INVASIVE MECHANICAL VENTILATION (IMV) - pearls

ASV mode

- The ventilator estimates the Vt and RR based patient's compliance
  - It maintains the driving pressure <15 (usually 10 to 12) and the set minute ventilation by modifying the VT and the RR dynamically based on patient's compliance

Initial setting:

- %Minute ventilation: usual start 100-125%, lower for airway obstruction (90%) and higher for ALI with increased ventilatory demand (125% or more)
- PEEP – similar to other modes
- FiO2– similar to other modes
- Other parameters
  - Flow trigger insp (2-3L/min default): lower to avoid missed effort and higher to prevent auto trigger
  - P ramp (50-70% default): lower to alleviate flow starvation and longer to avoid pressure spike
  - Expiratory trigger sensitivity (ETS-25% default, 40% for COPD): higher for obstructive process and lower for restrictive
    - it can be set between 5 and 80%
    - Increasing the ETS results in a shorter inspiratory time while decreasing it results in a longer inspiratory time
  - Pasv limit: 30 cmH20 to maintain plateau pressure <30 and driving pressure <15

APRV mode

- Phigh is the equivalent of the plateau pressure.
- Tidal volume often exceeded 6 mL/kg predicted body weight
- The driving pressure is not relevant - (Phigh-Plow) often exceeds 15 to 20
- The very brief T-low results in incomplete exhalation and autoPEEP are uniformly present

Elevated plateau pressure

- Result from the sum of lung and chest wall compliance: target <30
- Causes
  - Intrinsic lung disease
    - Pneumothorax
    - Pulmonary edema
    - Worsening ALI - ARDS
    - Main stem intubation
  - Reduced chest wall compliance (contrary to intrinsic lung disease, does not generate abnormally high expiratory flow rates)
    - Obesity
    - intraabdominal hypertension
    - Others: eschar development from burns, fentanyl-induced chest wall rigidity, etc

Elevated Peak airway pressure

- Results from the sum of airway resistance, lung compliance, and chest wall compliance
- Causes
  - Bronchospasm
  - Mucus plugging or narrowing of the ETT due to accumulation of secretions
    - Instillation of normal saline before suctioning does not improve secretion clearance and more likely causes a fall in oxygen saturation

  - Problems with the ventilator tubing and endotracheal tube
    - Kink in the endotracheal tube

The difference between peak and plateau airway pressure allows to differentiate increase in airway resistance versus decreased compliance:

- This is true only when the ventilator is programmed to a constant, rather than decelerating, inspiratory flow
- Normal Ppeak-Pplat difference: 8 - 10
- Increase in airway resistance
  - Elevated peak airway pressure but little change in the plateau pressure
  - Ppeak-Pplat difference > 8 to 10 cm H_2O
- Decreased compliance
  - Normal Ppeak-Pplat difference

PEEP

- Successful recruitment as a result of more PEEP would be expected to require lower driving pressure for the same Vt, because lung compliance is improved after alveolar recruitment
  - PC mode
    - Derecruited lungs: if increase in PEEP results in increased Vt and decrease PEEP in decreased Vt it is consistent with derecruited lungs
    - Overdistention: if increase in PEEP results in decrease in VT and decrease in PEEP in increased Vt it is consistent with overdistension
  - AC mode
    - Derecruited lungs: the magnitude of increase in Pplat should be the same as or less than the increase in PEEP
    - Overdistention: increase in PEEP results in out of proportion increased Pplat pressure

  - The pattern of change in airway pressure as the lungs are inflated with volume-control ventilation using a constant inspiratory flow rate (square wave pattern) provides clues as to the likelihood of overinflation
    - A concave upward contour of airway pressure vs time (with constant flow) suggests overinflation is present, because proportionally higher pressure is required to complete lung inflation
    - Concave downward shape indicates relatively modest increase in airway pressure as the lungs are fully inflated

Driving pressure

- Results from the Vt and compliance ratio
- It is calculated as Plateau pressure – PEEP (set and auto PEEP)
- Target associated with better outcome: <15
- Best measured when ventilation is passive
  - High effort changes the pleural pressure and affects the driving pressure
  - In PC mode peak airway pressure minus PEEP can be a good estimate

AutoPEEP – intrinsic PEEP

- The level of intrinsic PEEP can be measured directly only by programming an expiratory pause into the ventilator

- To trigger a breath, the patient must generate a flow ("flow triggering") that signals the ventilator to deliver the breath
    - Intrinsic PEEP may make this difficult because incomplete exhalation can lead to ineffective triggering and is associated with increased work of breathing
    - Inhaled bronchodilators, corticosteroids, and (sometimes) increases in extrinsic ventilator PEEP may alleviate such wasted efforts
        - Extrinsic ventilator-set PEEP may offset the patient's intrinsic PEEP, thus facilitating ventilator breath delivery
        - A target ventilator extrinsic set PEEP level that is 80% of the total intrinsic PEEP level measured is recommended as a starting point

Leak in the respiratory system

- When expiratory volume does not equal inspiratory volume, the ventilator is programmed to reset to zero, explaining the sudden drop in "lung volume" before each breath
- The flow graphic shows persisting flow at a constant level through the last two-thirds of each inspiration, representing leak flow
    - This persisting "inspiratory" flow can trigger the ventilator, even in paralyzed patients, causing auto cycling
- Causes
    - Endotracheal tube or tracheostomy cuff leak
        - Cuff underinflation or damage
        - Cephalad migration of the ETT (partial extubation)
        - Increase airway pressure causing leak around the intact cuff
        - NGT-OGT misplacement
        - Wide discrepancy between ETT and tracheal diameter
    - Ventilator inspiratory tubing
    - Bronchopleural-cutaneous fistula

Chest tube-Air leak

- Causes
    - Leak in the collection system
        - Clamping the chest tube as it connects to the pleural drainage unit will terminate the air leak seen in the suction chamber
    - Large bronchopleural fistula
    - Intraparenchymal placement
    - Outward migration of the chest tube such that one or more of its side holes sit outside the patient and can entrain air from the atmosphere
- Indications for placement of an additional chest tube
    - If the patient is clinically unstable owing to incompletely evacuated pleural air
    - Large bronchopleural fistula that is insufficiently treated by a single chest tube
- PEEP is frequently reduced In the presence of a bronchopleural fistula to try to decrease mean alveolar pressure, reduce the magnitude of air leaking through a bronchopleural fistula, and promote closure of the fistula

Ventilator synchrony - three phases

- Triggering - turning on coincident with effort
- Flow - providing sufficient flow throughout the breath to meet demand
- Cycling - ceasing support when neural output ceases (cycling off)

Ventilator dyssynchrony

The two most common dyssynchronies are ineffective (missed) triggering and double triggering (DT)

Triggering

- Ineffective (missed) trigger
  - Occurs when an inspiratory effort does not trigger a ventilator breath
    - Can be detected by observing the ventilator graphics for drop in positive airway pressure breaths while detecting patient inspiratory efforts
- Double trigger
  - Two ventilator breaths initiated by the patient delivered within one inspiratory time
  - The root cause for this dyssynchrony is a shorter inspiratory time of the mechanical breath in comparison to patient neural inspiratory time (shorter mechanical breath I-times to neural I-times)
    - Lengthening the mechanical breath inspiratory time to match the patient neural inspiratory time or increasing the ventilator output pressure and tidal volume may minimize or eliminate DT
- Reverse triggering
  - Respiratory muscle contraction occurs after the onset of a passive mandatory breath
  - It is thought that the passive mechanical thoracic insufflation triggers a patient-initiated breath as a reflex
  - The respiratory muscle activity is strong enough to trigger a second stacked or double cycled breath
  - Initially observed in deeply sedated patients and in brain-dead patients. Newer data suggest reverse triggering is more common than originally thought

Flow

- Occurs when the inspiratory flow is less than the patient desires
  - This results in patient generation of negative pressure during vigorous inspiratory effort
    - Can be seen in the pressure graphic
    - During each breath, airway pressure varies irregularly
    - Sometimes causes a concave appearance to the inspiratory pressure waveform

Cycling

- Premature
- Delayed
  - The inspiratory time of the mandatory breath may be longer than the patient desires; thus, ventilator cycling from inhalation to exhalation is “delayed” relative to the patient
  - The patient begins exhaling near the end of the breath delivery, generating additional positive thoracic pressure that produces a characteristic abrupt peak in pressure and early transition to expiratory flow while the ventilator continues in the inspiratory phase

Steps that could improve synchrony

- Increase sedation
- Increase minute ventilation
- Increase PEEP
- Change to a pressure-targeted mode
  - Pressure support almost always eliminates all double triggering
    - However, the majority of patients with ARDS with double triggering have an exceedingly high respiratory drive. Therefore, the elimination of double triggering with pressure-support ventilation comes at the cost of high tidal volumes

- Modify inspiratory time – flow
    - The most common causes of ventilatory dyssynchrony are the improper matching of mechanical breath I-times to neural I-times. Specifically, the mechanical breath inspiratory time is too short in comparison to longer neural I-time.
        - Increase inspiratory time in VCV and PCV and decrease the cycling percentage of peak flow in PSV
        - Increase inspiratory flow in cases of flow dyssynchrony

Ventilator alarms

- Peak airway pressure (Ppeak)
    - Usually set at 40. Consider adjustment (higher) in patients with increased chest wall resistance such as obesity and abdominal hypertension.
- Low minute ventilation
    - Usually set at 2-3 L/min to detect tube disconnection, airleaks and significant changes in RR and Vt.
- Most ventilators do not have an alarm for low tidal volume.
    - When an acute decrease in compliance or increase in resistance occurs in VC mode, the Ppeak increases sounding the Ppeak alarm, however, in PC mode will result in decreased Vt and no or minimal change in Ppeak and no pressure alarm is triggered.
    - Therefore, in PC mode set the low minute ventilation alarm rather than the peak airway pressures tidal volumes.
        - The low minute ventilation alarm threshold should be increased to a minute ventilation that is 60% to 80% of the patient's needed minute ventilation to allow for adequate monitoring for acute changes in the patient's respiratory compliance that might occur with development of mucous plugging of large airways, pneumothoraces, acute pulmonary edema, or migration of the endotracheal tube into a main stem bronchus.

Waveform capnometry

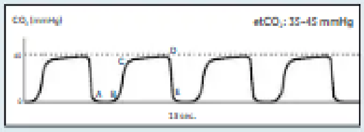
Can provide useful information about the changes in alveolar ventilation, dead space ventilation, and cardiac output.

$PetCO_2$ is normally 2 to 5 mmHg below $PaCO_2$

- PE, circulatory shock, and severe hypothermia can increase the $PaCO_2$ - $PetCO_2$ gradient to >5 mmHg
- PE increases alveolar dead space - ventilated but unperfused lung units. Alveolar dead space gas contains no CO_2, which therefore lowers the $PetCO_2$ relative to the $PaCO_2$
  Circulatory shock and severe hypothermia can transiently reduce the amount of CO_2 returning to the lung and thereby reduce the $PetCO_2$
- Main stem bronchial intubation increased shunt - perfused but unventilated lung units causing severe hypoxemia but have only a minor effect on $PaCO_2$ and $PetCO_2$
- If $PetCO_2$ increase >5% after the passive leg raising (PLR) maneuver, a fluid bolus will augment cardiac output by >15% (great specificity)
- Waveform analysis can be useful identifying specific conditions such as ETT malfunction, airway obstruction, and systemic hypoperfusion (see graphs below).

Normal Capnogram

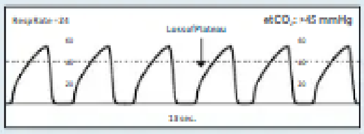
The normal capnogram is a waveform which represents the varying CO_2 level throughout the breath cycle.



Waveform Characteristics:

A-B: Baseline
B-C: Expiratory Upstroke
C-D: Expiratory Plateau
D: End-Tidal Concentration
D-E: Inspiration

Bronchospasm/Asthma



Other Possible Causes:

- Bronchospasm/COPD
- Obstruction in the expiratory limb of the breathing circuit
- Presence of a foreign body in the upper airway
- Partially kinked or occluded artificial airway

*Increasing $etCO_2$ (Hypoventilation)

Other Possible Causes:

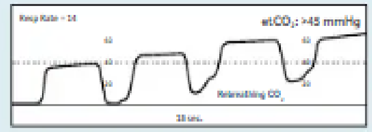
- Decrease in respiratory rate
- Decrease in tidal volume
- Increase in metabolic rate
- Rapid rise in body temperature (malignant hyperthermia)

*Decreasing $etCO_2$ (Hyperventilation)

Other Possible Causes:

- Increase in respiratory rate
- Increase in tidal volume
- Metabolic acidosis
- Fall in body temperature

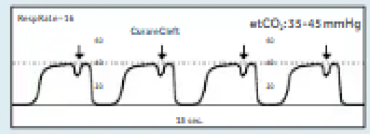
Rebreathing CO_2



Other Possible Causes:

- Faulty expiratory valve
- Inadequate inspiratory flow
- Partial rebreathing
- Insufficient expiratory time

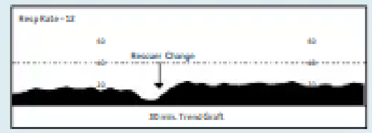
Curare Cleft



Other Possible Causes:

- Patient is mechanically ventilated
- Depth of cleft is proportional to degree of muscle relaxants

Cardiac Arrest



Other Possible Causes:

- Decreased or absent cardiac output
- Decreased or absent pulmonary blood flow
- Sudden decrease in CO_2 values

Return of Spontaneous Circulation

Other Possible Causes:

- Increase in cardiac output
- Increase in pulmonary blood flow
- Gradual increase in CO_2 production

Sudden loss of waveform

- ET tube disconnected, dislodged, kinked or obstructed
- Loss of circulatory function

Decreasing $EtCO_2$

- ET tube cuff leak
- ET tube in hypopharynx
- Partial obstruction

CPR Assessment

- Attempt to maintain minimum of 10mmHg

Sudden increase in $EtCO_2$

- Return of spontaneous circulation (ROSC)

Bronchospasm ("Shark-fin" appearance)

- Asthma
- COPD

Hypoventilation

Hyperventilation

Decreased $EtCO_2$

- Apnea
- Sedation