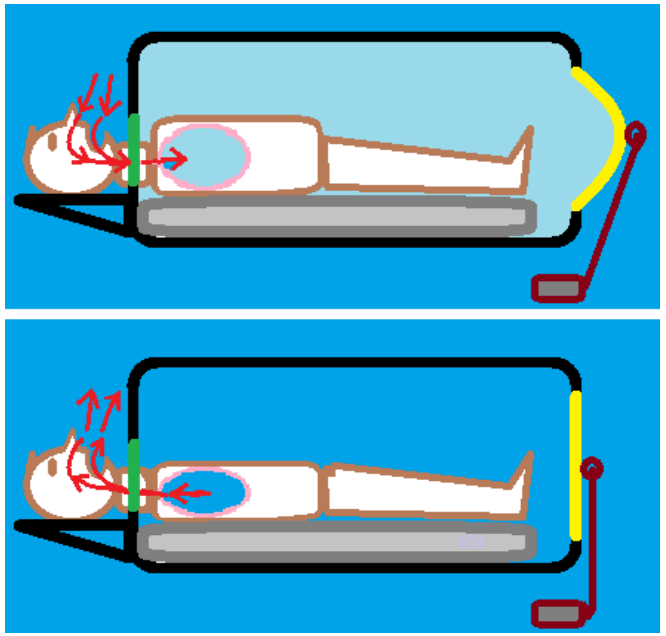
Basics of Mechanical Ventilation Modes

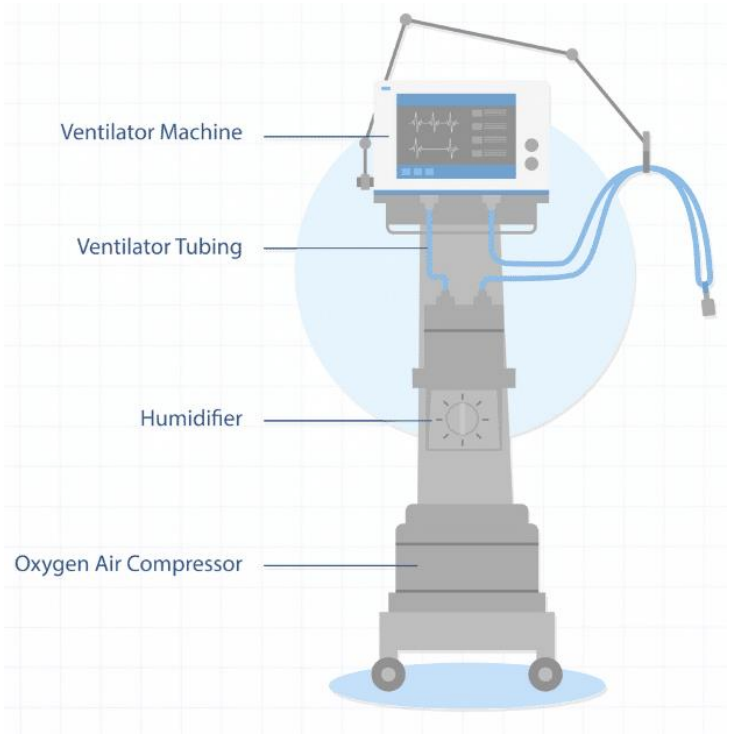
History of Mechanical Ventilation

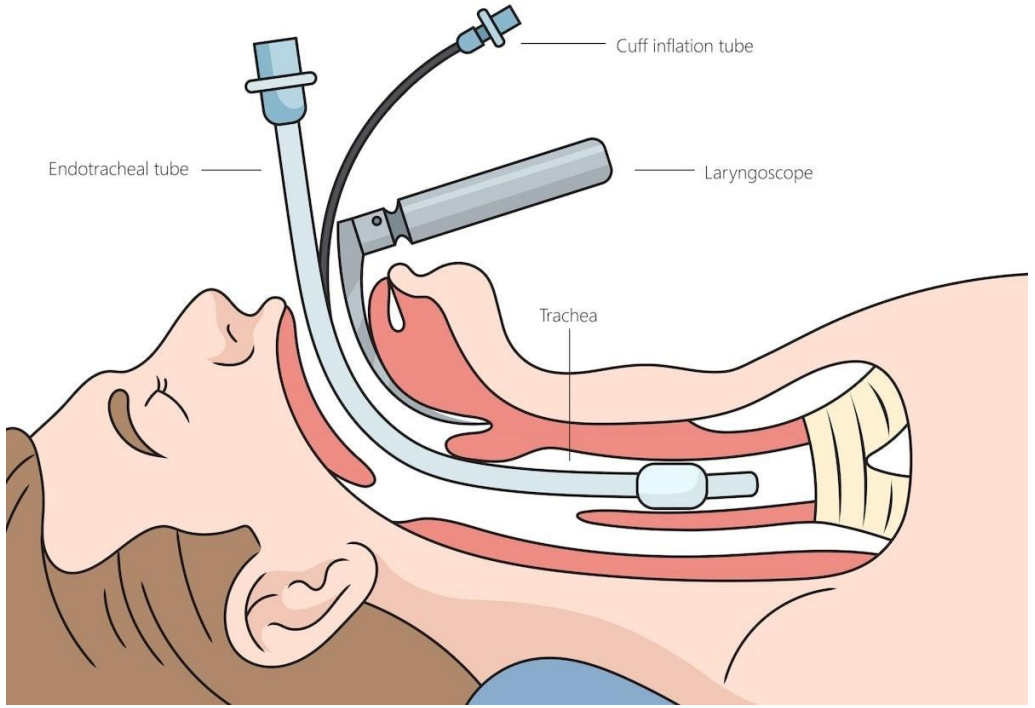
- Negative pressure (Iron lung - early 1900s)



Positive Pressure Ventilation

- Invasive ventilators

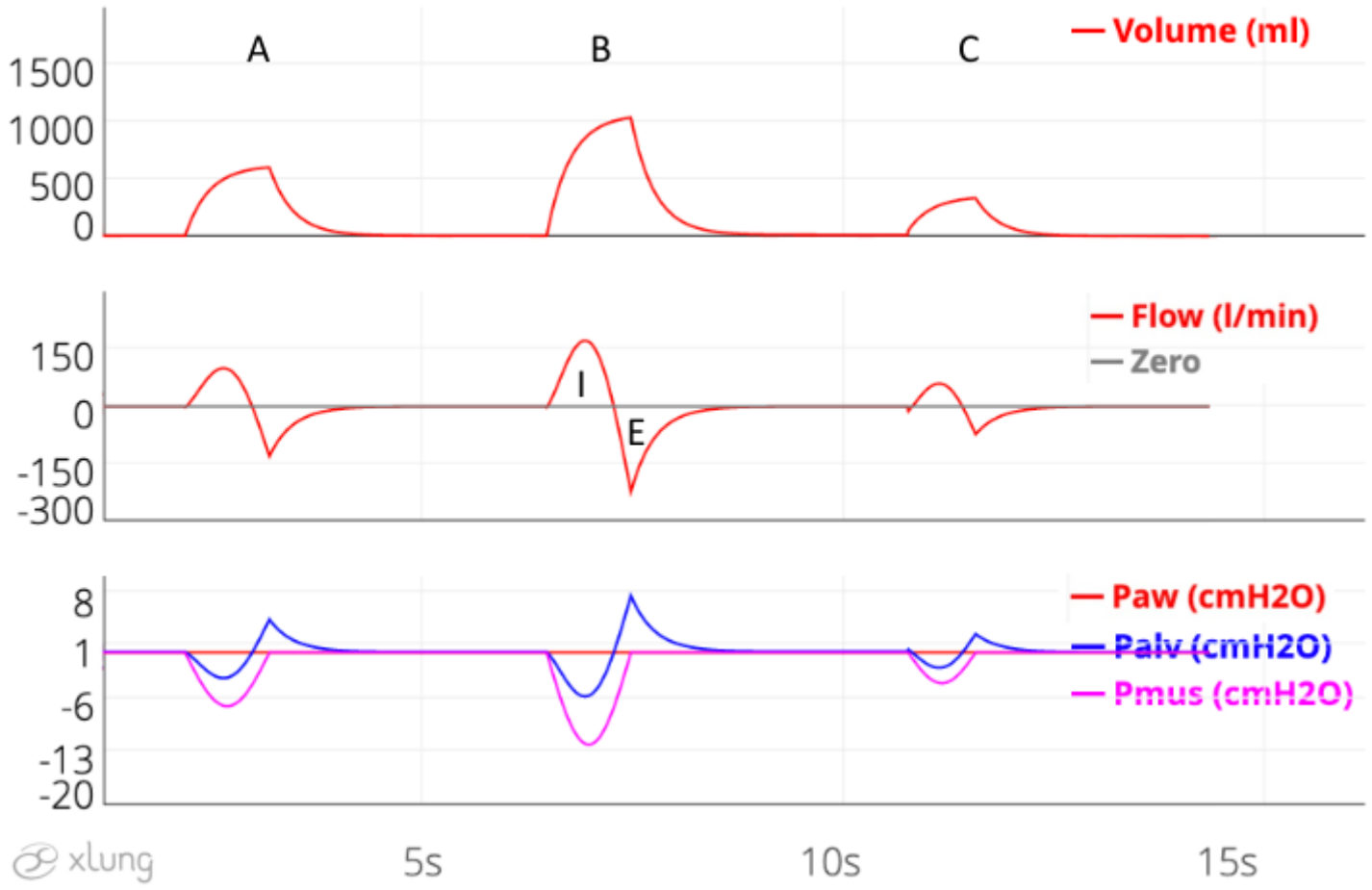




Non-Invasive Ventilators

- Can only be used for delivering CPAP/BPAP

Spontaneous Breath Cycles



Ventilator-Delivered Breath

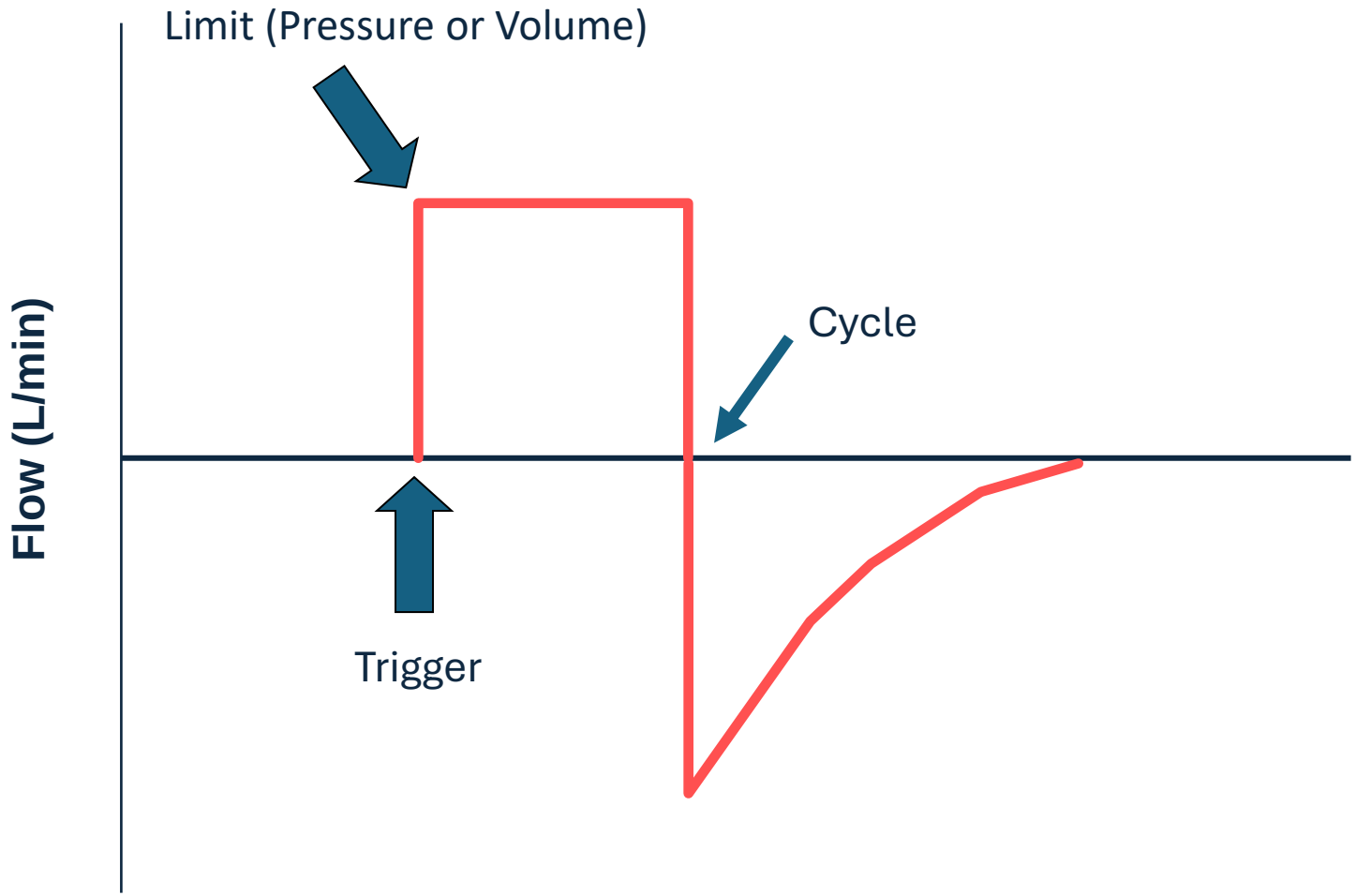
Trigger

Time

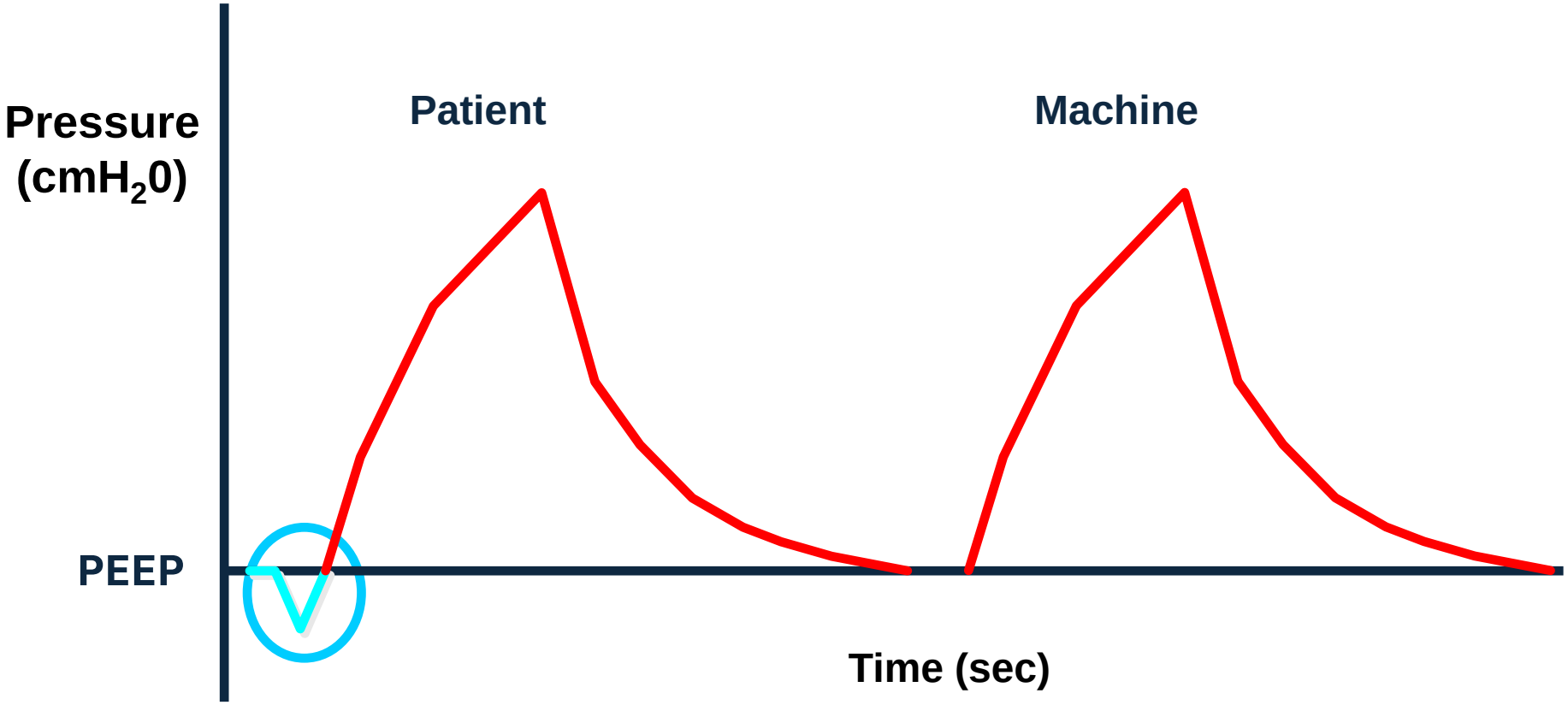
Pressure

Flow

Neuromuscular activity

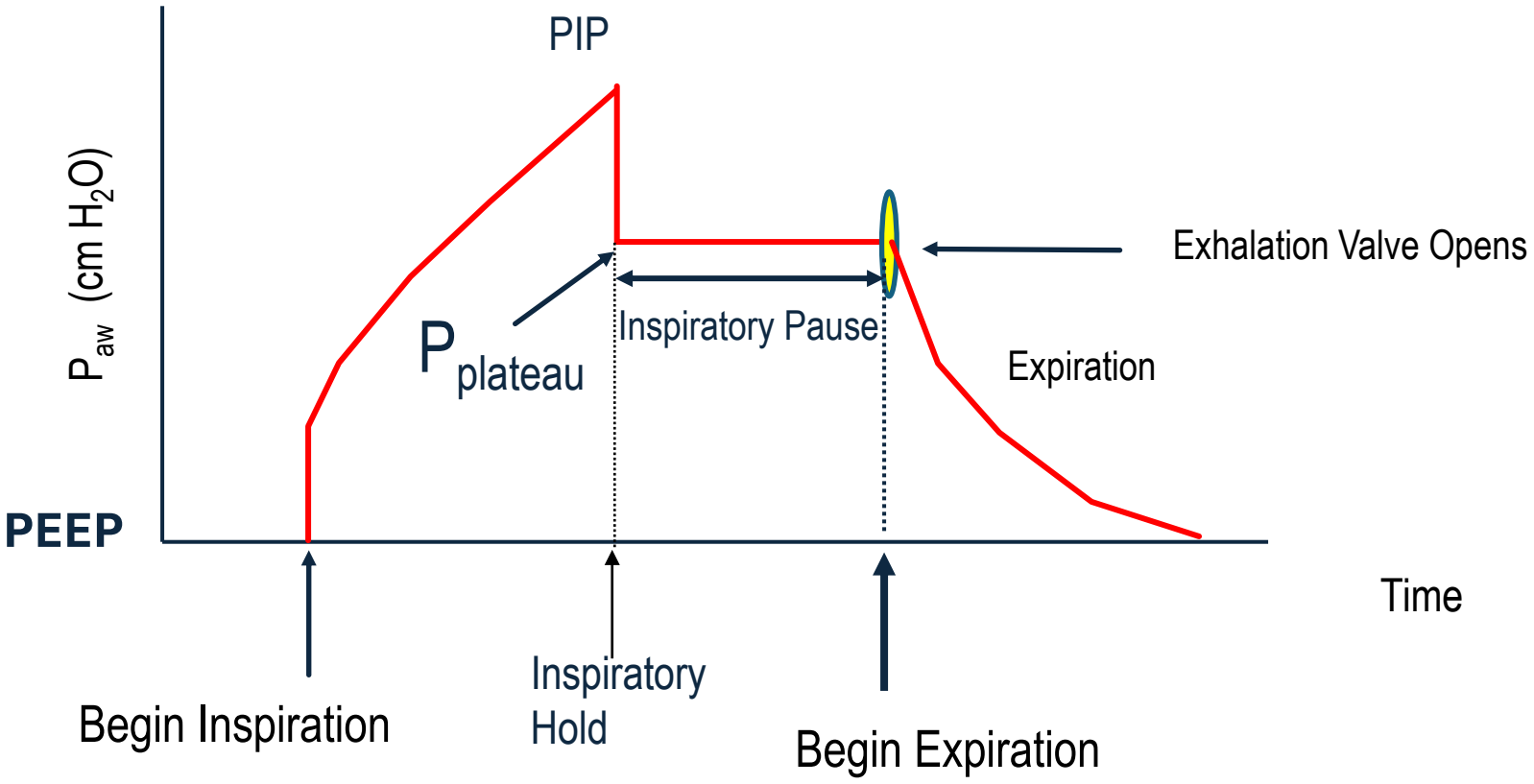


Patient-Triggered vs. Machine-Triggered Breath



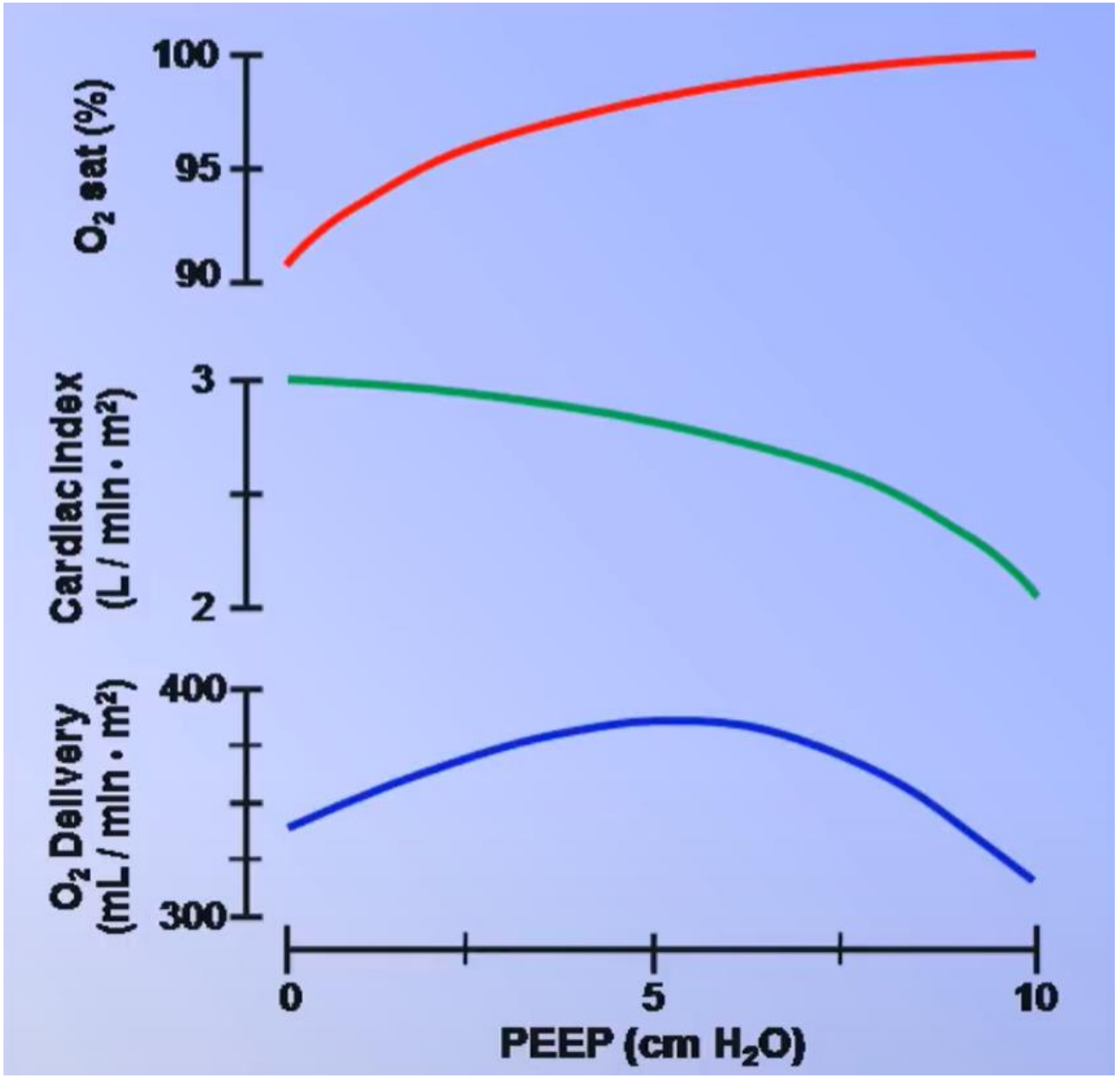
Mechanical Ventilation Parameters

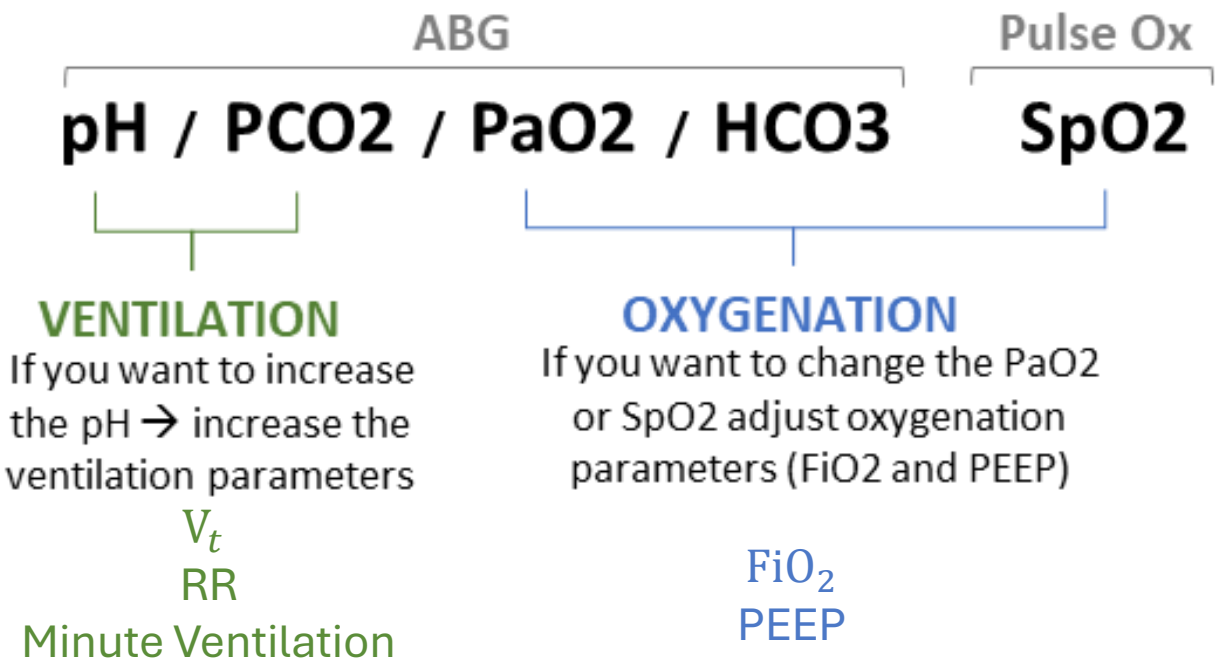
- V_t (5-8 ml/kg)
- Frequency (RR)
- Minute Ventilation (V_t × RR)
- FiO_2(usually starts with 100% then titrates to <60%)
- PEEP (5-20 cmH20)
- PS (min: 8-10 cm H_2O to correct for ET resistance, many ventilators support automatic tube resistance)
- I:E (Inspiration time to expiration time ratio – typically set to 1:2)


PIP
P_{aw} (cm H_2O)
$P_{plateau}$
Inspiratory Pause
Exhalation Valve Opens
Expiration
PEEP
Time
Begin Inspiration
Inspiratory Hold
Begin Expiration

PEEP

- A minimum of 3-5 is usually set. Higher PEEP is indicated in ARDS
- Mitigates alveolar collapse (a consequence of the ET bypassing the glottic apparatus)
- Improves oxygenation by limiting alveolar collapse PEEP mitigates end-expiratory
- prevent cyclic opening and closing of alveoli (and thereby prevent ventilator-induced lung injury)
- Auto-PEEP should be considered (in COPD and those with high minute ventilation)
- Too much PEEP decreases cardiac index


100
95
90
O_2 sat (%)
3
2
Cardiac Index
(L / min · m²)
400
300
O_2 Delivery
(mL / min · m²)
0
5
10
PEEP (cm H_2O)


ABG
Pulse Ox
pH / PCO2 / PaO2 / HCO3
SpO2
VENTILATION
If you want to increase the pH → increase the ventilation parameters
V_t
RR
Minute Ventilation
OXYGENATION
If you want to change the PaO2 or SpO2 adjust oxygenation parameters (FiO2 and PEEP)
FiO_2
PEEP

Volume-Limited vs Pressure-Limited

Volume Preset

- Set parameter is the tidal volume; airway pressure is variable
- Constant tidal volume in the face of changing lung characteristics
- Patient-ventilator asynchrony due to fixed flow rate
- No leak compensation

Pressure Preset

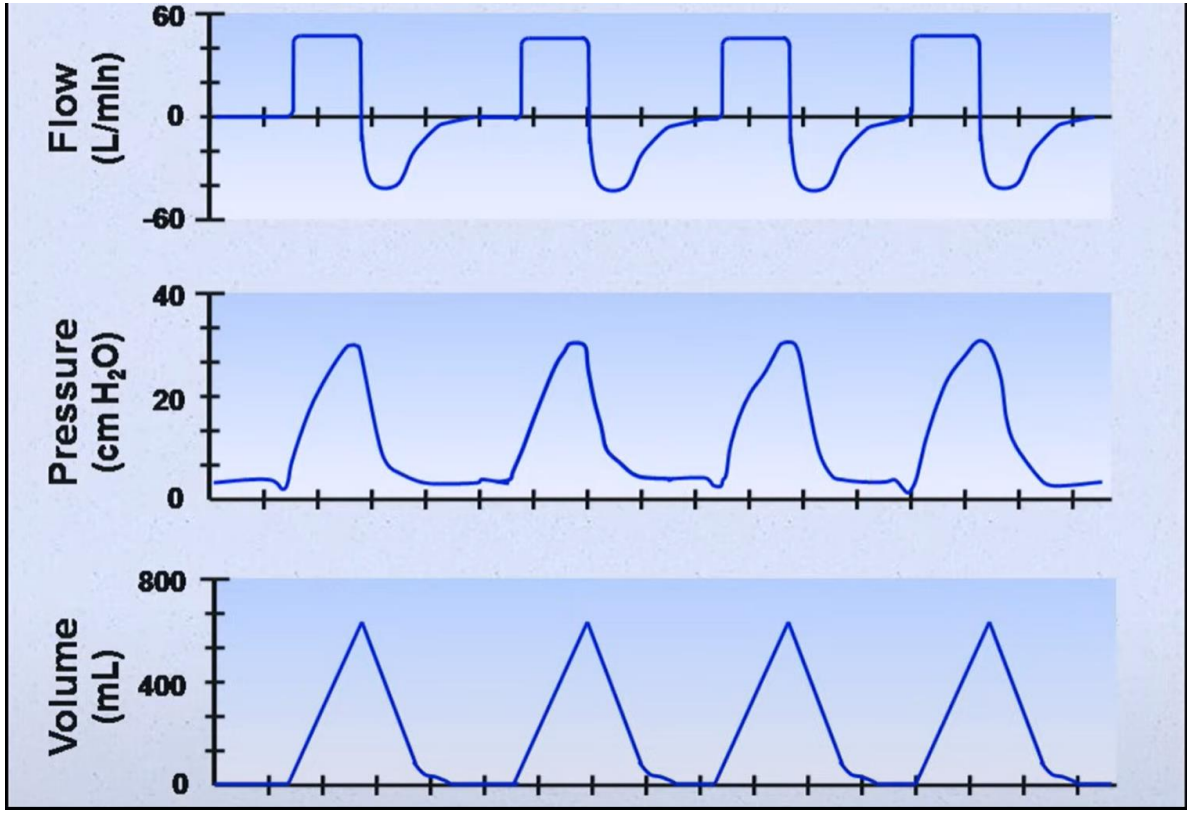
- Set parameter is airway pressure; tidal volume delivered is variable
- Tidal volume varies with changes in lung characteristics
- Flow will vary according to patient's demands
- Compensates for leaks

Continuous mandatory ventilation (CMV)

- Mechanism:
  - Sets a **Controlled** Minute Ventilation (Rate and Volume)
  - Does **Not Allow** Any Patient-Triggered Breaths
- Advantages:
  - **Lowest Work of Breathing**
  - Set Minute Ventilation is Easily Adjusted
- Disadvantages:
  - Less Comfortable
  - May See Ventilator Desynchrony with Wasted Effort
  - May Require Deeper Sedation or Paralytics

Assist-Control Ventilation (AC)

- Mechanism:
  - Sets a **Minimum** Minute Ventilation (Rate and Volume)
  - Allows Patient-Triggered Breaths in Addition to Set Minimum Breaths
  - Patient-Triggered Breaths are at the **Set Volume**

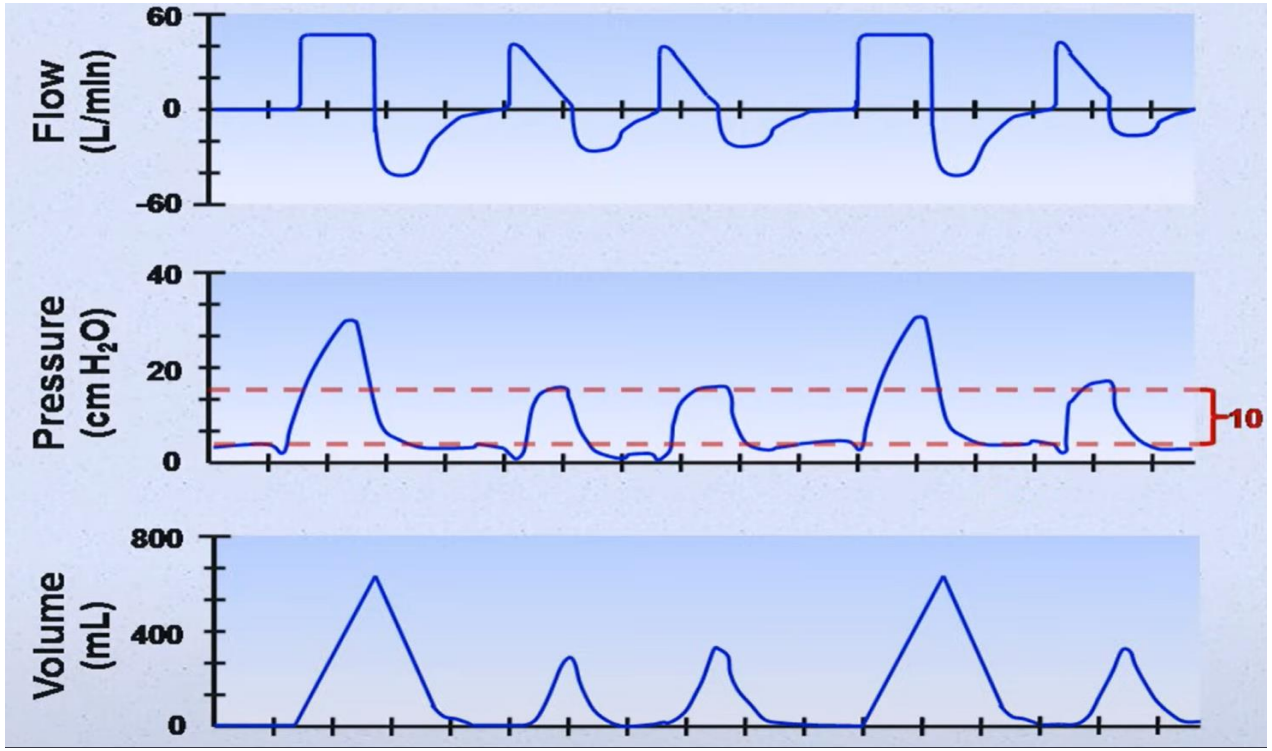


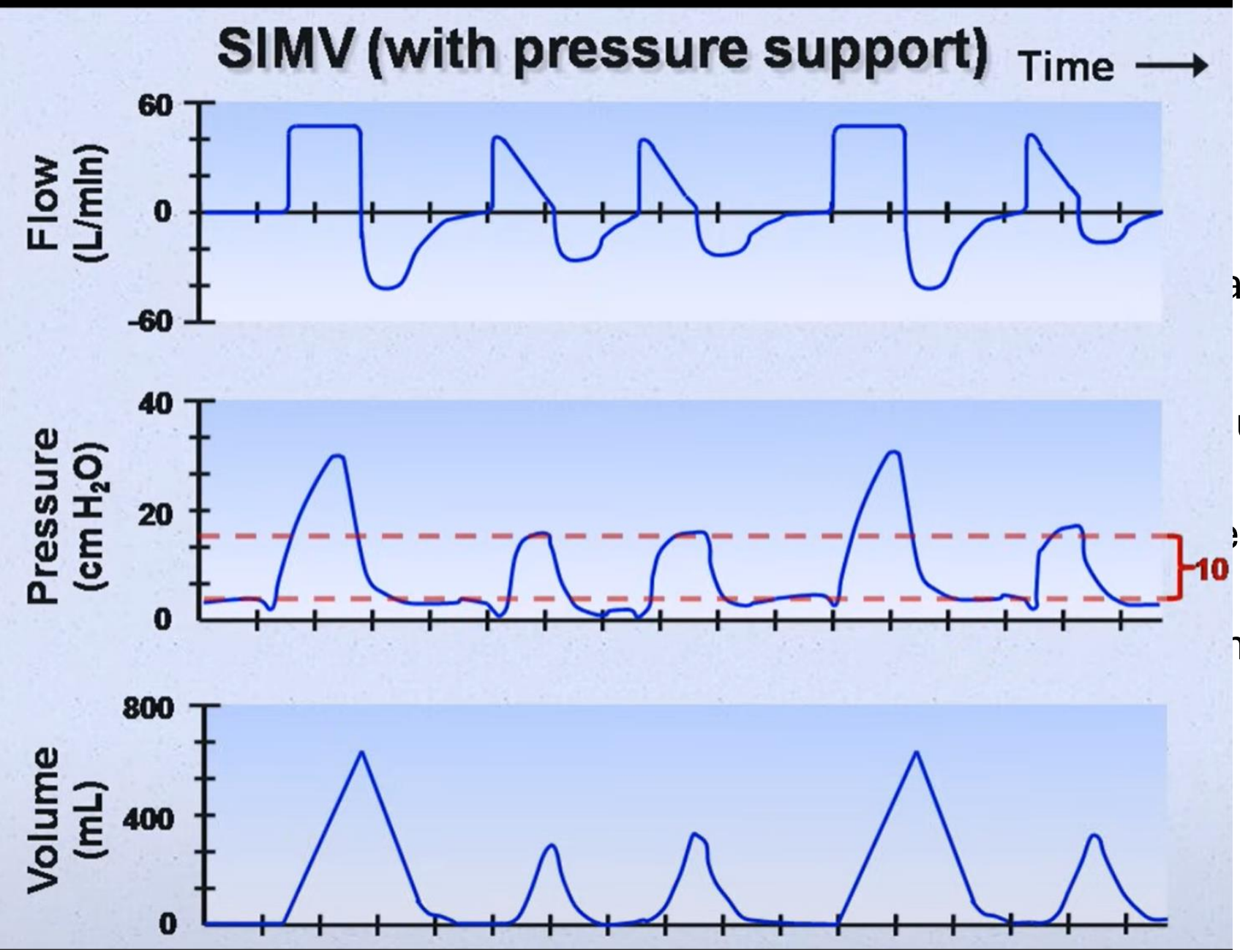
Assist-Control Ventilation (AC)

- Advantages:
  - Increased Comfort
  - Allows Sedation Weaning
  - Improved Ventilator Synchrony
  - Lower Work of Breathing than SIMV
- Disadvantages:
  - Higher Work of Breathing than CMV
  - Can Hyperventilate with “Breath-Stacking”

Synchronized Intermittent Mechanical Ventilation (SIMV)

- Mechanism:
  - Sets a **Minimum** Minute Ventilation (Rate and Volume)
  - Allows Patient-Triggered Breaths in Addition to Set Minimum Breaths
  - Patient-Triggered Breaths are at a **Patient's Own Volume**
  - Is often coupled with PSV





aths allowed in between

us breaths allowed in

eduled delivery of

machine breath with the

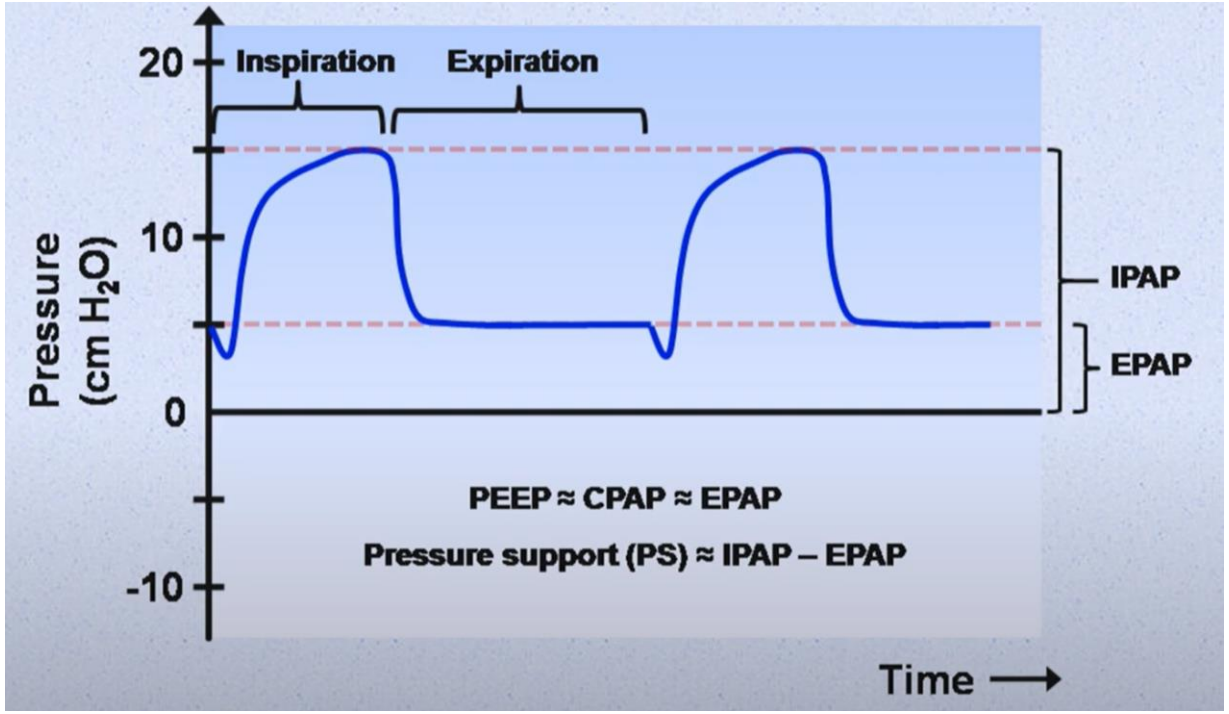
at the scheduled time

SIMV

- Advantages:
  - May Allow Exercise of Respiratory Muscles
- Disadvantages:
  - Highest Work of Breathing and Can Cause Respiratory **Fatigue**
  - Less Comfortable
  - Can Hyperventilate with “Breath-Stacking”

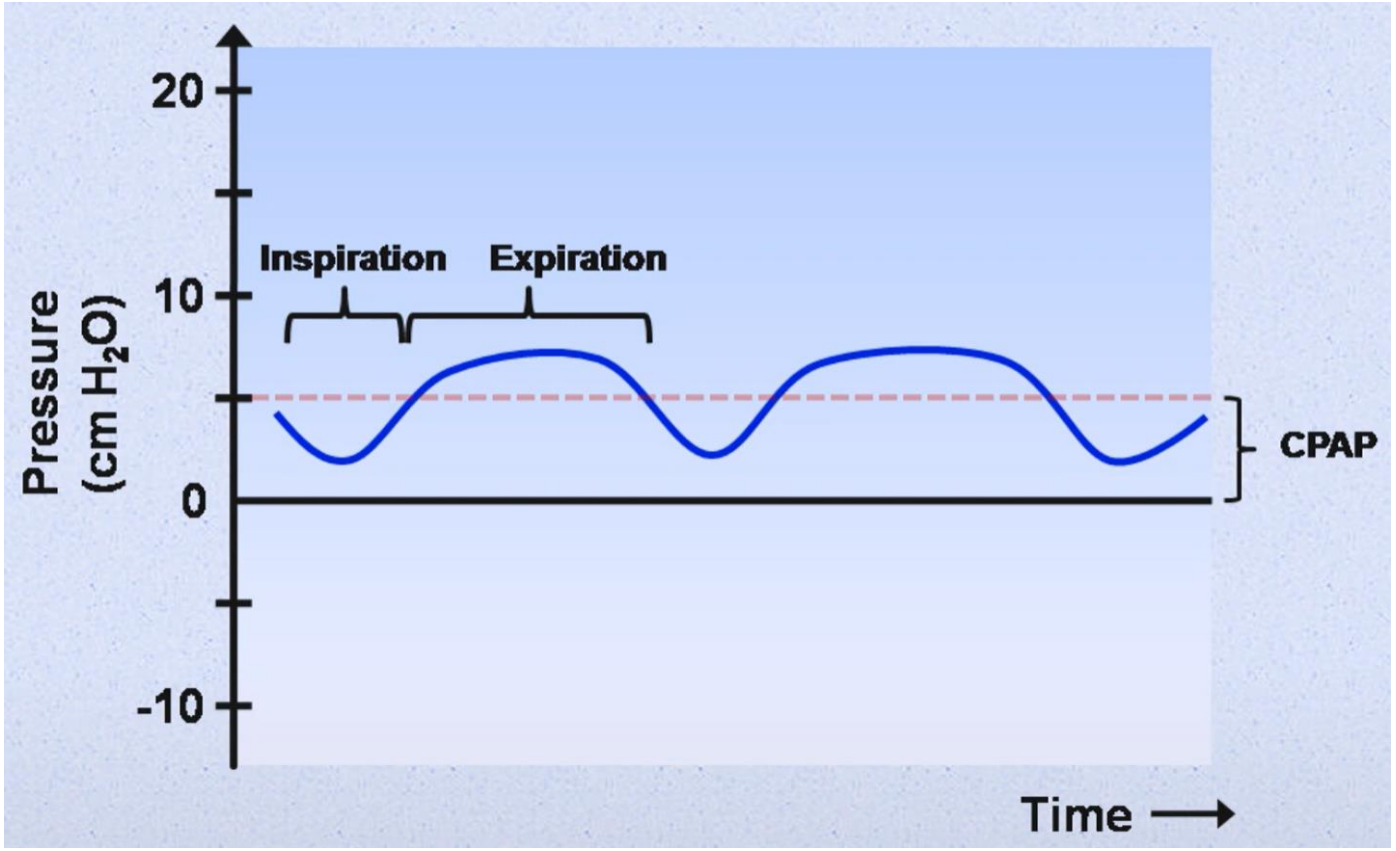
PSV

- PSV with non-zero PEEP is similar to BPAP
- Is usually combined with SIMV
- Can also delivered through non-invasive ventilations
- Used for weaning trial



CPAP

- Is similar to spontaneous breathing with non-zero PEEP

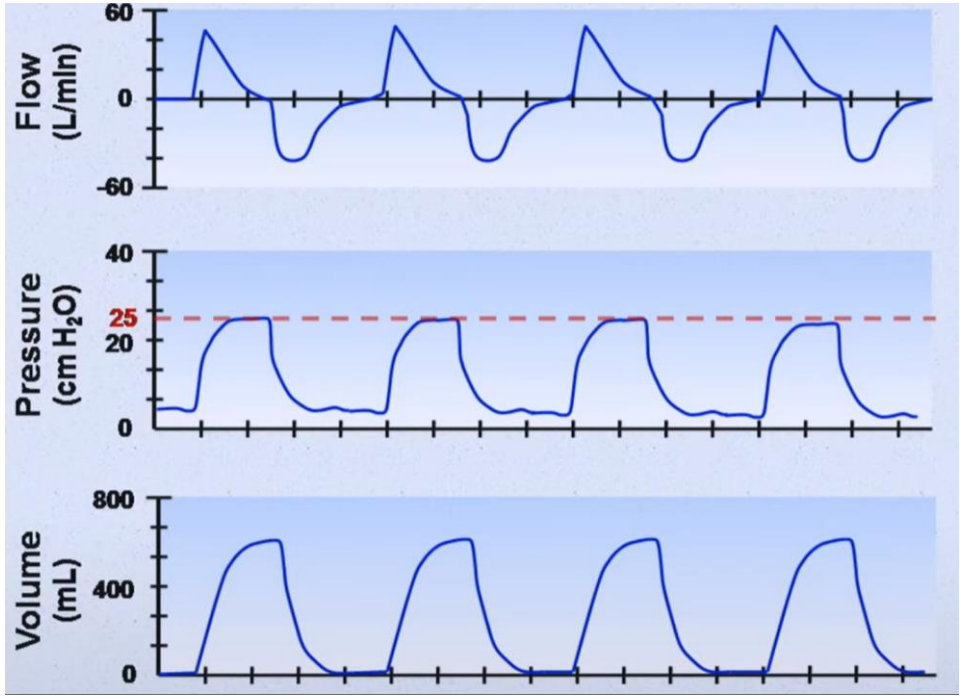


PIP and P_{Plat} for ventilation monitoring

High Peak Pressures Low Plateau Pressures	High Peak Pressures High Plateau Pressures
Mucus Plug	ARDS
Bronchospasm	Pulmonary Edema
ET tube blockage	Pneumothorax
Biting	ET tube migration to a single bronchus
	Effusion

Pressure controlled

- Provides a Set Airway Pressure for the Given Inspiratory Time
- **Adjusts the Inspiratory Pressure Level** Instead of Tidal Volume
- Less often used compared to volume controlled



- Advantages:
  - Peak Inspiratory Pressure (PIP) is Constant (Inspiratory Pressure + PEEP)
    - Decreased Risk for Barotrauma by Lower PIP
    - Indicated in patients with low lung compliance and high risk of barotrauma
  - Increased Mean Airway Pressure and Duration of Alveolar Recruitment
  - Increased Comfort and Decreased Work of Breathing
  - May Allows Better Synchrony with the Ventilator
- Disadvantages:
  - Tidal Volume and Minute Ventilation is Variable (no minimum minute ventilation can be guaranteed)

Advanced modes

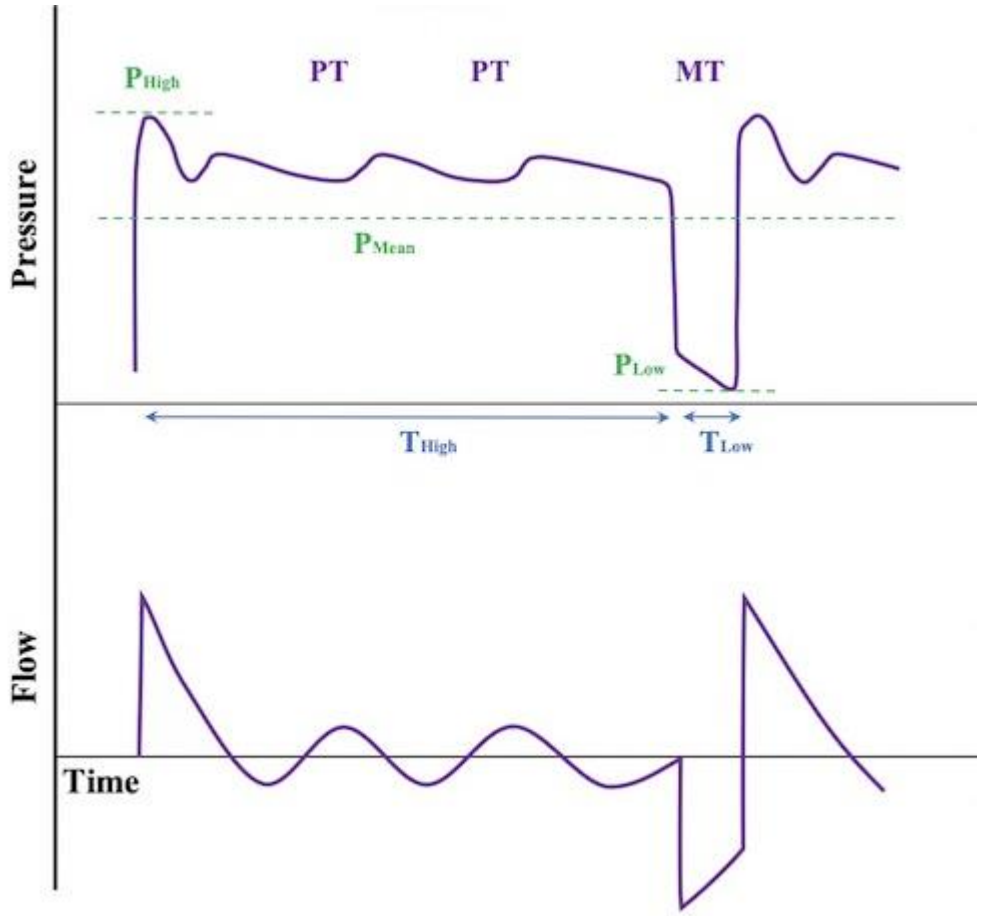
Adaptive Support Ventilation (ASV)

- Continual Adjustments are Automatically Made to Respiratory Rate and Inspiratory Pressure to Achieve a Goal Minimum Minute Ventilation
- Patient-Triggered Breaths are Given Pressure Support
- Machine-Controlled Breaths are Given as Needed to Achieve a Calculated Respiratory Rate (similar to SIMV)

- Attempts Lung Protective Strategies to Prevent Volutrauma, Barotrauma and Auto PEEP

Airway Pressure Release Ventilation (APRV)

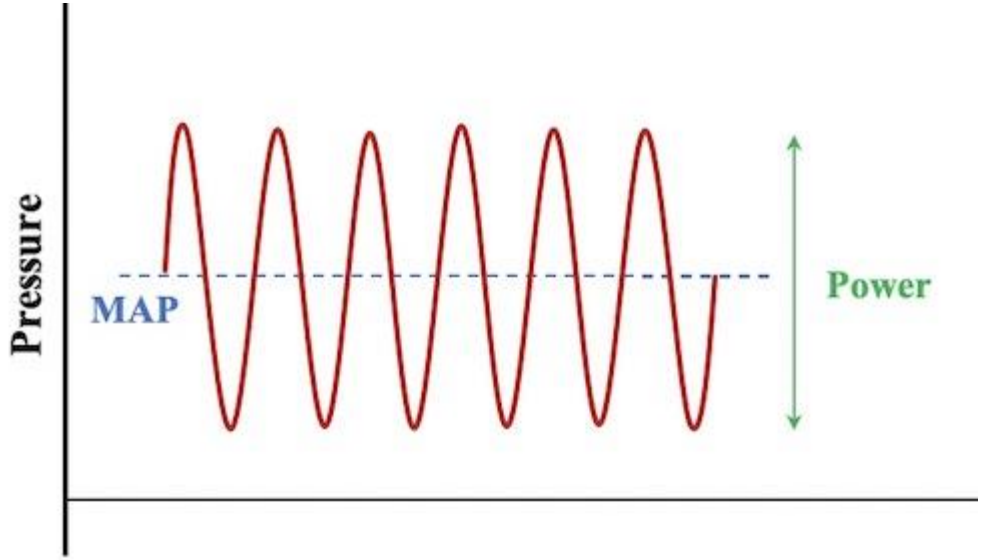
- Indicated in severe ARDS
- Relies on patient spontaneous breathing



High-Frequency Oscillatory Ventilation (HFOV)

Measure ABG/SpO2

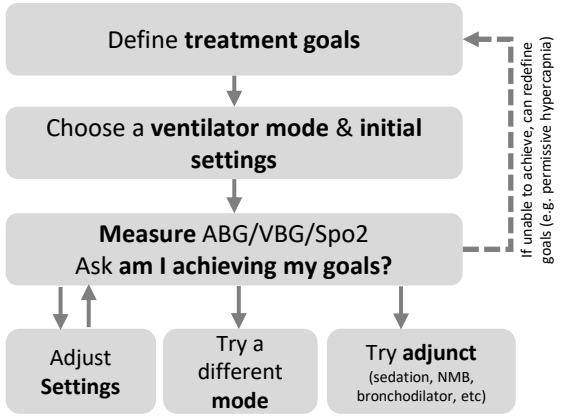
- Frequency: 3-15 Hz
- Often used in NICUs
- Often used in NICUs, Indicated for severe ARDS
- High MAP and relatively low PIP to prevent barotrauma



OVERVIEW OF VENTILATOR MODES by Nick Mark MD

ONE onepagericu.com @nickmmark

Link to the most current version →



Goals for mechanical ventilation:

1. **Oxygenation** – support PaO2/SpO2
2. **Ventilation** – maintain pH
3. **Patient comfort** – vent synchrony, ↓ sedation
4. **Facilitate weaning** – minimize muscle loss, promote readiness to wean from support

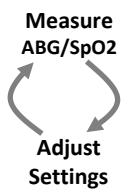
Ventilator Modes:

Fall into two broad categories: ***pressure*** and ***volume*** modes. *Each mode has three features*:

- Trigger (T) – what initiates a breath?
- Cycle (C) – what ends a breath?
- Limit (L) – what stops a breath early?

Each mode has Pro's and Con's to consider.

Measurement and optimization:



ABG: **pH / PCO2 / PaO2 / HCO3** — Pulse Ox: **SpO2**

VENTILATION
If you want to increase the pH → increase the ventilation parameters

OXYGENATION
If you want to change the PaO2 or SpO2 adjust oxygenation parameters (FiO2 and PEEP)

v1.0 (2020-04-03)

Mode	Description	Pro's	Con's	Major settings / example	Monitor
VC Volume Control (a.k.a. assist control volume)	Every breath delivered (mandatory and patient triggered) are all the same set **volume** T – time/pressure/flow, C – volume, L – volume	Good general-purpose mode; Ensures a minimum MV is achieved. Good mode for lung protective ventilation (LPV)	Requires you to monitor pressures to avoid barotrauma. (See my *OnePager* on ARDS for details.)	**RR, TV, PEEP, FIO2** **12 bpm, 450cc, +8, 60%** *(RR – respiratory rate, TV – tidal volume)*	Pressures (Ppeak, Pplat)
PC Pressure Control (a.k.a. assist control pressure)	Every breath delivered (time & patient) are a set **pressure** for a set time T - time/pressure/flow, C – time, L - pressure	Good for limiting pressure; may be more comfortable for select patients. Also can be used for LPV (no difference in mortality)	Requires you to monitor volumes to avoid volutrauma or hypoventilation	**RR, IP, T_I, Risetime, PEEP, FIO2** **12 bpm, 25 cmH_2O, 0.9 sec, 0.15 sec, +8, 60%** *(IP – inspiratory pressure, T_I – inspiratory time)*	Volumes (TV, MV)
PRVC Pressure Regulated Volume Control (a.k.a. VC+)	***Hybrid*** PC mode that dynamically changes inspiratory pressure to deliver a desired volume T - time/pressure/flow, C – volume, L - volume	Guarantees TV but delivers pressure-controlled breaths; (e.g. low risk of causing VILI), which potentially may be more comfortable for patients	In patients who are struggling to breath the machine will provide less support	**RR, TV, T_I, Risetime, P_{max}, PEEP, FIO2** **12 bpm, 450cc, 0.9 sec, 0.15 sec, 30 cmH_2O, +8,60%** *(P_{max} – maximum pressure)*	Pressures & volumes
SIMV Synchronous Intermittent Mandatory Ventilation	Delivers mandatory breaths with a fixed volume but patient **can't** trigger (patient breaths are not the same as mandatory breaths); can use PS T – time , C – volume, L - volume	May be useful for patients with hiccups to avoid alkalemia	Seldom used; not effective for weaning; often found to be uncomfortable	**RR, TV, PEEP, FIO2** **12 bpm, 450 cc, +8, 60%**	Pressure (Ppeak Pplat)
PS Pressure Support	**All** breaths are patient initiated; ventilation determined solely by patient (no backup rate). T – pressure/flow, C – flow, L - pressure	Ideal weaning mode (used in SBTs and for prolonged periods); most comfortable because it allows patient to control ventilation	Does not guarantee a rate; need to monitor to ensure adequate ventilation	**PS, PEEP, FiO2** **+10, +5, 40%** *Note that **PS** is above **PEEP** so "Ten over Five" PIP = 15cmH2O*	Volumes (TV, MV)
APRV Airway Pressure Release Ventilation (a.k.a. Bi-Vent)	**Inverse ratio ventilation** (e.g. I time > E time) that allows patient to breath spontaneously; can combine w/ PS T – time, C – time, L - pressure	Great for ARDS patients who are spontaneously breathing (e.g. not on NMB); *may improve comfort & oxygenation (but no mortality benefit)*	Complex mode/settings; Risk of VILI if settings are done improperly; doesn't make sense if on NMB	**T_{High}, T_{Low}, P_{high}, P_{low}, FIO2** **5.5 sec, 0.5 sec, 25 cmH_2O, 0 cmH_2O, 60%** *(Thigh/low – time high/low, Phigh/low – pressure high/lowNote that **Plow** is analogous to **PEEP**)*	Volumes & gas exchange PCO2 / EtCO2

Thank you for your attention!