

MECHANICAL VENTILATION

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DISCLOSURES

- I have no financial disclosures.

OBJECTIVES

- Describe indications for mechanical ventilation
- Review the main modes of mechanical ventilation
- Describe complications of mechanical ventilation
- Trouble shoot ventilator emergencies

CASE

- A 62 year old man with COPD on home oxygen is admitted to the medicine floor with increased oxygen need and wheezing. Shortly after admission a rapid response is called for increased work of breathing despite a trial of bi-level. ABG on bi-level: pH 7.21/paCO₂ 84/paO₂ 64.
- You arrive to find the patient minimally responsive. The respiratory therapist starts bag mask ventilation and anesthesia is called. What will you recommend for initial ventilator settings?



INDICATIONS

- **INTUBATION:**

- Airway protection

- Need for mechanical ventilation

- Procedural sedation

- **MECHANICAL VENTILATION:**

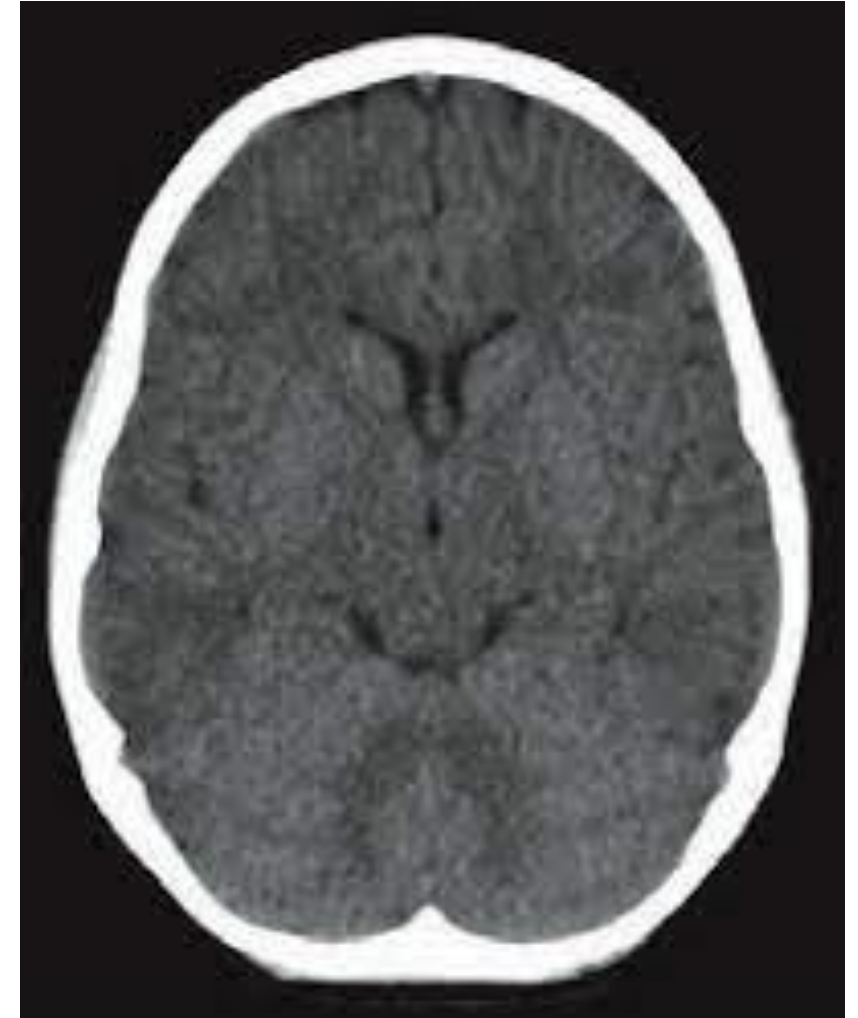
- Respiratory failure

- Work of breathing

- Neuromuscular failure

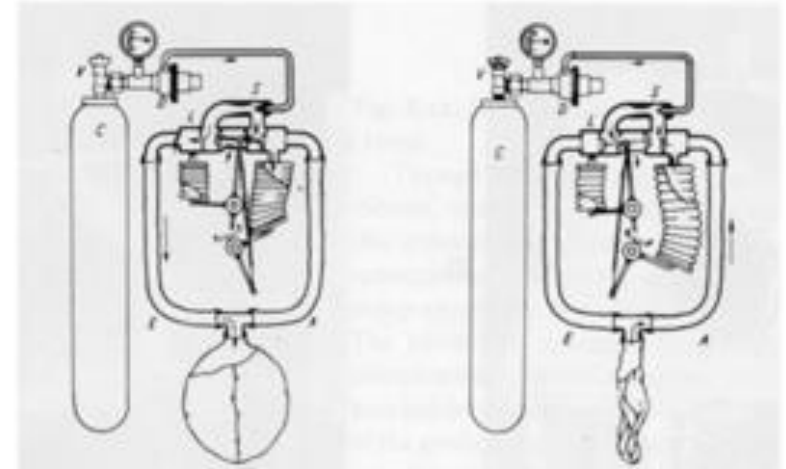
- Shock

CAUTIONS

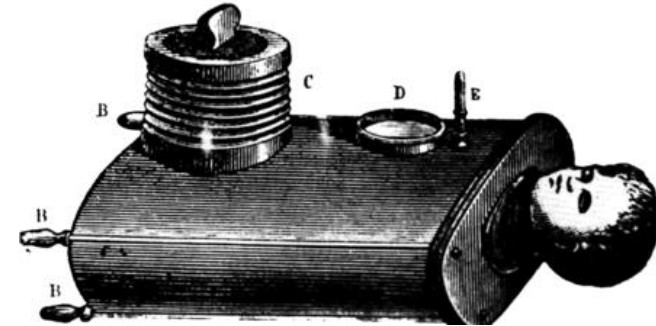
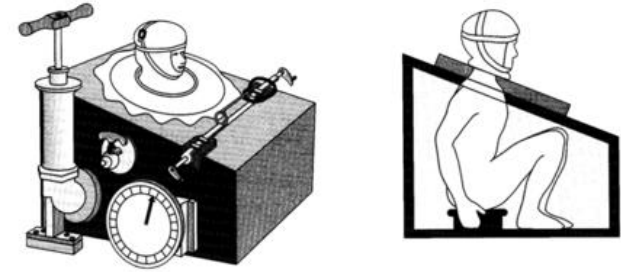


POSITIVE PRESSURE VENTILATION

And the Lord God formed man of the
dust of the ground
and breathed into his nostrils the
breath of life. (Genesis 2:7)



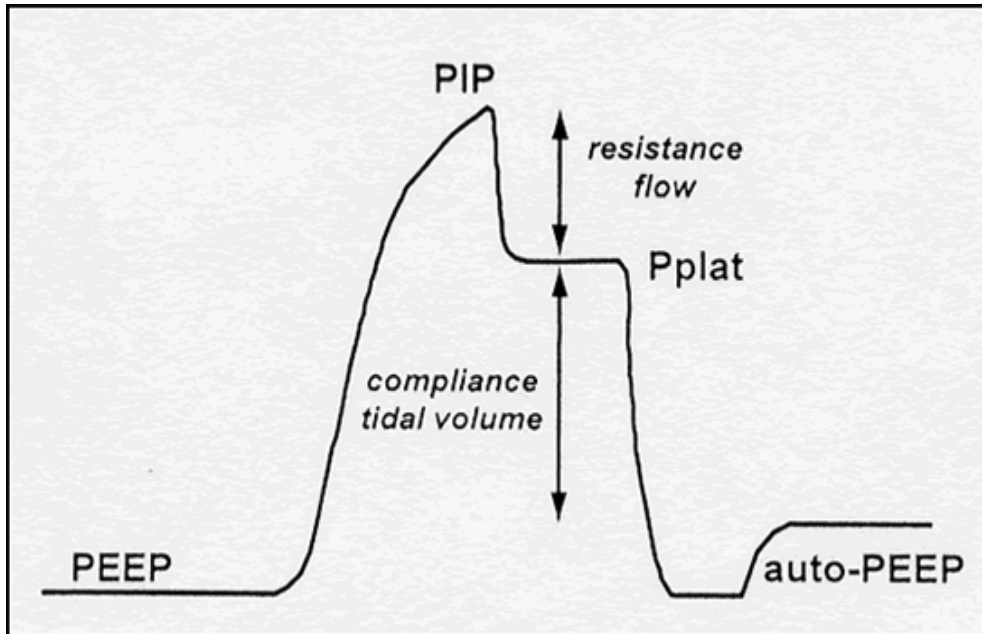
ATTEMPTS TO MIMIC NORMAL PHYSIOLOGY



BACK TO POSITIVE PRESSURE



PRESSURES

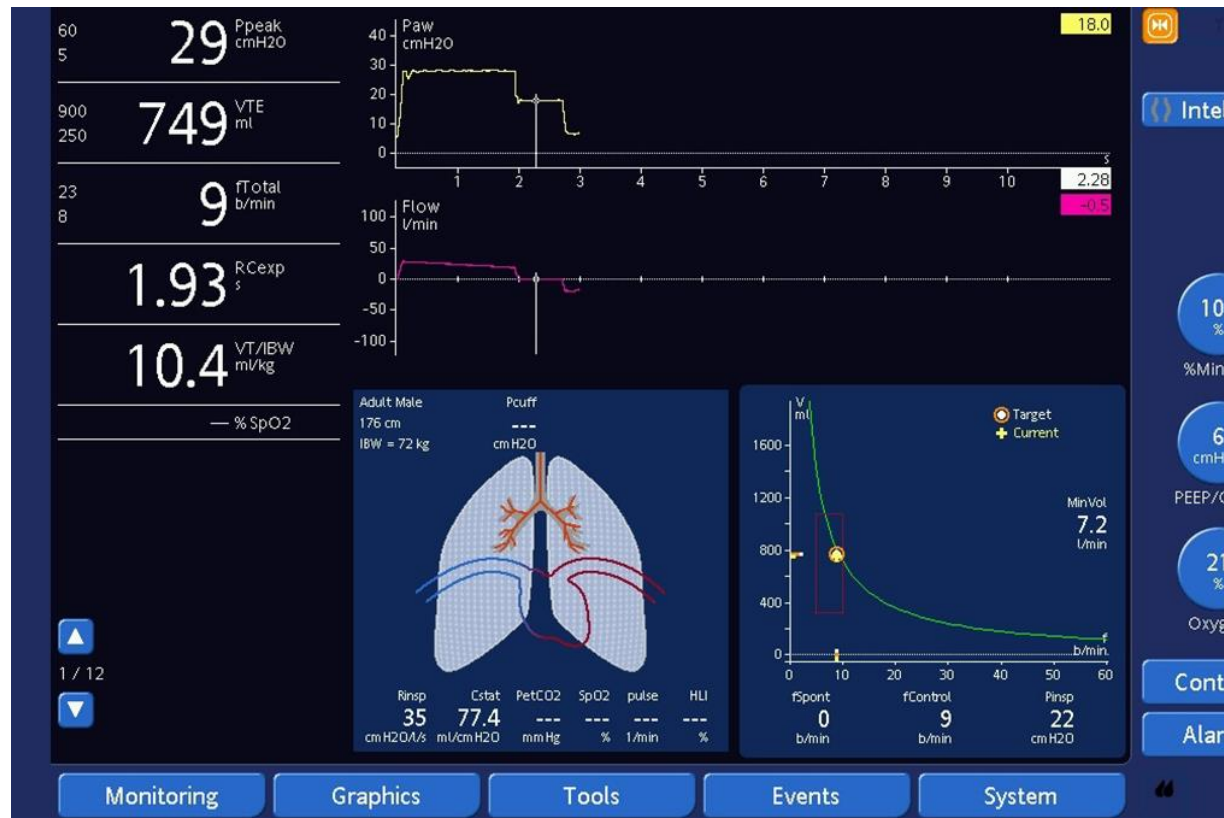


Peak pressure: Inspiratory flow resistance + elastic recoil of the lung and chest wall + PEEP (positive end-expiratory pressure)

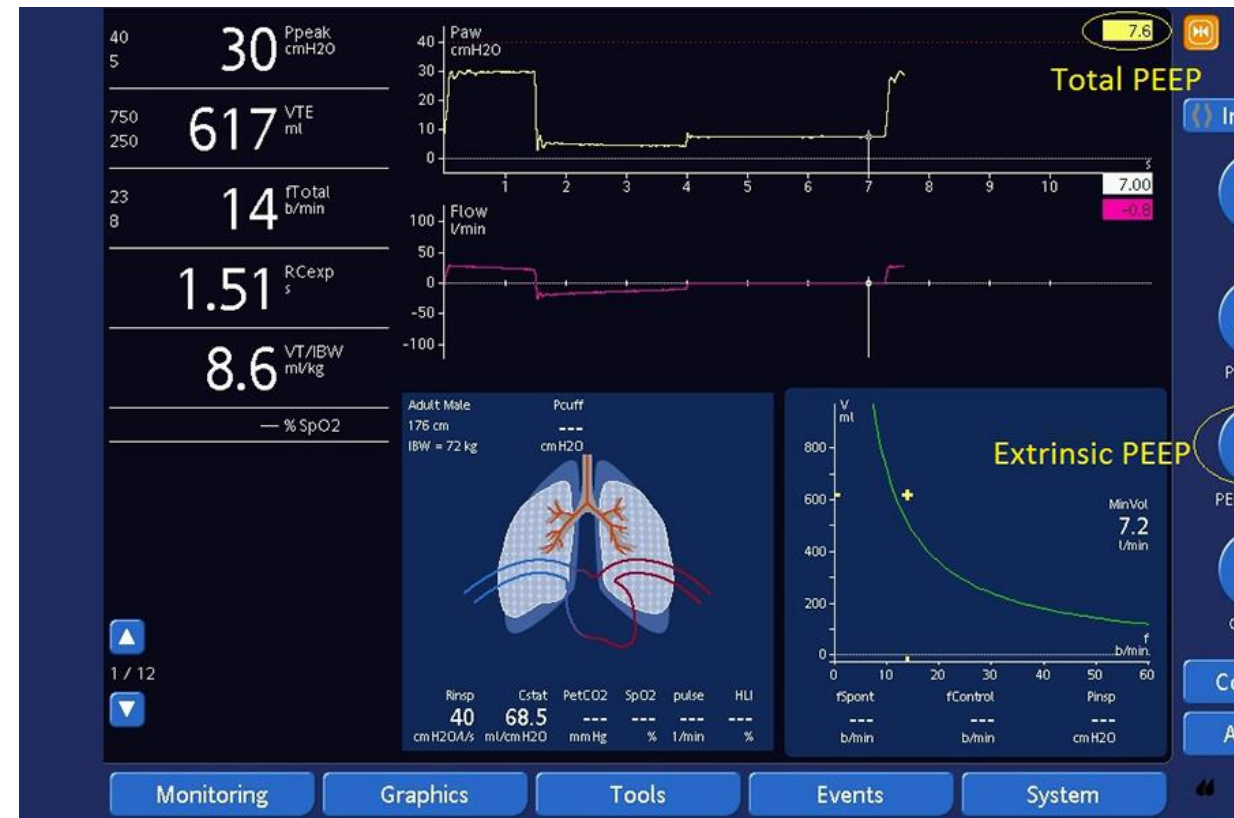
Plateau pressure: Elastic recoil of lung and chest wall + PEEP

Auto-PEEP: Intrinsic end-expiratory positive pressure above set PEEP

MEASURING PLATEAU AND AUTO-PEEP



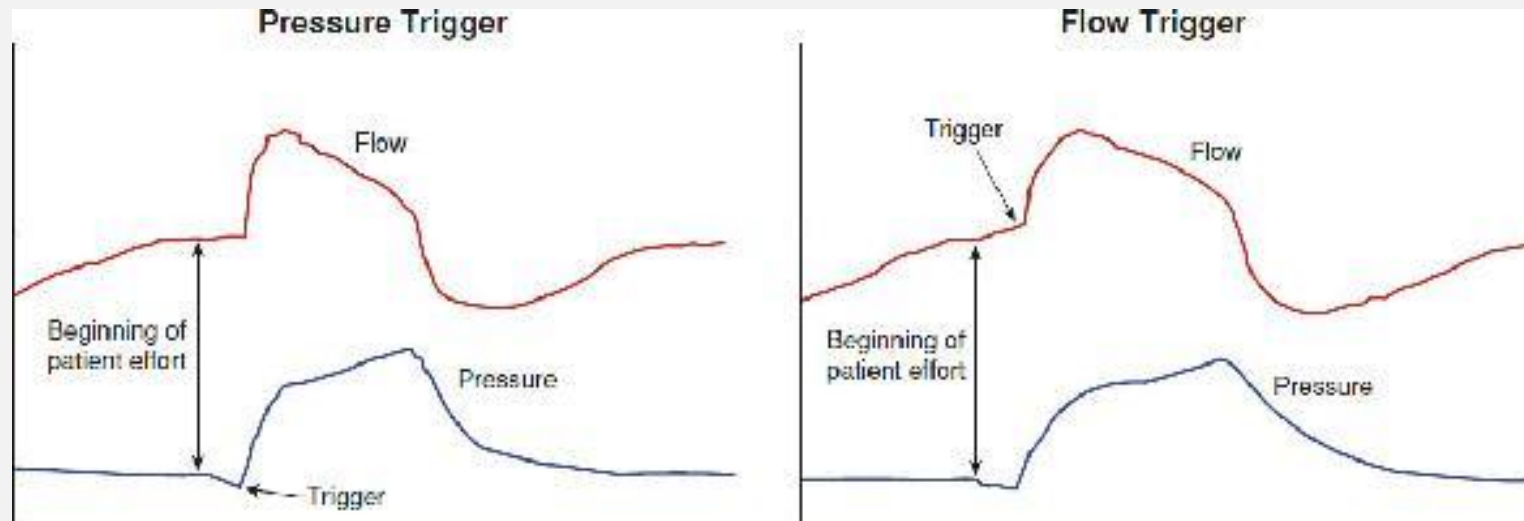
End-inspiratory pause



End-expiratory pause

TRIGGER: INSPIRATION BEGINS

- Pressure triggering
- Volume triggering
- Flow triggering
- Time triggering



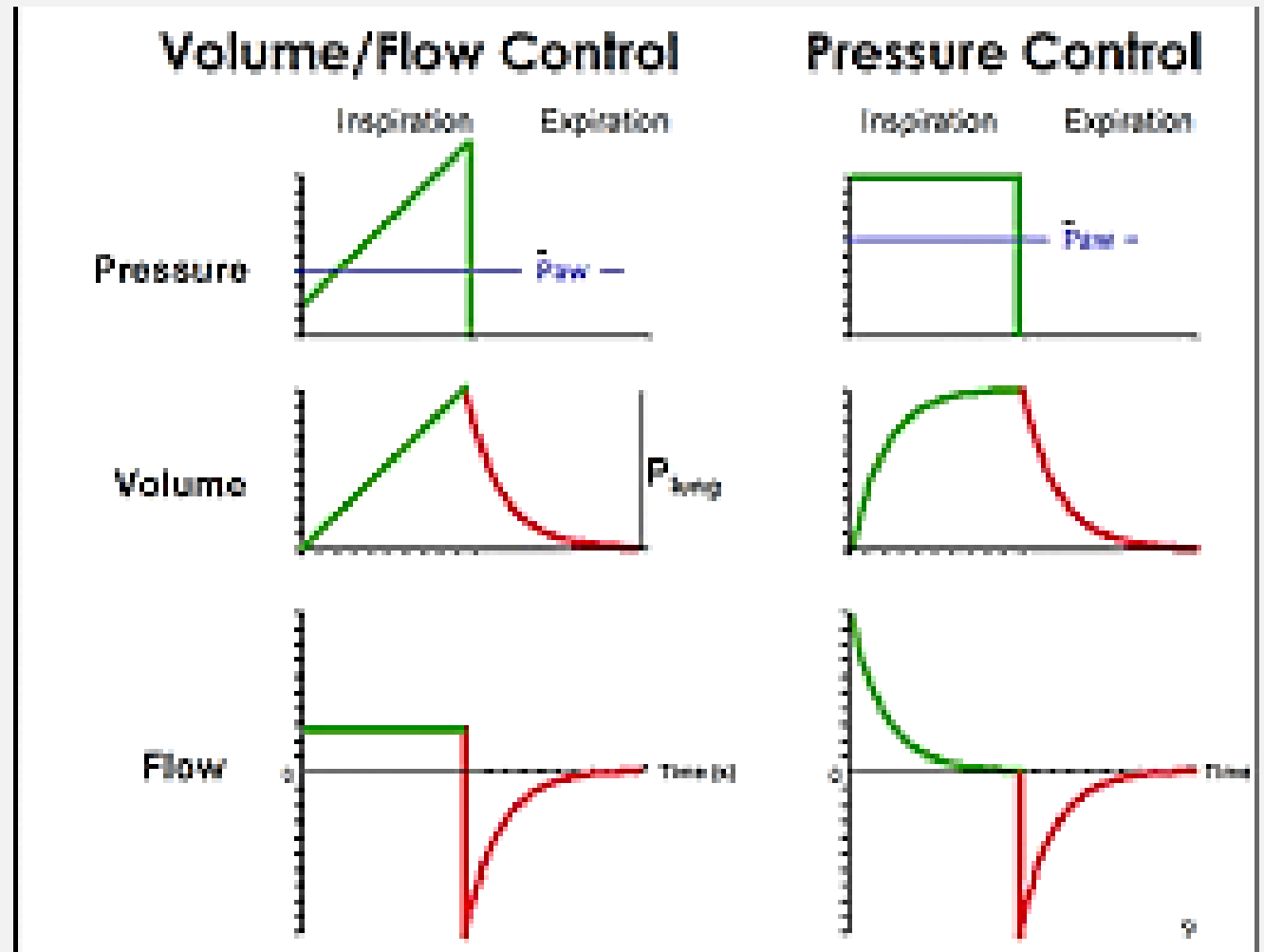
CYCLING: TERMINATES INSPIRATION

- Pressure: delivering constant pressure per breath (**volume** will vary)
- Volume: delivering a fixed volume per breath (**pressure** will vary)
- Flow: in spontaneous modes like PS

BREATH TYPE

- Mandatory breaths: triggered, limited, and cycled by the ventilator.
- Assisted breaths: limited and cycled by the ventilator but triggered by the patient.
- Spontaneous breaths: triggered, limited, and cycled by the patient

PRESSURE VERSUS VOLUME CONTROL



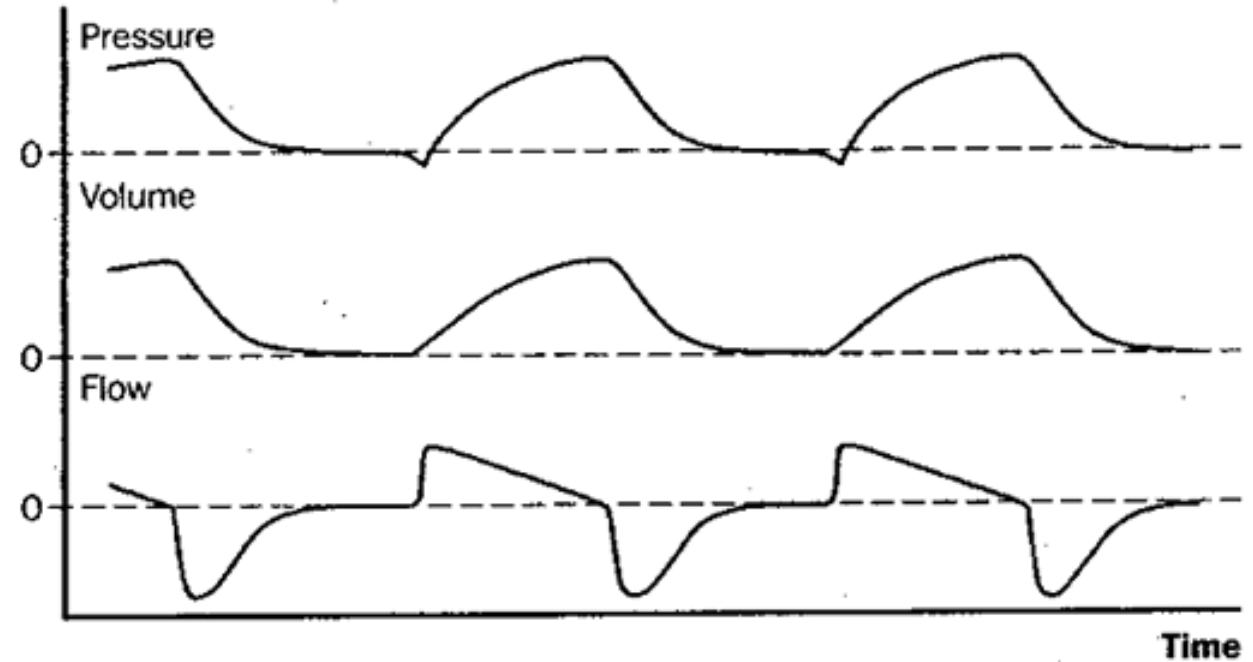
VOLUME CONTROL

Oxygenation:

PEEP, fiO_2

Ventilation:

RR and TV



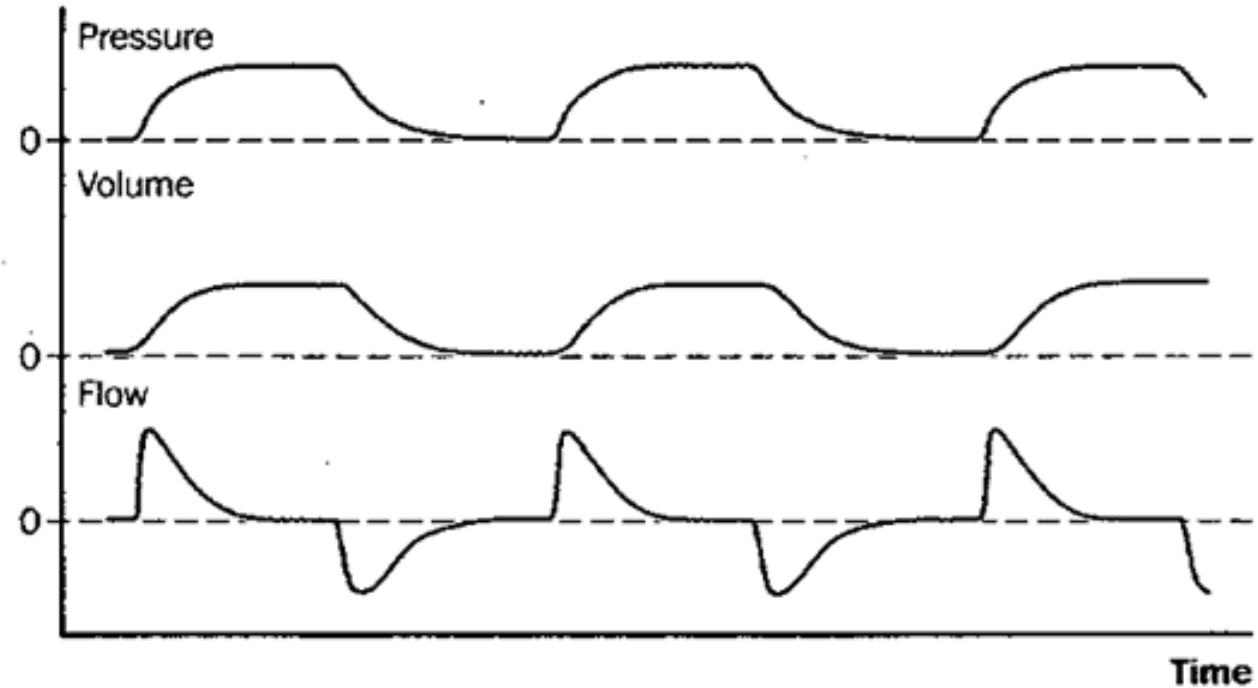
PRESSURE CONTROL

Oxygenation:

PEEP, fio_2

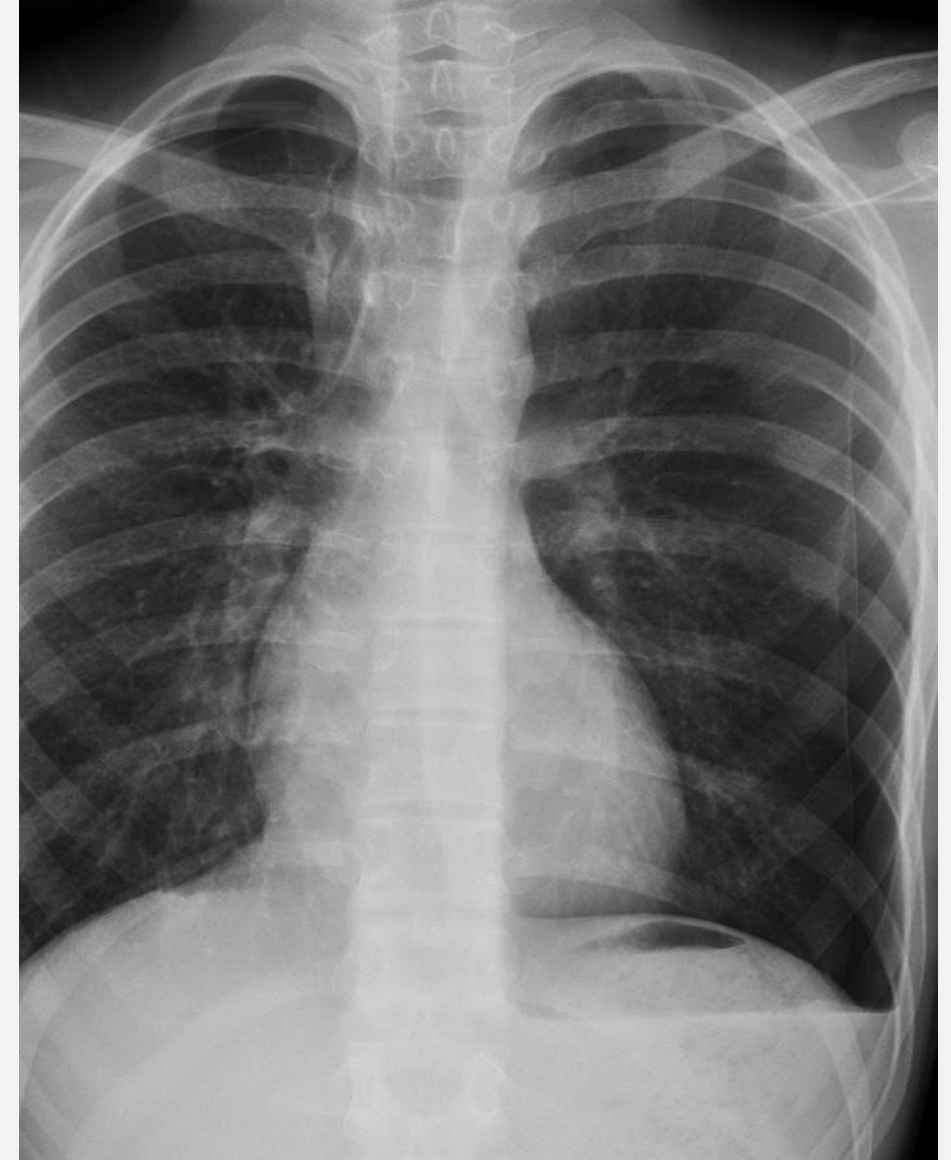
Ventilation:

RR and Maximum
Inspiratory Pressure

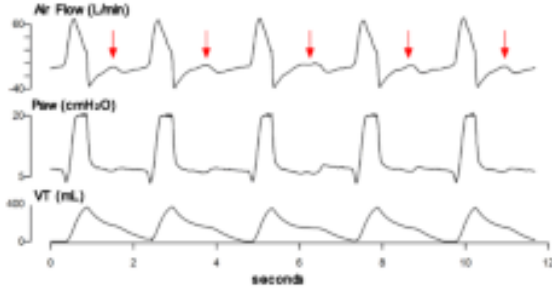
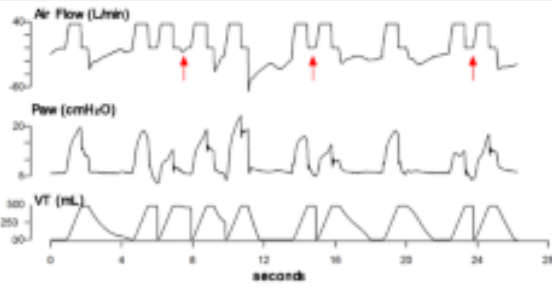
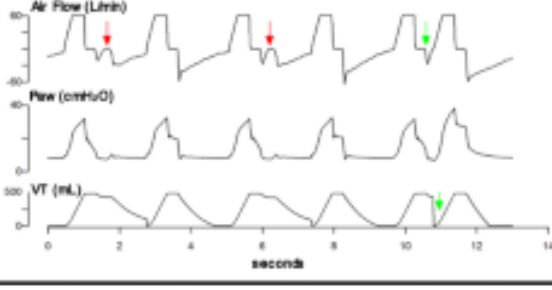
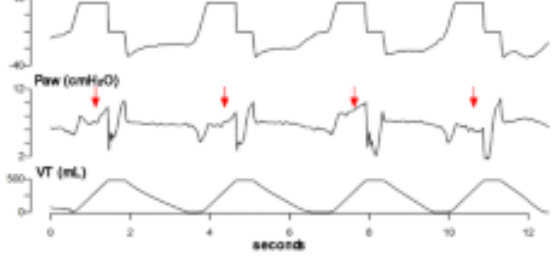


COMPLICATIONS

- PEEP and auto-PEEP effects
- Barotrauma
- Dyssynchrony
- Hemodynamic changes

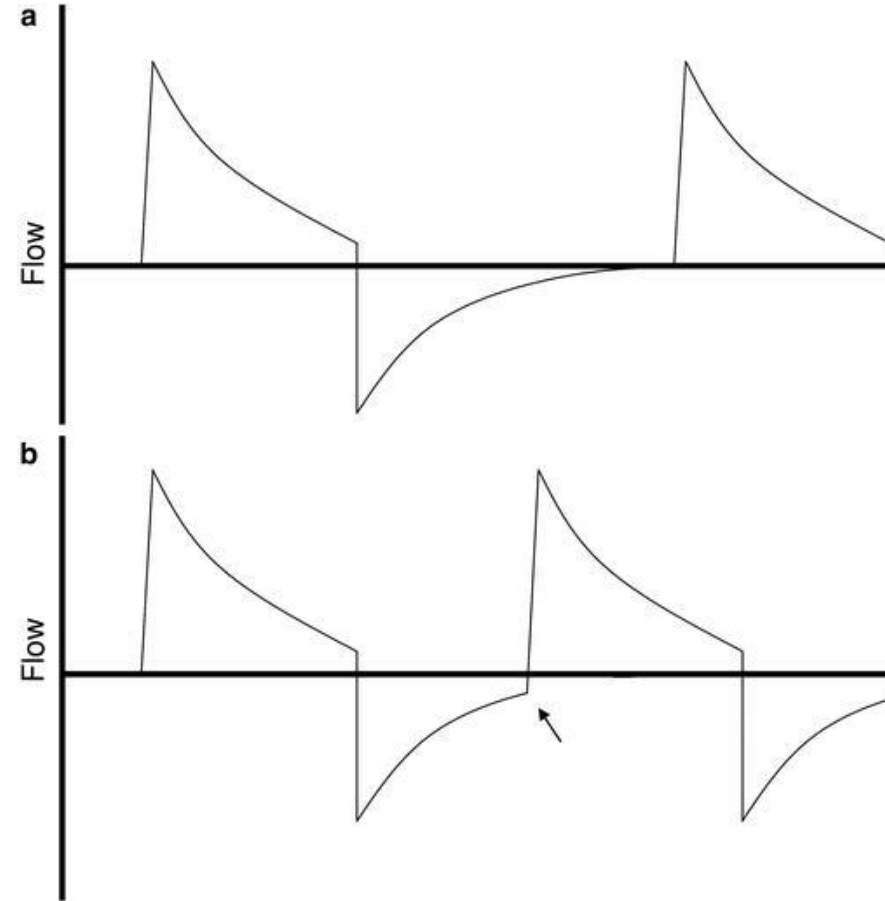


DYSSYNCHRONY

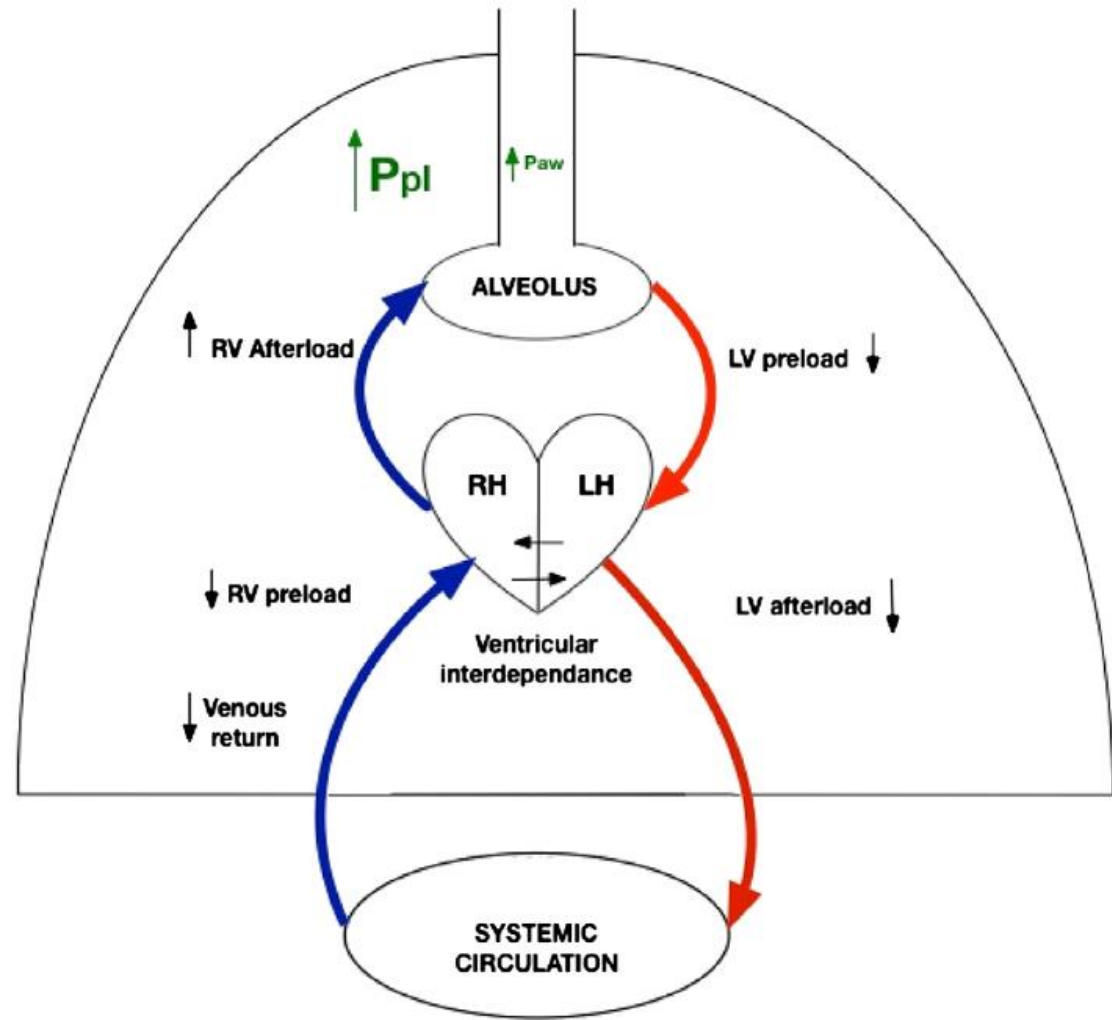
Asynchrony	Graphic representation	Description	Causes
Ineffective Efforts		Inspiratory muscle efforts not followed by a ventilator breath (red arrows)	Inadequate trigger sensitivity Excessive assistance Overdistension/Air trapping Low respiratory drive Low level of pCO ₂ Oversedation
Double Cycling		Inspiratory effort that continues beyond the ventilator inspiratory time producing a second or a third ventilator breath (red arrows) without expiration. Consequently, the volume of the first breath is added to the second or third breath.	Inadequate setting of ventilator inspiratory time Inadequate trigger sensitivity (too sensible) Inadequate circuit pressurization Patient effort too strong Reverse triggering
Reverse Triggering		Ventilator insufflations that trigger diaphragmatic muscle contractions (red arrows) in response to passive insufflation of the lungs. When the diaphragmatic muscle contraction occurs at the end of inspiration a double cycled breath can occur (green arrow) .	Oversedation Overdistension/Air trapping
Inspiratory Airflow Dyssynchrony		Strong patient inspiratory effort (concavity in pressure tracing) due to insufficient inspiratory airflow in a patient ventilated in assist-volume controlled mode.	Inadequate gas flow Dyspnea Delirium/Pain

AUTO-PEEP

- Increase dead space if over-distension
- Decrease in RV preload



CARDIAC VENTILATOR INTERACTIONS



TROUBLE SHOOTING

Patient
distress

Disconnect from ventilator
and bag

Confirm ventilator tubing and machine
functioning

Exam:

Vital signs
Peak pressures, hard to bag?
Chest wall and breath sounds
Able to suction?

Resistance to bagging?

Suction
Bronch to evaluate ETT
Change ETT

Decreased resistance?

ETT above cords?
Cuff leak?

NI resistance to bagging?

Change in compliance?
Change in resistance?
Need for sedation?

CASE REDUX

- After rapid bagging, the patient is intubated by anesthesia. He becomes hypotensive just after intubation. Anesthesia pushes phenylephrine and leaves. Systolic blood pressures are still in the 70s and oxygen saturations are in the 80s. Exam confirms equal but diminished breath sounds.

Patient removed from the ventilator. As they are transferring to manual bagging the patient has a moment to expire for some time. Blood pressure improves. After slow bagging with moderate TVs, placed on ventilator with RR of 10, TV 7 cc/kg, PEEP of 5 and fio2 50%.

- **NEXT STEPS?**

BEYOND BASICS....

Hybrid volume and pressure control models

Refractory hypoxemia

Proning!

Inverse ratio pressure control

Airway pressure release ventilation

High frequency oscillation

Special circumstances

Esophageal balloon

Neurally adjusted ventilation

QUESTION 1

A 45 year old woman with ARDS is mechanically ventilated on volume control ventilation. The ventilator settings are:

TV 375 cc, RR 22, fio₂ 80%, PEEP of 5

ABG on these settings reveals the following:

pH of 7.28, paCO₂ of 54, paO₂ of 59

WHICH OF THE FOLLOWING WOULD BE
THE MOST APPROPRIATE VENTILATOR
ADJUSTMENT?

- A. Increase RR to 25
- B. Increase TV to 400 cc
- • C. Increase PEEP to 10
- D. Increase fio2 to 100%

EXPLANATION

- The goal of ventilation in ARDS is to maintain oxygenation without causing more damage to the lung. A low tidal volume strategy improves outcomes and permissive hypercapnia, as long as pH is maintained above around 7.2, is not intrinsically harmful. This patient is ventilated with appropriately low tidal volumes and there is no need to try to normalize the pH. The oxygenation is borderline, however, and it would be important to try to use PEEP as a tool for oxygenation in case this allows the high fio_2 to be weaned.

QUESTION 2

- An 86 year old man has been intubated for 2 weeks after cardiac arrest. He has been maintained on volume control ventilation, with peak airway pressures in the teens. On rounds one morning his ventilator alarms with high peak pressures, now registering in the 50s. The plateau pressure measures 19.

WHICH IS OF THE FOLLOWING IS THE
MOST LIKELY DIAGNOSIS?

- A. Pneumothorax
- B. Self-extubation
- C. Flash pulmonary edema
- D. Mucus plug



EXPLANATION

- A first step in trouble shooting high pressures on the ventilator is determining the relationship between peak and plateau pressures. In this case the peak pressure is much higher than the plateau, suggesting the problem is with resistance to flow. Of the conditions listed, only a mucus plug would primarily cause a change in resistance.

TAKE HOME POINTS

- Mechanical ventilation offers an invasive method to target a given airway pressure or tidal volume in order to support patients with respiratory failure or those who require intubation for profound encephalopathy.
- Trouble shooting ventilator emergencies begins with physical examination and review of ventilator waveforms and changes in peak and plateau pressures.
- Common complications of mechanical ventilation include barotrauma, hemodynamic compromise and patient- ventilator dyssynchrony.

REFERENCES

De Haro, Candelaria, et al. "Patient-ventilator asynchronies during mechanical ventilation: current knowledge and research priorities." *Intensive care medicine experimental* 7.1 (2019): 1-14.

Girard, Timothy D., and Gordon R. Bernard. "Mechanical ventilation in ARDS: a state-of-the-art review." *Chest* 131.3 (2007): 921-929.

Kacmarek, Robert M. "The mechanical ventilator: past, present, and future." *Respiratory care* 56.8 (2011): 1170-1180.

Tobin MJ. Advances in mechanical ventilation. *New England Journal of Medicine*. 2001 Jun 28;344(26):1986-96.