**, FIO2 **80%** ▶| **24h**, FIO2 **60%** ▶| **36h**

- Administration of FIO2 0.5 for long term usually does NOT result in toxicity.

- Retrlental Fibroplasia in prematurity(less than 1kg in both weight and 28 weeks gestation)

- Suppress of ventilation

- Convulsion (> 2ATA) ➡ the most acute toxic effect of 02

Oxygenation Using FiO2 and PEEP

$$\text{Desired FiO2} = \frac{\text{PaO2 (desired)} \times \text{FiO2 (known)}}{\text{PaO2 (known)}}$$

$$\text{Desired FiO2} = \frac{(60 \text{ mm Hg})\ (0.50 \text{ FiO2})}{40 \text{ mm Hg}}$$

Desired FiO2 = 0.75

Improving Ventilation / Oxygenation

- Oxygenation Using FiO_2 and PEEP
  - Adjusting FiO_2
    - Because of the linear correlation between PaO_2 and FiO_2 the following equation can be used to select the desired FiO_2 to achieve a desired PaO_2:

$$\text{Desired } FiO_2 = \frac{PaO_2 \text{ (desired)} \times FiO_2 \text{ (known)}}{PaO_2 \text{ (known)}}$$

Achieving correct PaO2

$$\frac{\text{Desired PaO2} \times \text{FiO2}}{\text{Current PaO2}}$$

Example: A patient is currently hypoxic with a PaO2 Of 60 on an FiO2 of .45. The physician orders to maintain A PaO2 of at least 80 mmHg and asks you to adjust the Ventilator accordingly

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

Increase the FiO2 to .60 to achieve a PaO2 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_2O 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

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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

- **<u>Time</u>:** the ventilator cycles at a set frequency as determined by the controlled rate.

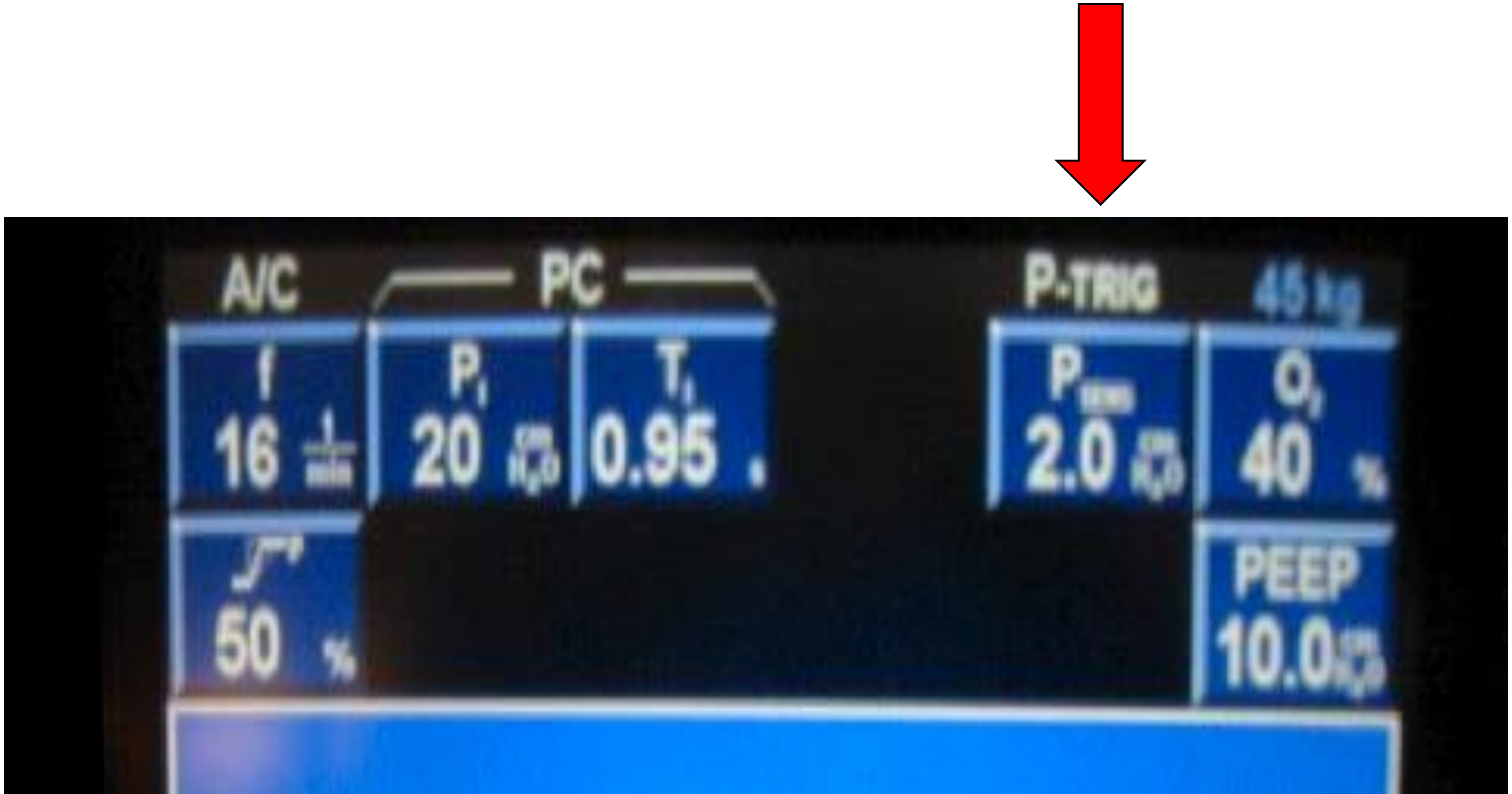
- **<u>Pressure</u>:** the ventilator senses the patient's inspiratory effort by way of a decrease in the baseline pressure.

- **<u>Flow</u>:** 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)



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

Volume Controlled

Pressure Controlled

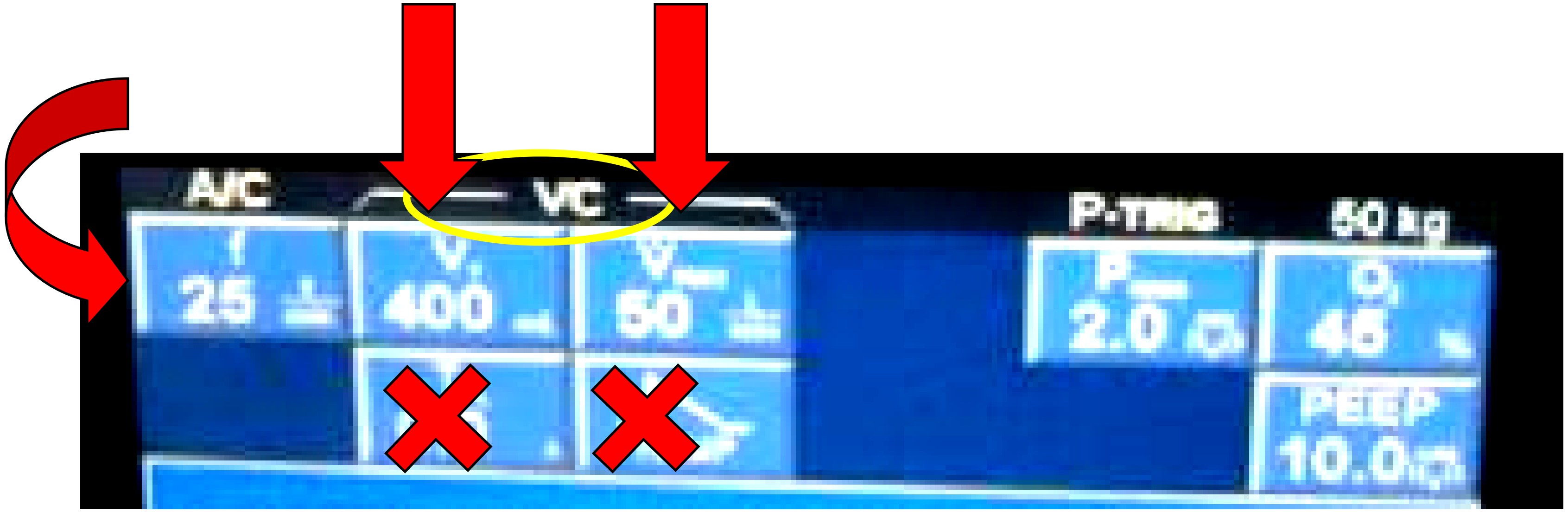
EITHER CAN BE USED WITH A/C OR SIMV!

What do you set?

Volume Controlled

<u>You set:</u>
Tidal volume
Peak flow
Rate

Where are those?



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

What do you set in PC?

Pressure Controlled

<u>You set:</u>
Pressure limit
Time spent in inspiration (Itime)
Rate

<u>You set:</u>
Pressure limit
I:E ratio
Rate

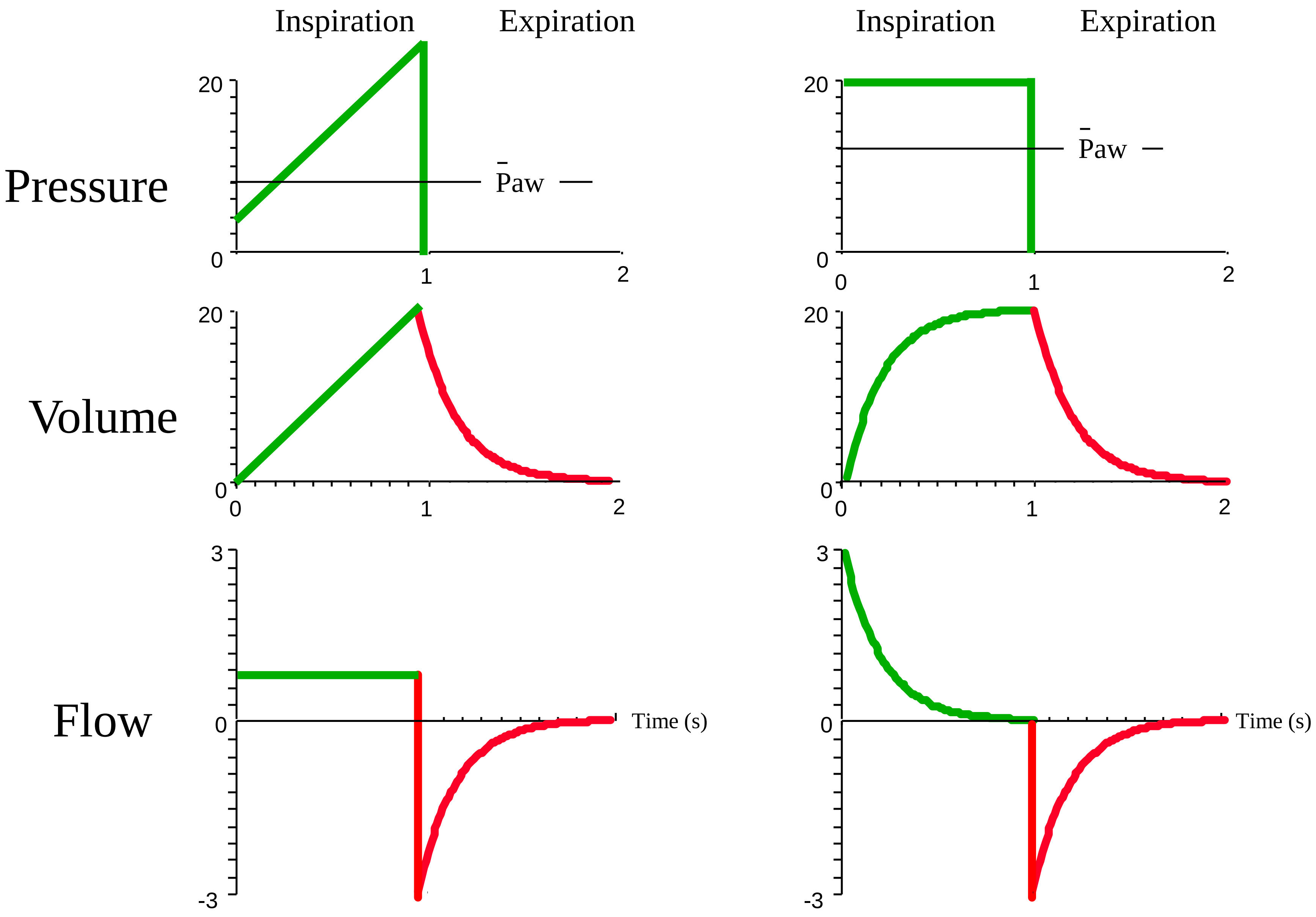
Where are those?

- 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 H2O
  - 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.

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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

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_2 (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

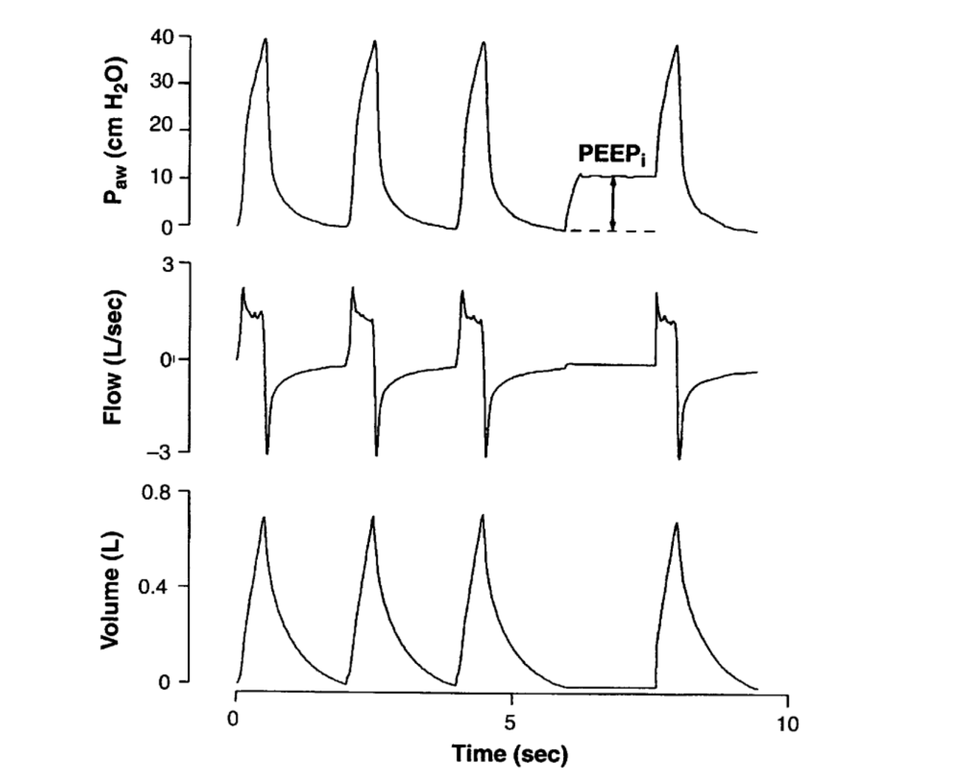
- Why does hyperinflation occur?
  - Airflow limitation because of dynamic collapse
  - No time to expire all the lung volume (high RR or Vt)
  - Expiratory muscle activity
  - Lesions that increase expiratory resistance

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 Pk, then occult PEEP is present

Auto-PEEP or Intrinsic PEEP

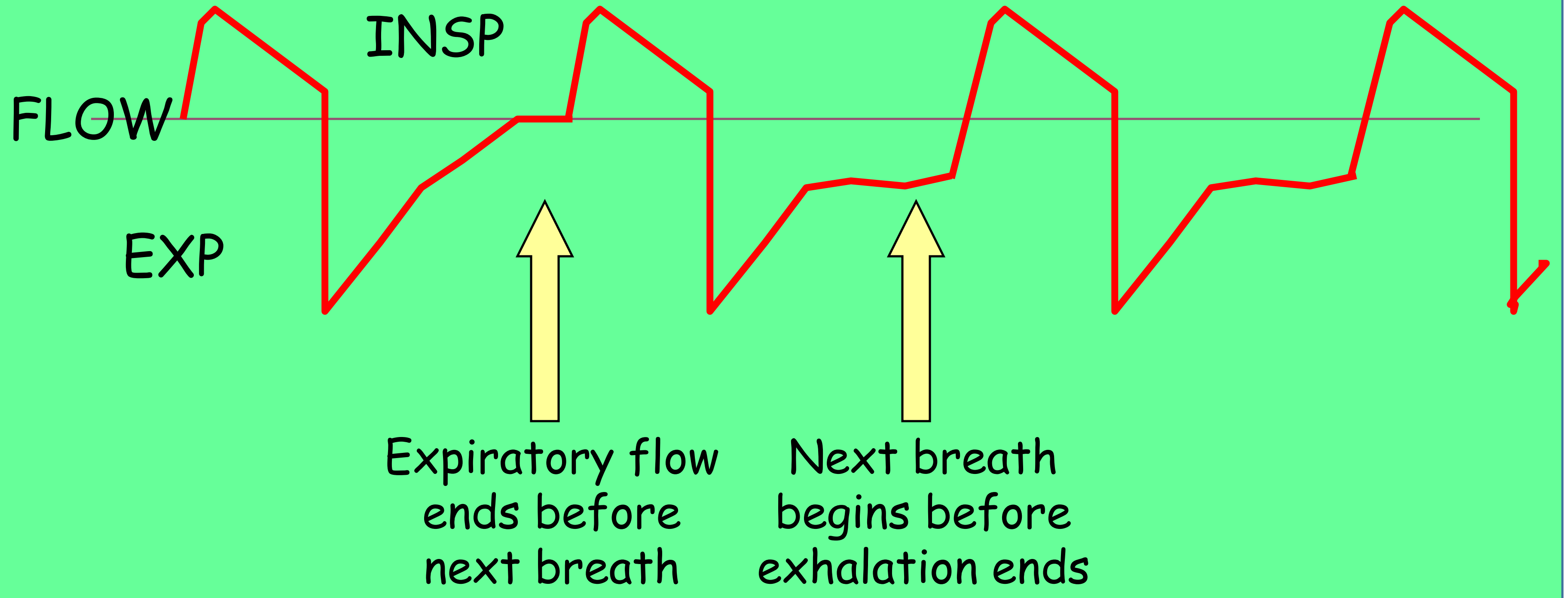
- Auto-PEEP is measured in a relaxed pt with an end-expiratory hold maneuver on a mechanical ventilator immediately before the onset of the next breath



Auto-PEEP or Intrinsic PEEP

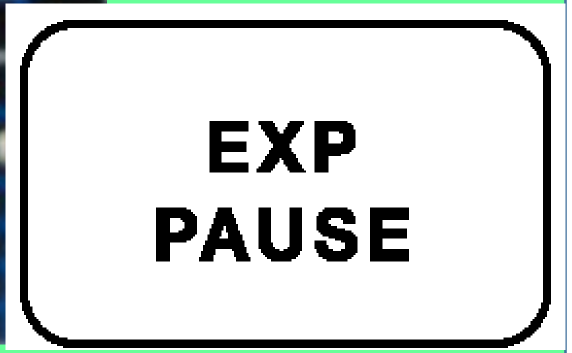
- Adverse effects:
  - Predisposes to barotrauma
  - Predisposes hemodynamic compromises
  - Diminishes the efficiency of the force generated by respiratory muscles
  - Augments the work of breathing
  - Augments the effort to trigger the ventilator

What is "Auto-Peep"?

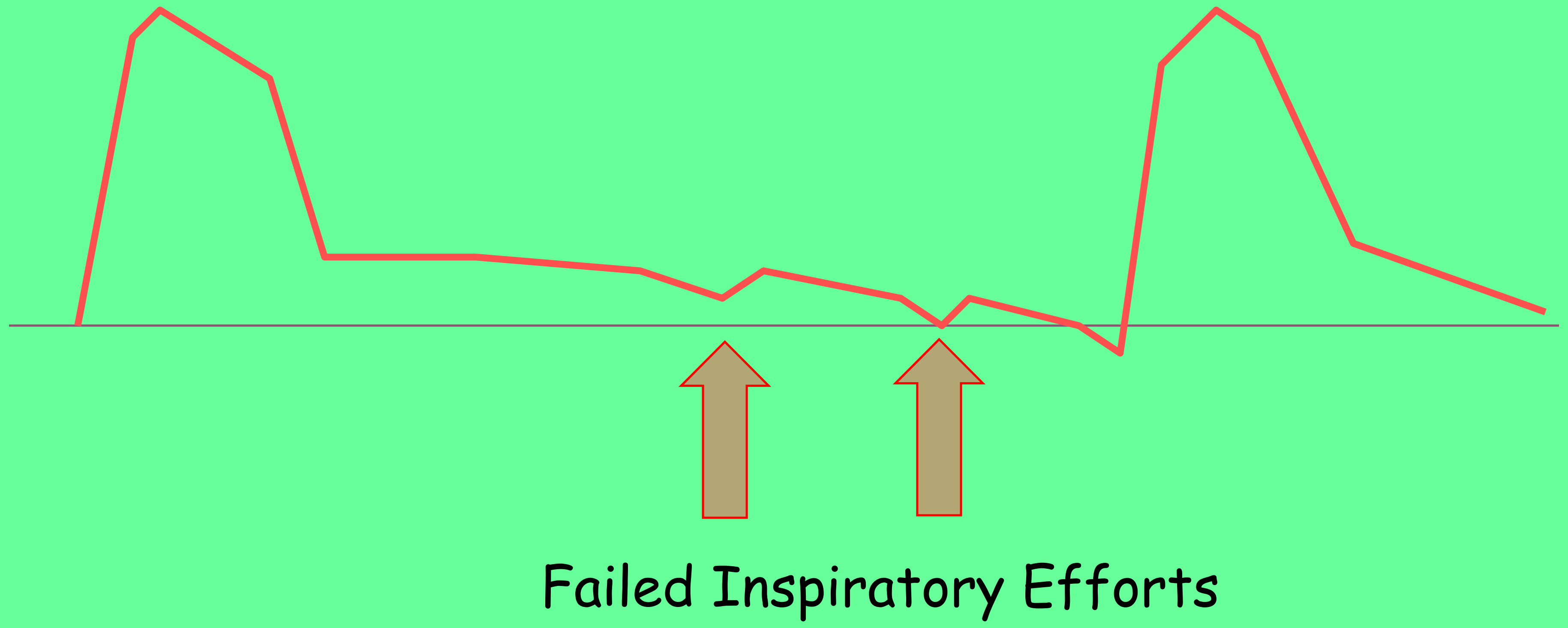


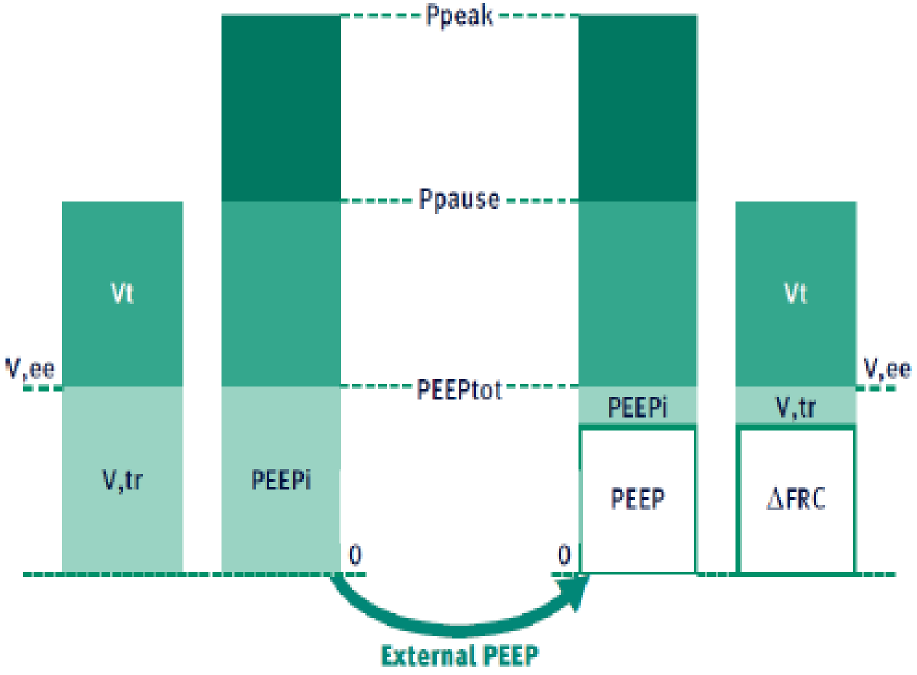
Obstructive lung disease (pursed lip)
Rapid breathing (breath stacking)
Forced exhalation (anxiety)

What is “Auto-Peep”?



Another clue to Auto-PEEP





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.

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- 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

dr.shumay[illegible]slam@gmail.co

- 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

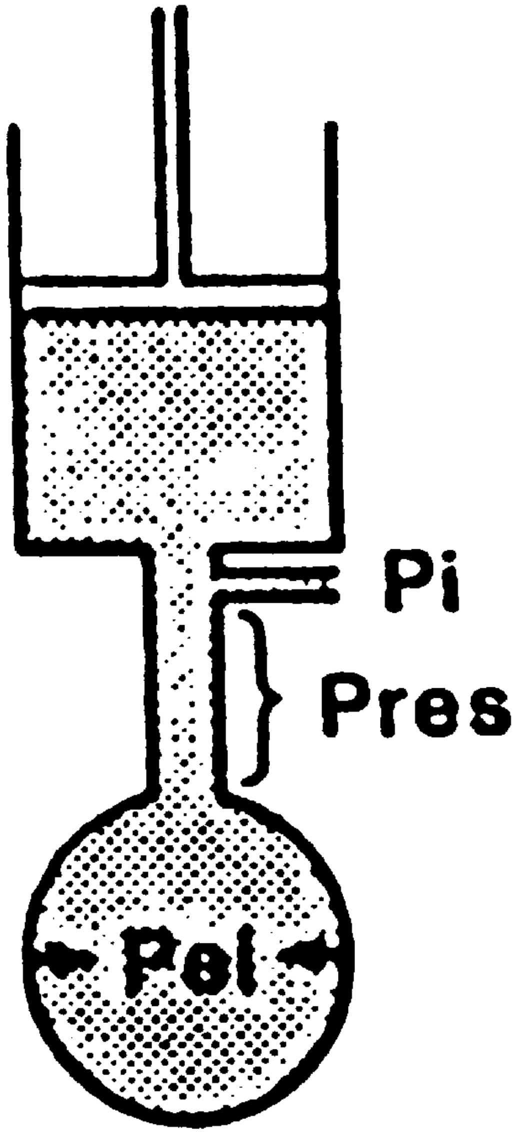
CPAP

- 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



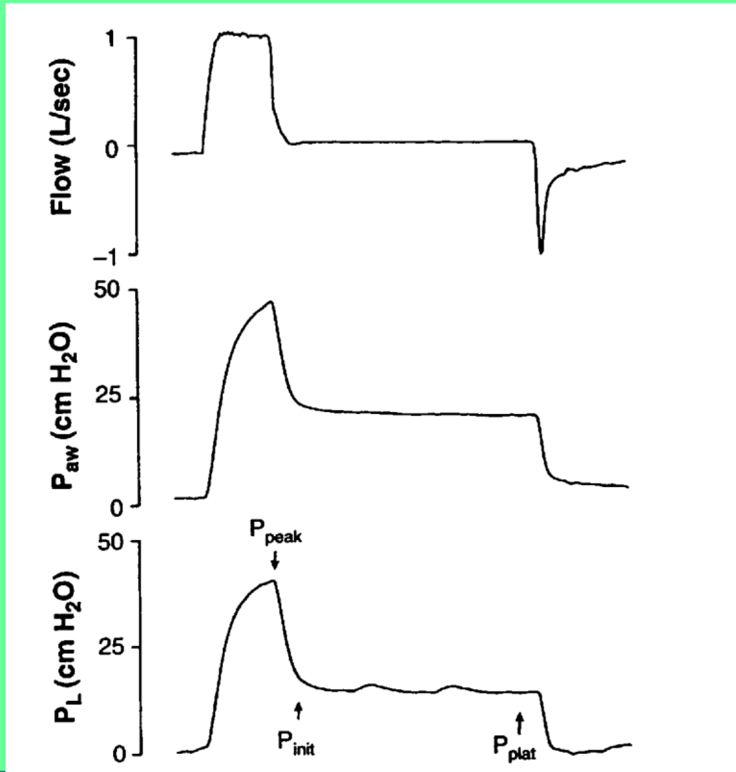
Peak Pressure (Ppeak)

- Ppeak = Pplat + Pres

  Where Pres reflects the resistive element of the respiratory system (ET tube and airway)

- Pressure measured at the end of inspiration

- Should not exceed 50cmH2O?



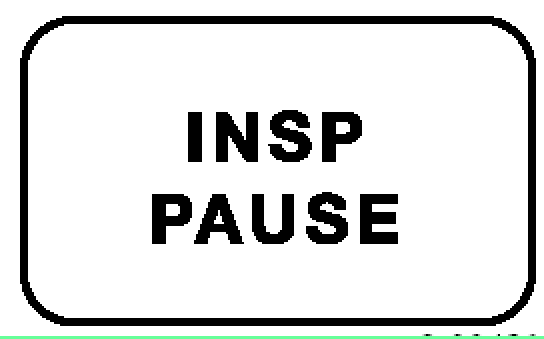
Compliance pressure (Pplat)

- Represent the static end inspiratory recoil pressure of the respiratory system, lung and chest wall respectively

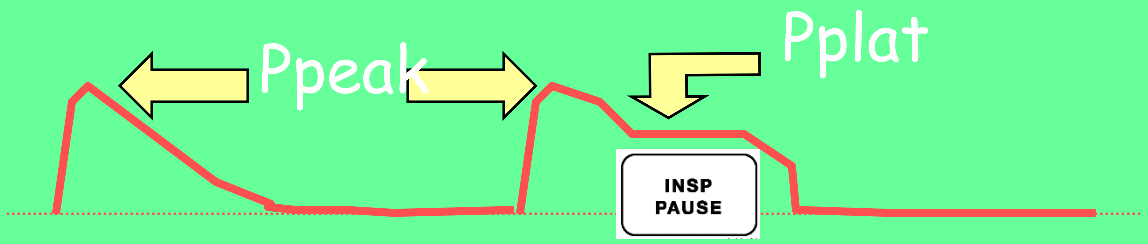
- Measures the static compliance or elastance
- End inspiratory hold, important in lung protective strategy

Plateau Airway Pressure

- Normally Pplat = Ppeak – 5to10 mmHg
  - In what situations isn't that the case?
- Why are we more interested clinically in Pplat?

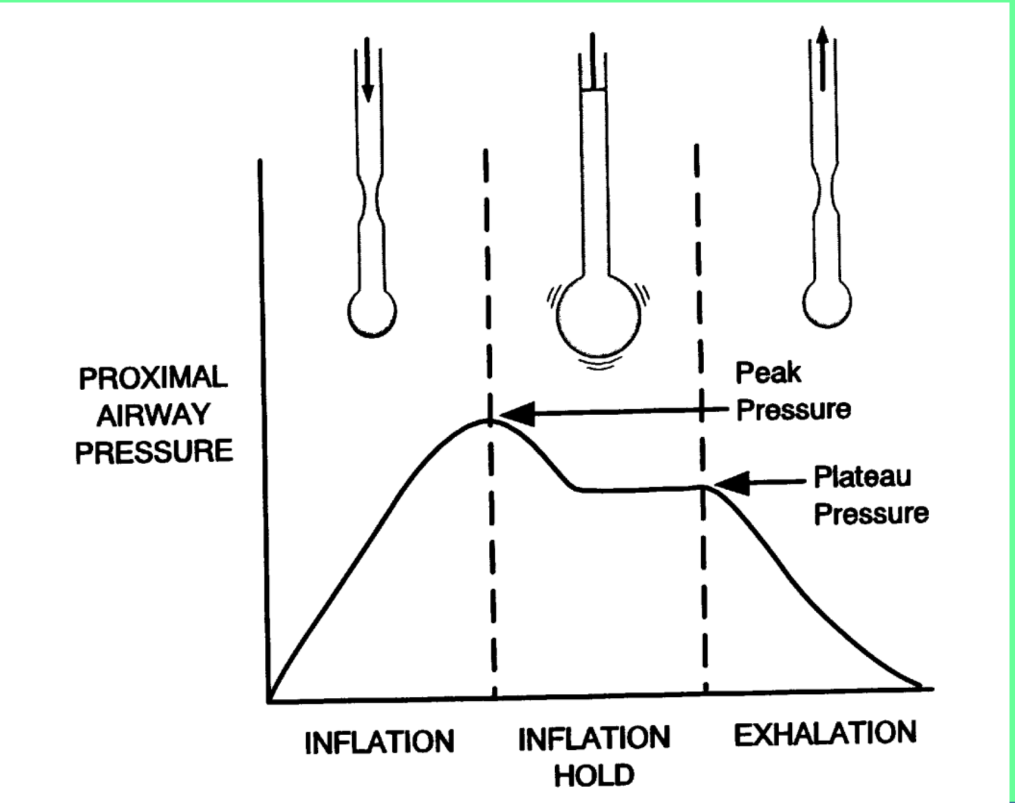


Puts a pause in the inspiratory cycle – no flow – measures pressure



Pplat

- Measured by occluding the ventilator 3-5 sec at the end of inspiration
- Should not exceed 30 cmH2O



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 unstability(because of longer duration of T insp)

Monitoring Lung Mechanics

Proximal Airway Pressures (end-inspiratory)

1. Peak Pressure Pk

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

2. Plateau Pressure Pl

Occlude expiratory tubing at end-inspiration

Function of elastance alone

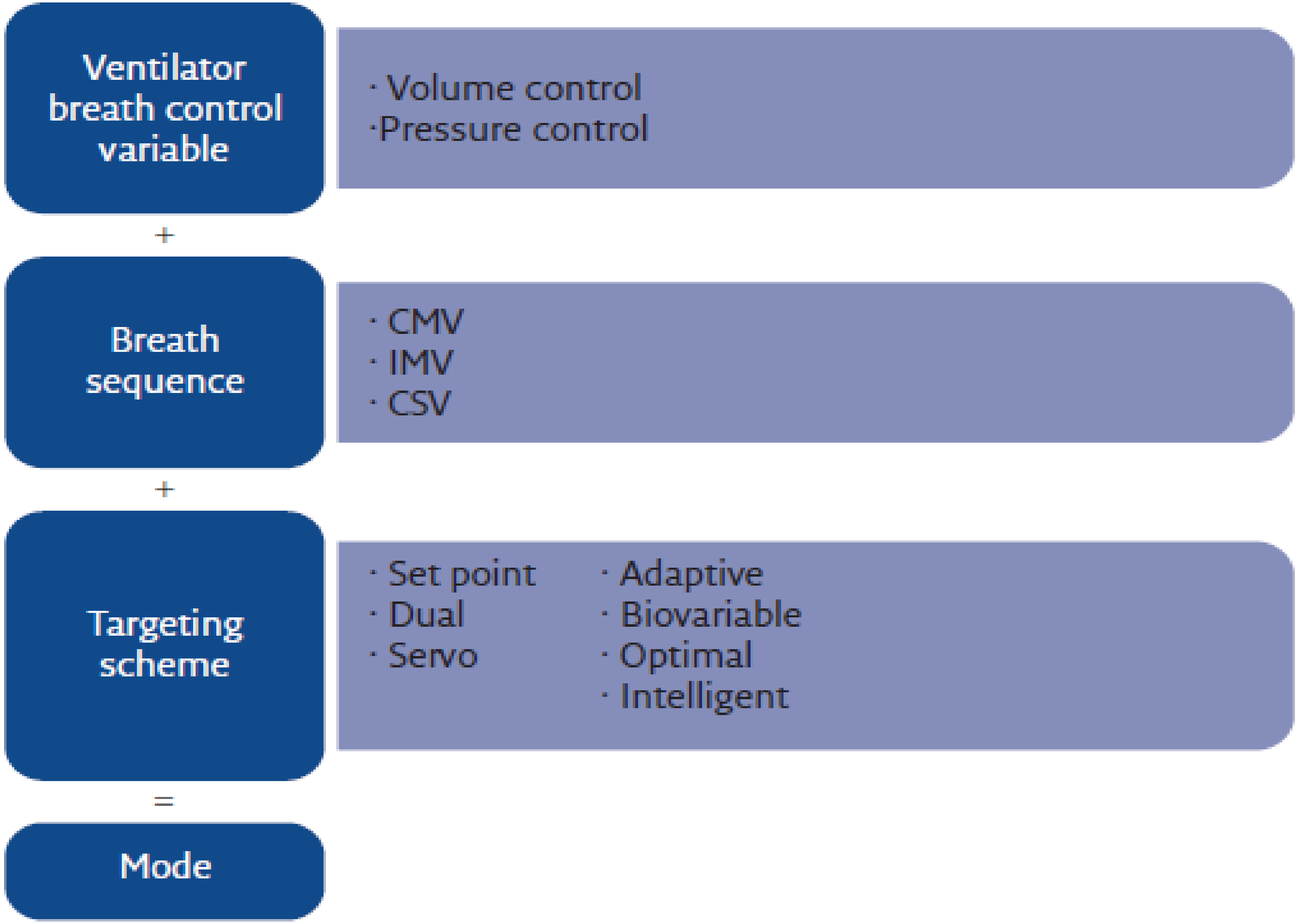


Figure 5 *Construction of the ventilation mode taxonomy suggested by Chatburn. The name of a ventilation mode results from three elements. CMV: continuous mandatory ventilation; IMV: intermittent mandatory ventilation; CSV: continuous spontaneous ventilation. Reproduced and modified from [31] with permission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

Use of Airway Pressures

Pk increased Pl unchanged

Tracheal tube obstruction

Airway obstruction from secretions

Acute bronchospasm

Rx: Suctioning and Bronchodilators

Use of Airway Pressures

Pk and Pl 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

$$C_T\ (L/cm\ H_2O) = \Delta V\ (L)/\Delta P\ (cm\ H_2O) \qquad (1)$$

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:

$$1/C_T = 1/C_L + 1/C_{CW} \qquad (2)$$
$$[\text{or } C_T = (C_L)(C_{CW})/C_L + C_{CW}]$$

N

Compliance

Static Compliance (Cstat)

Distensibility of Lungs and Chest wall

Cstat = Vt/Pl

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

Provides objective measure of severity of illness in a pulmonary disorder

Dynamic Compliance

Cdyn: Vt/Pk

*Subtract PEEP from Pl or Pk 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.

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

Static compliance

Vt /P plat-PEEP

Dynamic compliance

Vt / P peak-PEEP

Therefore C static is greater than C dynamic

Resistance

Airway Resistance

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

$$R\ (\text{cm } H_2O / L / \text{sec}) = \frac{\Delta P\ (\text{cm } H_2O)}{\Delta \dot{V}\ (L / \text{sec})} \qquad (4)$$

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

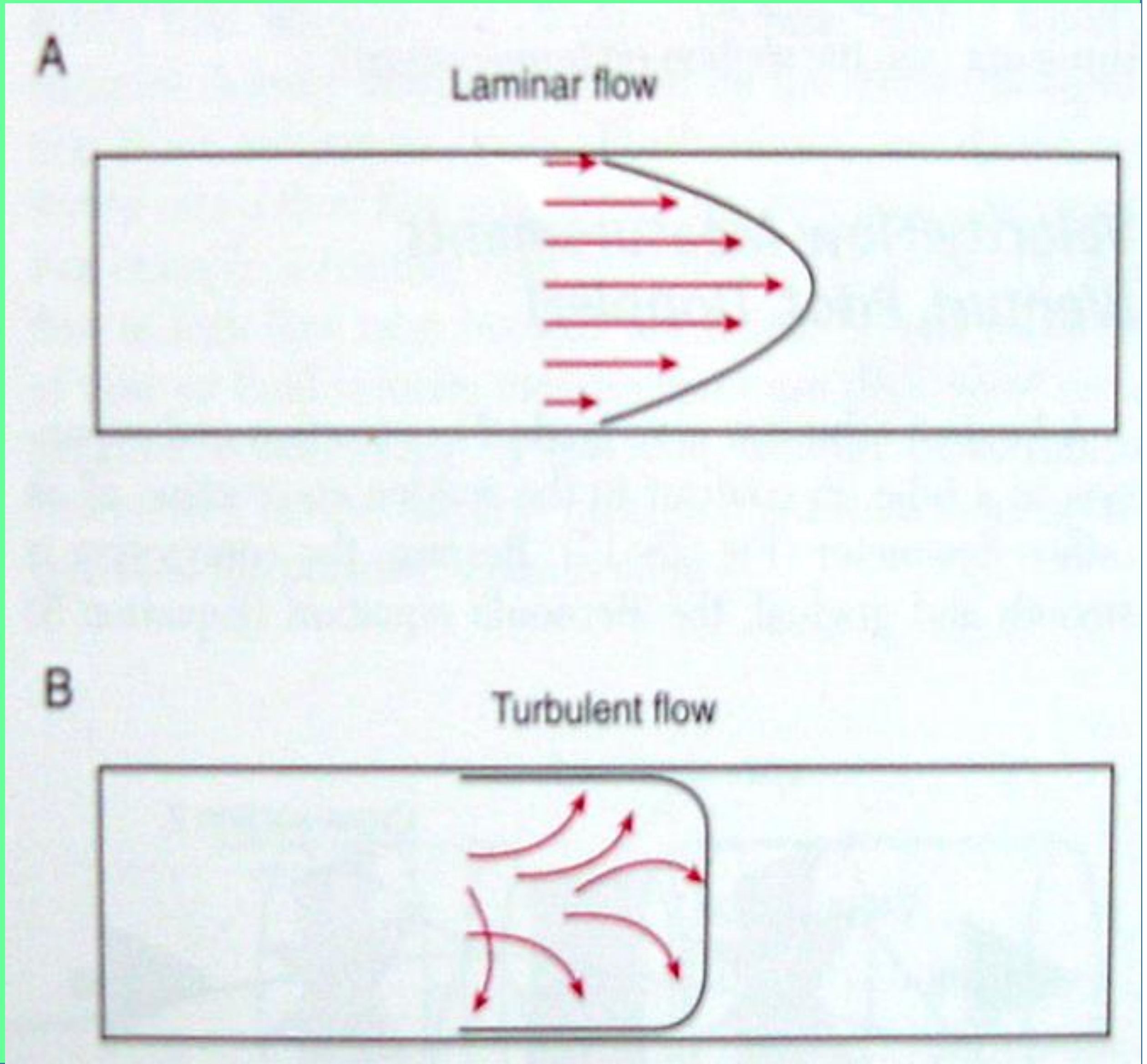
1-Laminar

Q=πpr4/8ηl

Hagen-poiseuille

2-Turbulent

Q2=4π2pr5/ρfl



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).

- 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 x BUR
- Peak flow: 60
- FiO2: 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

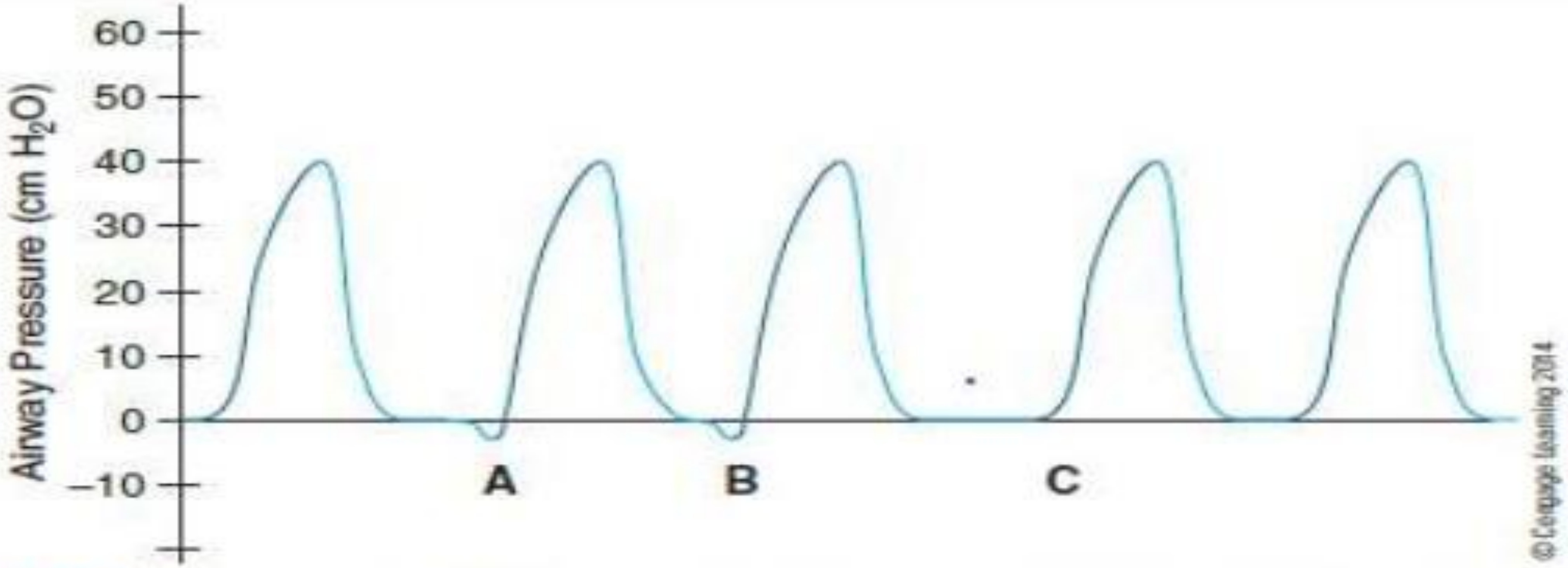


FIGURE 4-5 Assist/control mode pressure tracing. Each assisted or controlled breath triggers a mechanical tidal volume. (A) An assisted breath; note the negative deflection at the beginning of inspiration. (B) Another assisted breath that is initiated by the patient sooner than (A). (C) A controlled 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 $PaCO_2$

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.

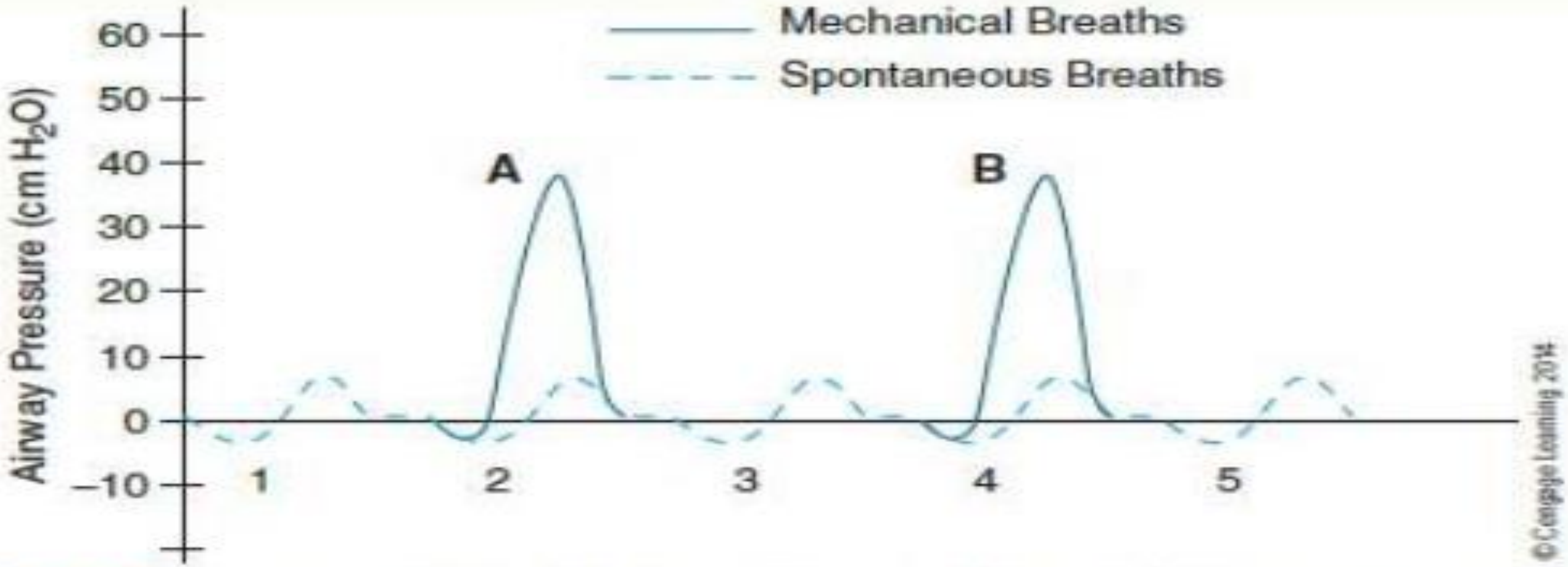


FIGURE 4-7 Synchronized intermittent mandatory ventilation (SIMV) pressure tracing with two mandatory breaths and five anticipated spontaneous breaths (only three active). SIMV mode does not cause breath stacking since the mandatory breaths are delivered slightly sooner or later than the preset time 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.

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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

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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.

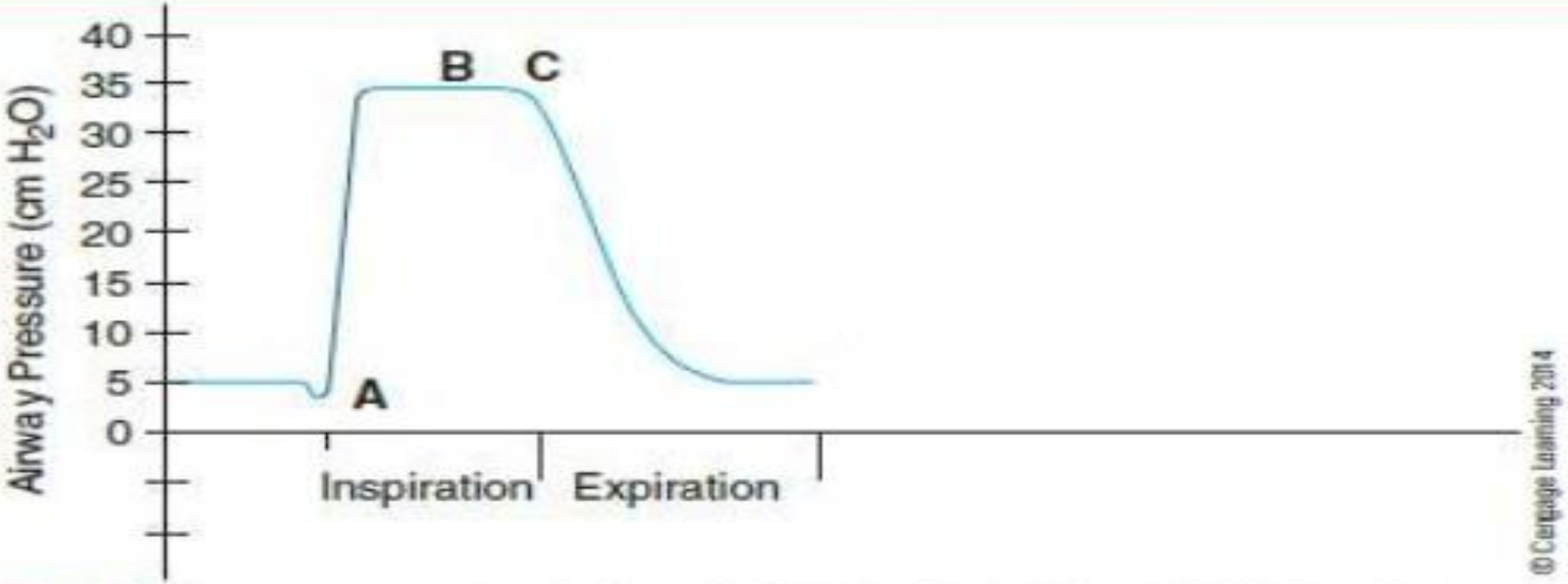

FIGURE 4-8 Pressure support ventilation (PSV) with PEEP of 5 cm H_2O. (A) Inspiratory effort; (B) Pressure support plateau of 30 cm H_2O (peak inspiratory pressure of 35 cm H_2O, PEEP of 5 cm H_2O); (C) Beginning expiratory phase when the inspiratory flow drops to 25% (or other predetermined %) of its 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_2O) are required to prevent alveolar collapse (which can lead to cyclic atelectasis and ventilator-associated lung injury)

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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.

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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

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