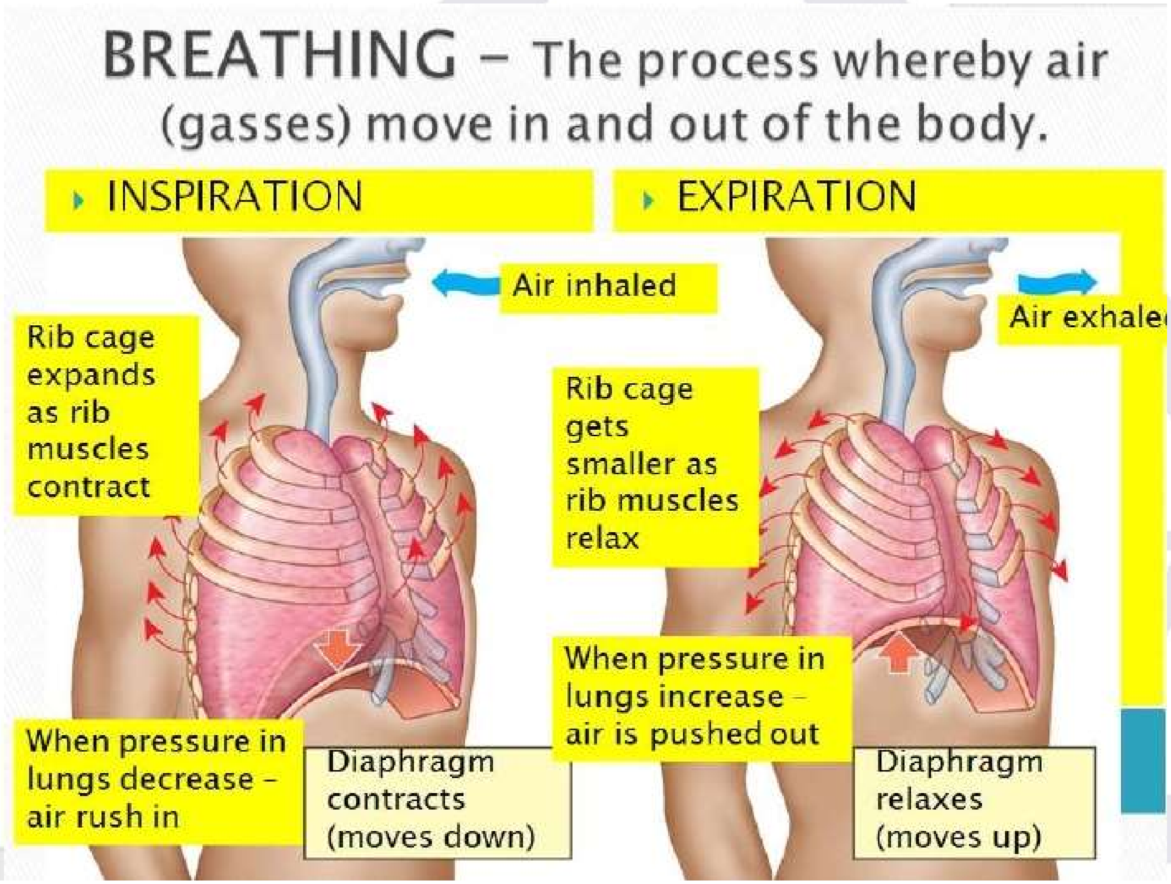
Basics of Mechanical Ventilation

Ehab G Daoud MD, FACP, FCCP

Associate Professor of Medicine, JABSOM, University of Hawaii
Medical director of respiratory program, Kapiolani Community College
Critical Care Medicine

Normal Breathing (Negative Pressure)



The Ventilator

- Best Invention in history ???? saves lives
- Created the modern ICU

Rules:

- Love your ventilator; listen to what it tells you, its your friend
- Use its lingo
- Beware of your ventilator
- **Adjust the ventilator to the patient not patient to ventilator**

Ventilator Lingo

- ***How are you doing (correct)***

  (Flow Triggered, Flow Targeted, Volume Cycled Assist control mode)

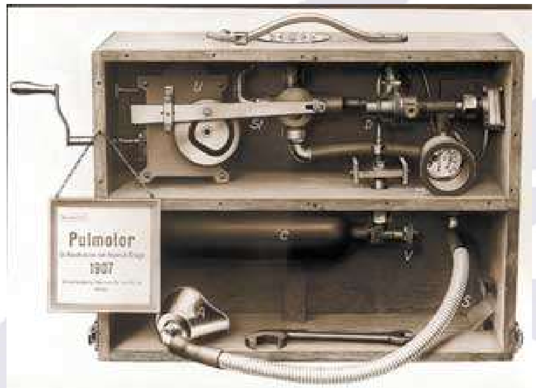
  (Flow Triggered, Pressure targeted, Time Cycled Assist Control mode)

- ***Whad up yo, Howzit (slang)***

  (Volume control) (AC)

  (Pressure control) (PC)

Ventilator Evolution



Ventilator Evolution

- 1970: 3 modes of ventilation
- 2014: > 200 modes of ventilation

  > 50 ventilator tradenames

Goals of Mechanical Ventilation

- Safety:
- Oxygenation & Ventilation
- -Avoid Ventilator Induced Lung Injury (volutrauma, barotrauma, atelectrauma, biotrauma, ergotrauma)

- Comfort: Patient ventilator Synchrony, auto-PEEP

- Liberation: Minimize duration of mechanical ventilation

Indications for Mechanical Ventilation

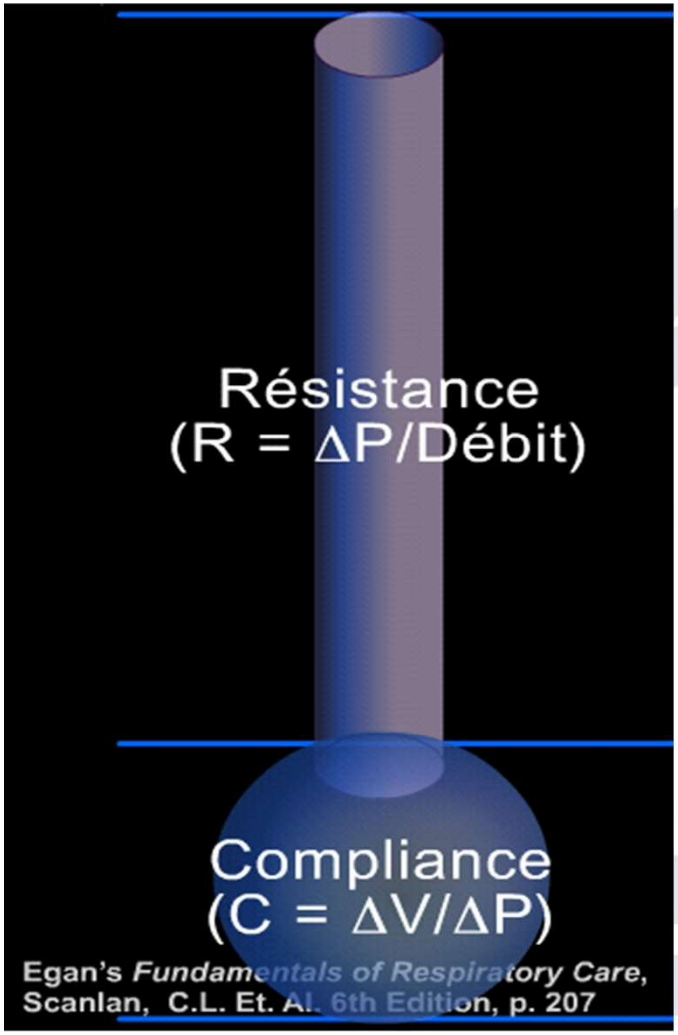
Alveolar filling processes
Pneumonitis - infectious, aspiration
Noncardiogenic pulmonary edema/ARDS (eg, due to infection, inhalation injury, near drowning, transfusion, contusion, high altitude)
Cardiogenic pulmonary edema
Pulmonary hemorrhage
Tumor (eg, choriocarcinoma)
Alveolar proteinosis
Intravascular volume overload of any cause
Pulmonary vascular disease
Pulmonary thromboembolism
Amniotic fluid embolism, tumor emboli
Diseases causing airways obstruction: central
Tumor
Laryngeal angioedema
Tracheal stenosis
Diseases causing airways obstruction: distal
Acute exacerbation of chronic obstructive pulmonary disease
Acute, severe asthma

Hypoventilation: decreased central drive
General anesthesia
Drug overdose
Hypoventilation: peripheral nervous system/ respiratory muscle dysfunction
Amyotrophic lateral sclerosis
Cervical quadriplegia
Guillain-Barré syndrome
Myasthenia gravis
Tetanus, tick bite, ciguatera poisoning
Toxins (eg, strychnine)

Hypoventilation: chest wall and pleural disease
Kyphoscoliosis
Trauma (eg, flail chest)
Massive pleural effusion
Pneumothorax
Increased ventilatory demand
Severe sepsis
Septic shock
Severe metabolic acidosis

UpToDate

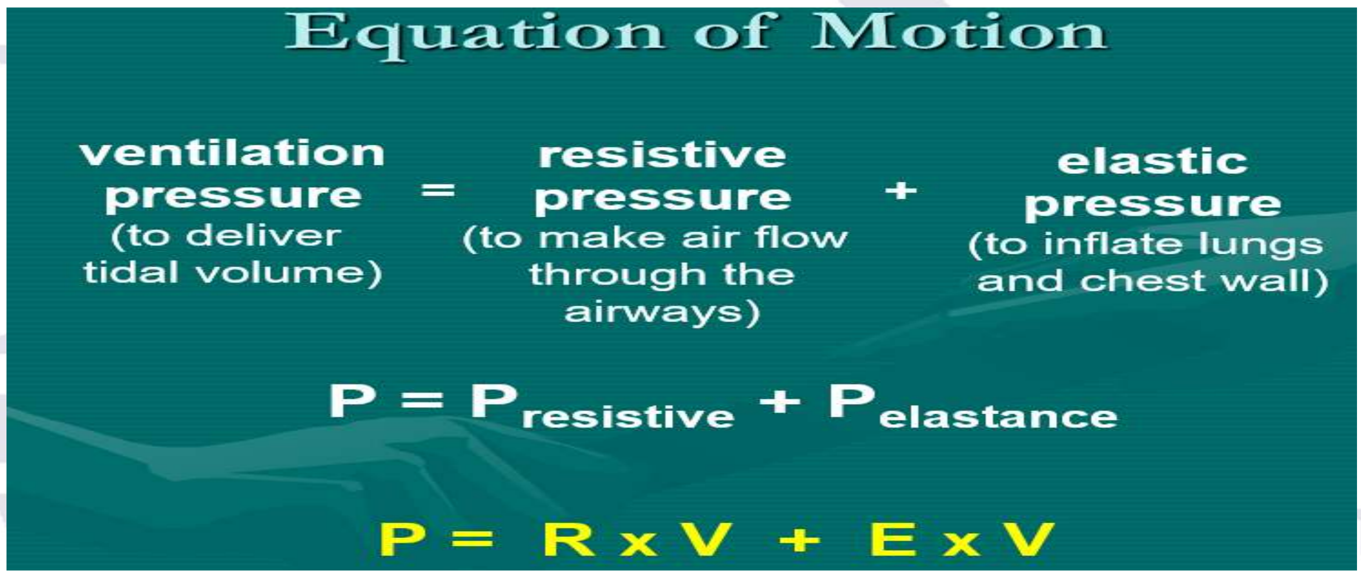
Respiratory Mechanics



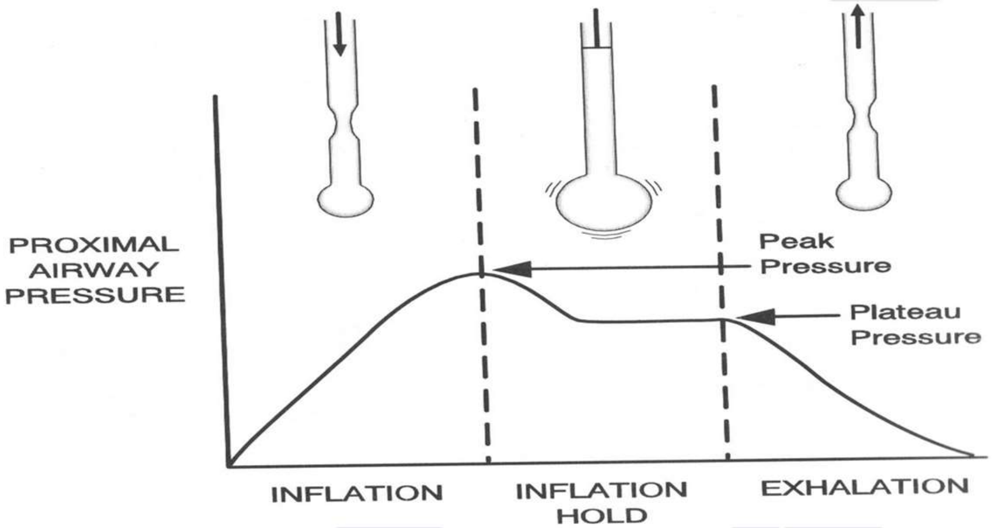
Airway resistance: Proportional to length, flow and inversely related to Radius

$$\frac{P1-P2}{V}$$

Compliance: 1/Elastance
How much pressure required to obtain a certain volume

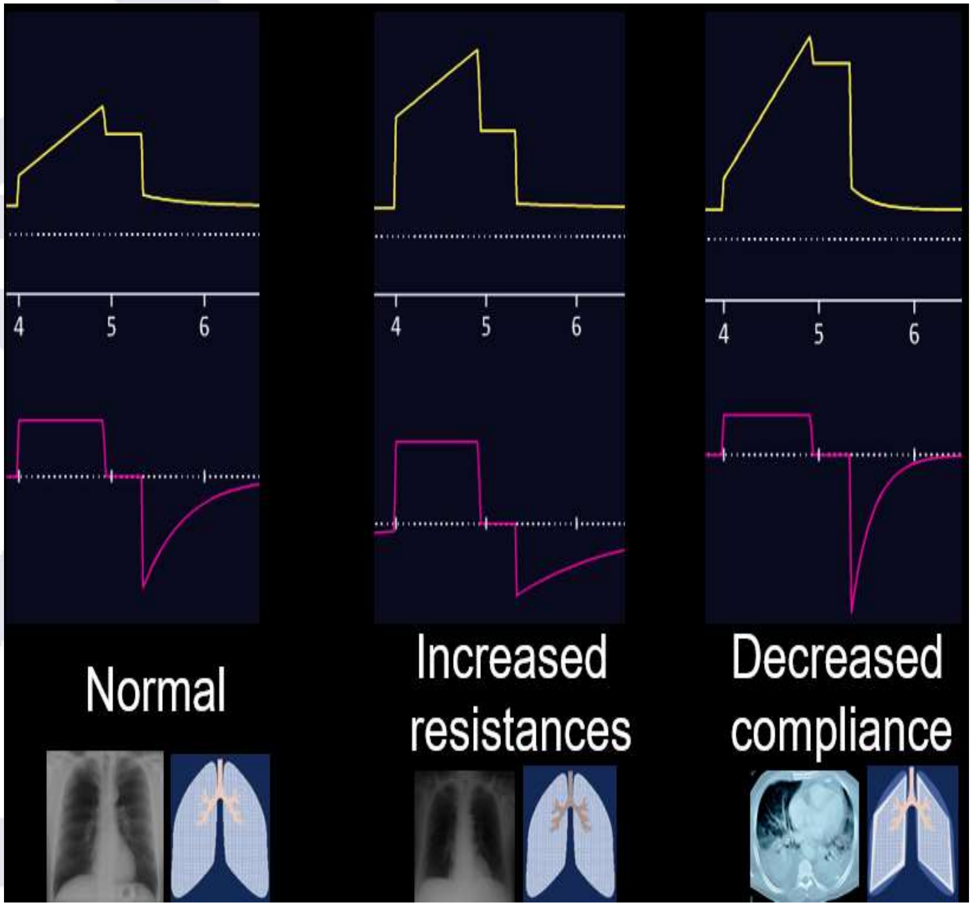


Respiratory Mechanics



Static Compliance (ml/cmH2O)=
Tidal volume/Plateau pressure-Total PEEP

Resistance (cmH2O/L/S) = PIP – Ppl/Flow

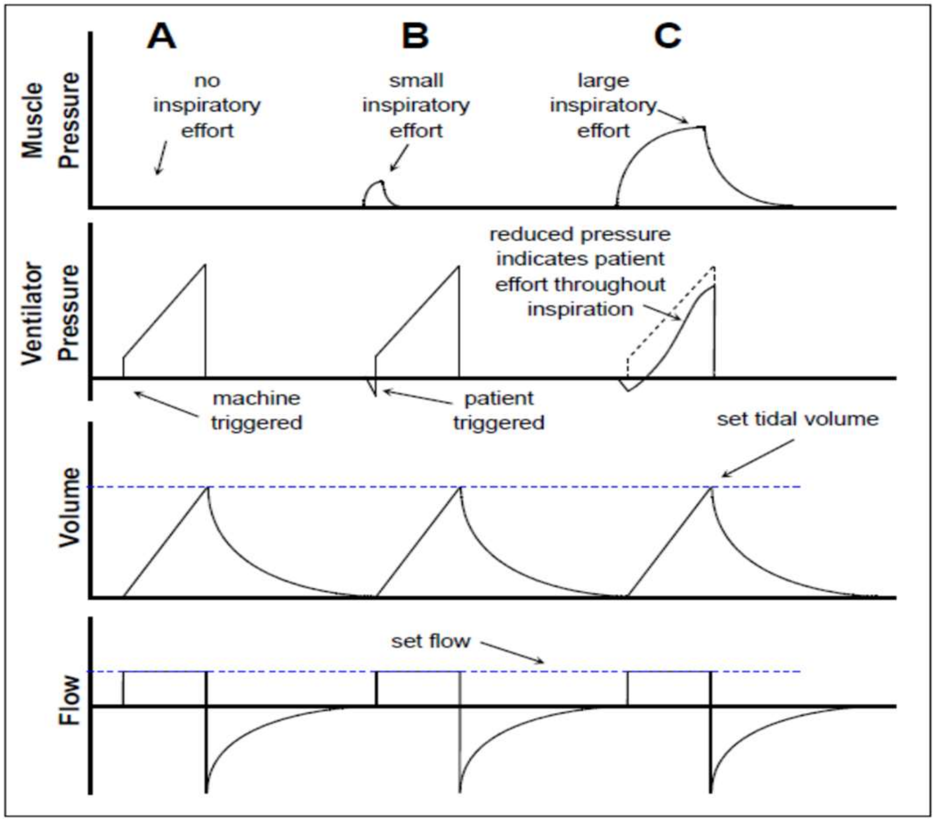


Positive Pressure Breath

Trigger: How does Inspiration start

Limit: Maximum value during Inspiration

Cycle: How does inhalation stops and exhalation starts



Modes of Mechanical Ventilation

■ **WHAT IS A MODE? A mode of mechanical ventilation has three essential components:**
- **The control variable**
- **The breath sequence**
- **The targeting scheme.**

Mechanical breath description
Control variable—the mechanical breath goal, ie, a set pressure or a set volume

Trigger variable—that which starts inspiration, ie, the patient (generating changes in pressure or flow) or a set rate (time between breaths)

Limit variable—the maximum value during inspiration

Cycle variable—that which ends inspiration

Breath sequence
Continuous mandatory ventilation—all breaths are controlled by the ventilator, so usually they have the same characteristics regardless of the trigger (patient or set rate); no spontaneous breaths are allowed

Intermittent mandatory ventilation—a set number of mechanical breaths is delivered regardless of the trigger (patient initiation or set rate); spontaneous breaths are allowed between or during mandatory breaths

Continuous spontaneous ventilation—all breaths are spontaneous with or without assistance

Type of control or targeting scheme [a]
Set point—the ventilator delivers and maintains a set goal, and this goal is constant (eg, in pressure control, the set point is pressure, which will remain constant throughout the breath); to a degree, all modes have some set-point control scheme

Servo—the ventilator adjusts its output to a given patient variable (ie, in proportional assist ventilation, the inspiratory flow follows and amplifies the patient's own flow pattern)

Adaptive—the ventilator adjusts a set point to maintain a different operator-selected set point (ie, in pressure-regulated volume control, the inspiratory pressure is adjusted breath to breath to achieve a target tidal volume)

Optimal—the ventilator uses a mathematical model to calculate the set points to achieve a goal (ie, in adaptive support ventilation, the pressure, respiratory rate, and tidal volume are adjusted to achieve a goal minute ventilation)

Modes of Mechanical Ventilation

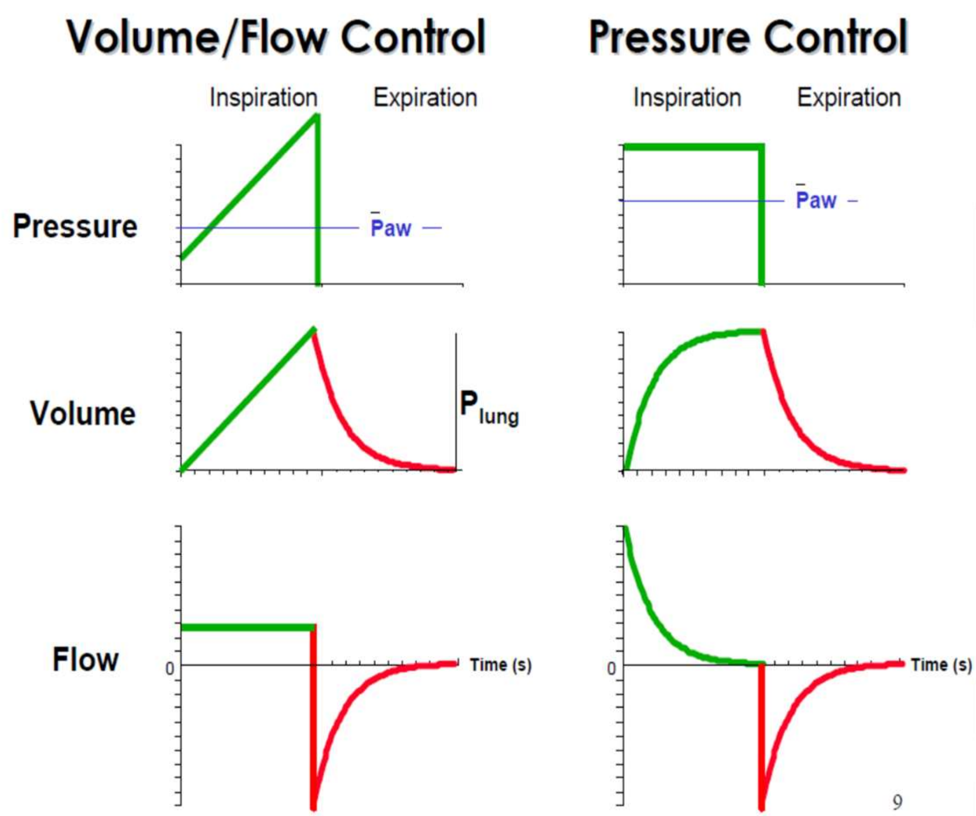
Classification of modes of ventilation

CONTROL VARIABLE	BREATH SEQUENCE	TARGETING SCHEME	EXAMPLES OF COMMERCIALLY AVAILABLE MODES
Volume	Continuous mandatory ventilation	Set point	Volume control, VC-A/C, CMV, (S)CMV, Assist/Control
		Dual	CMV + pressure limited
		Adaptive	Adaptive flow
	Intermittent mandatory ventilation	Set point	SIMV, VC-SIMV
		Dual	SIMV + pressure limited
		Adaptive	AutoMode (VC-VS), mandatory minute volume
Pressure	Continuous mandatory ventilation	Set point	Pressure control, PC-A/C, AC PCV, high-pressure oscillatory ventilation [a]
		Adaptive	Pressure-regulated volume control, [a] VC+AC [a], AMV+AutoFlow [a]
	Intermittent mandatory ventilation	Set point	Airway pressure-release ventilation, [a] SIMV PCV, BiLevel, [a] PCV+ [a]
		Adaptive	VC+SIMV, V V+SIMV APVSIMV, SIMV+AutoFlow, Automode (PRVC-VS)
		Optimal	Adaptive support ventilation [a]
	Continuous spontaneous ventilation	Set point	Continuous positive airway pressure, pressure support
		Dual	Volume assured pressure support, volume augment
		Servo	Proportional assist ventilation, [a] automatic tube compensation
		Adaptive	Volume support
		Intelligent	SmartCare

Alternative modes of mechanical ventilation: A review for the hospitalist
Mireles-Cabodevila E, Diaz-Guzman E, Heresi GA, et al. CCJM 2009, 76 (7) 417-430

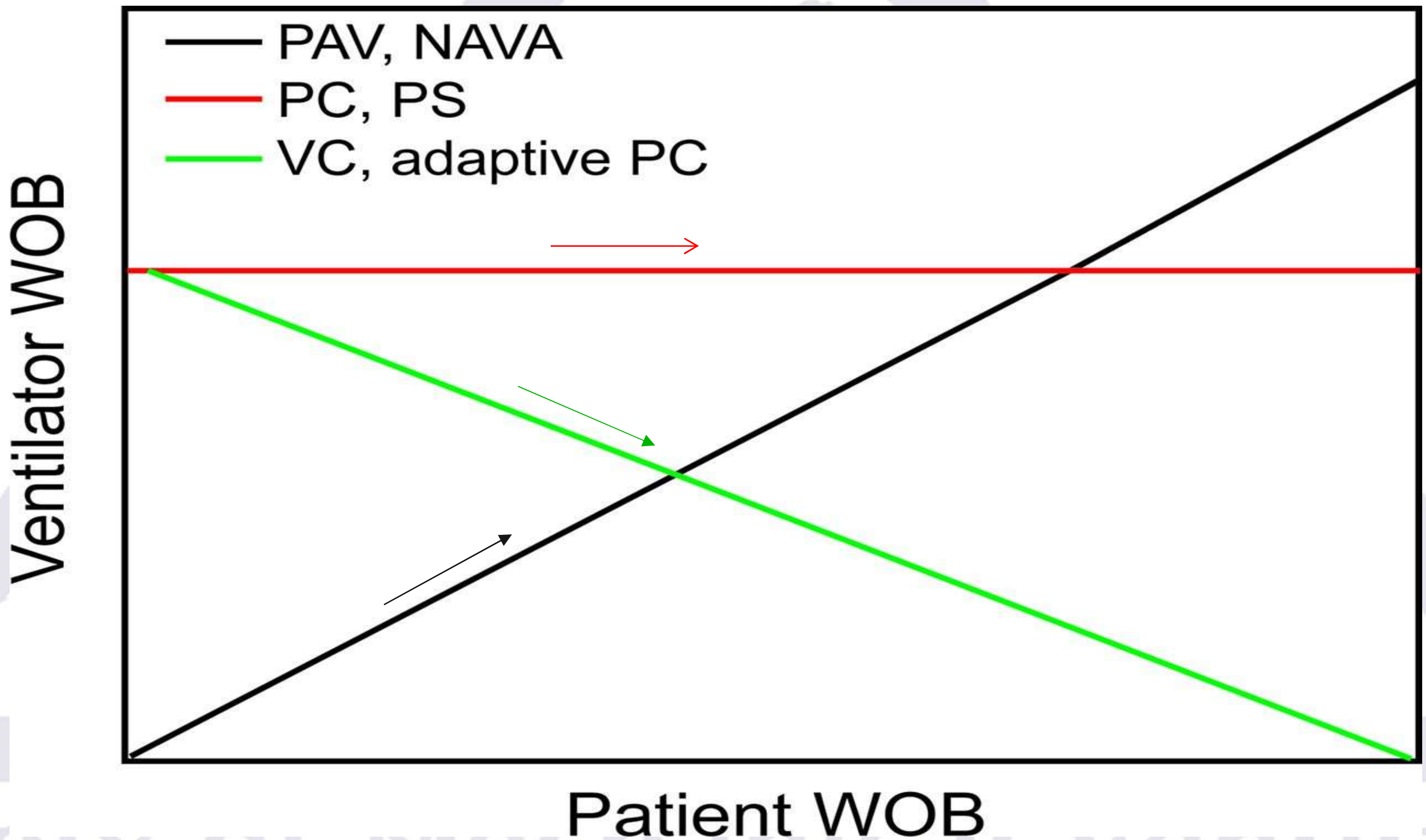
Modes of Mechanical Ventilation

- Same tidal volume every breath
- Same inspiratory flow every breath
- Varying inspiratory pressure (compliance, resistance, Pt's WOB)
- Easy
- Worsens Dysynchrony
- May worsen Pt's work of breathing
- Inferior oxygenation (less mean airway pressure)



- Same inspiratory pressure every breath
- Varying inspiratory flow
- Varying tidal volume every breath (compliance, resistance, WOB)
- Little more difficult
- Can result in higher tidal volumes
- Superior synchrony
- Superior oxygenation (Higher mean airway pressure)
- May reduce VILI

Patient-Ventilator Interaction



PEEP (Positive End Expiratory Pressure)

Probably most important Parameter to apply and adjust

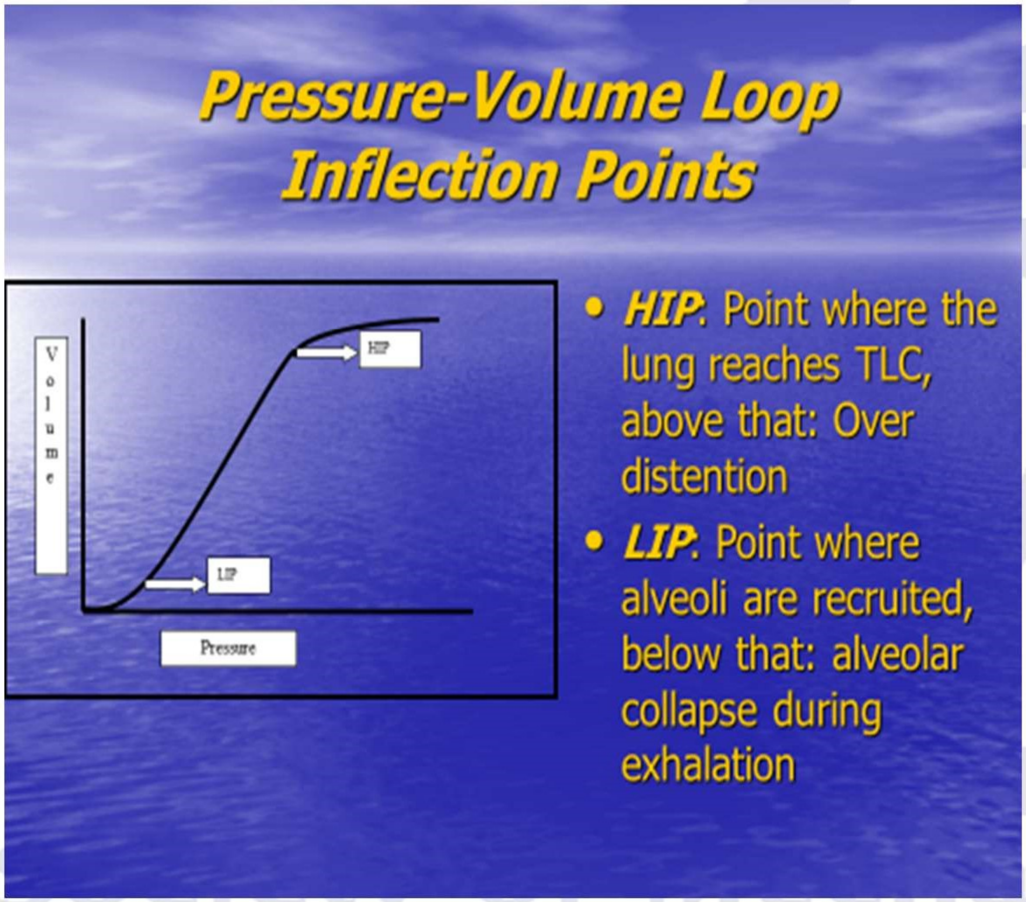
Many ways to do it (no agreement in literature)

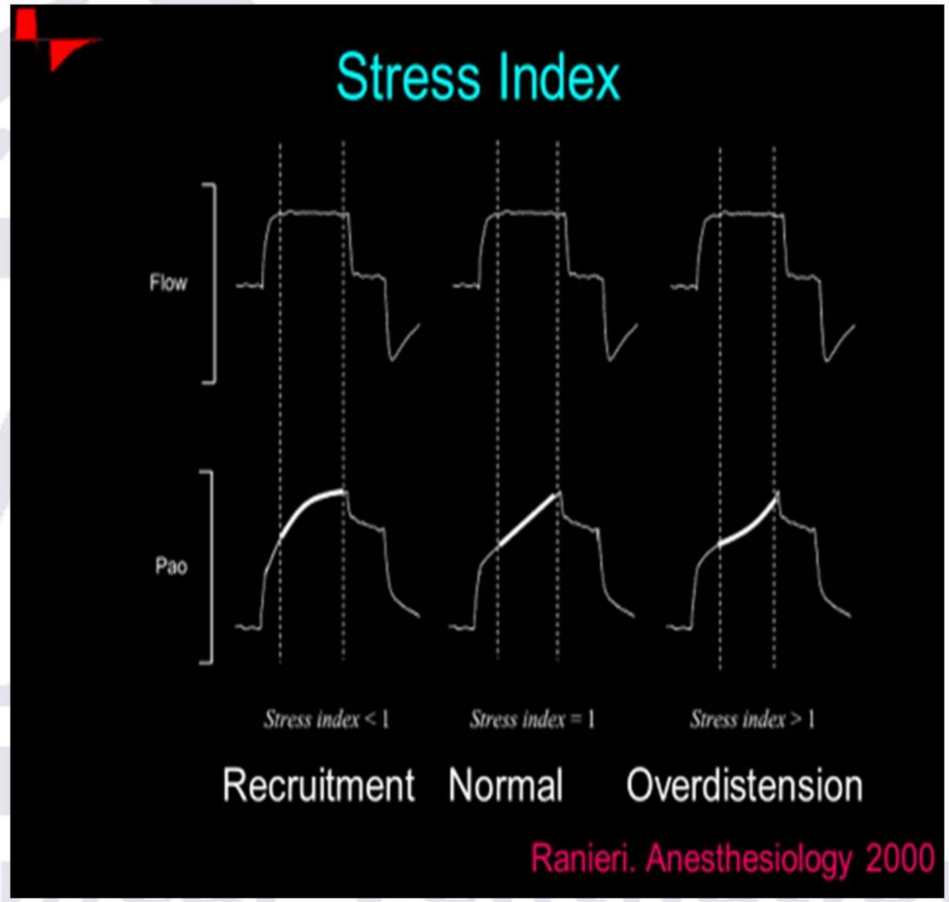
Improves oxygenation

Too low can cause VILI

Too high can cause overdistention & hemodynamic instability

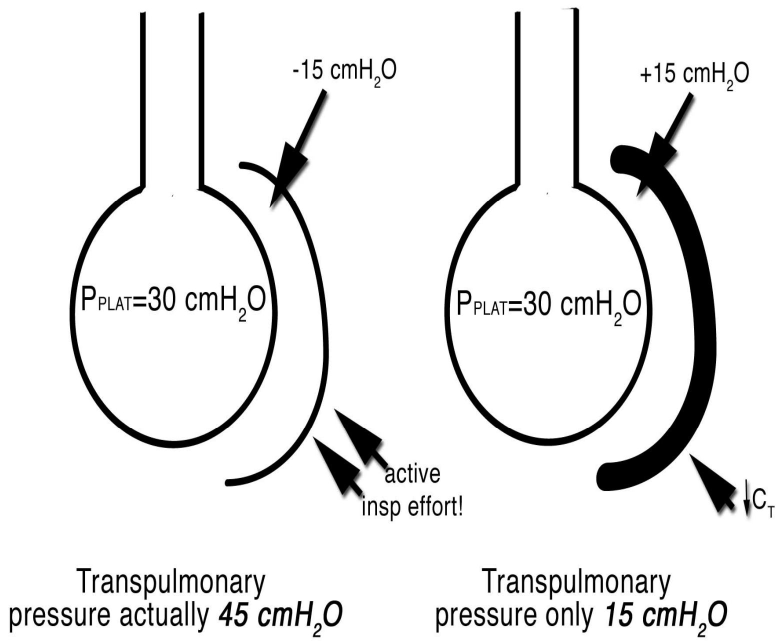
PEEP (Positive End Expiratory Pressure)





PEEP (Positive End Expiratory Pressure)

Esophageal balloon and Trans-Pulmonary pressure measurement



PEEP-FiO2 table

Lower PEEP/higher FiO2

FiO_2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7
PEEP	5	5	8	8	10	10	10	12

FiO_2	0.7	0.8	0.9	0.9	0.9	1.0
PEEP	14	14	14	16	18	18-24

Higher PEEP/lower FiO2

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5
PEEP	5	8	10	12	14	14	16	16

FiO_2	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	18	20	22	22	22	24

Weaning & Liberation

Weaning & Liberation

Weaning	Liberation
The process of abruptly or gradually withdrawing ventilatory support	The removal of the artificial airway

Weaning & Liberation
Facts

- Mechanical ventilation can be abruptly withdrawn in 75% of patients whose respiratory failure has been improved or resolved can
- 25% of patients will need progressive withdrawal of mechanical ventilation
- 40% of time spent on the ventilator is for weaning
- 56% of patients with unplanned extubation did not require re-intubation
- Weaning parameters are not good predictors of extubation
- Weaning with high PSV >7 cmH2O is not weaning
- 10% - 15% extubation failure is acceptable

Weaning & Liberation

Weaning
When?

Respiratory Criteria:

- ☑ $PaO_2 \geq 60$ mm Hg on $FiO_2 \leq 40$–50% and PEEP ≤ 5–8 cm H_2O
- ☑ $PaCO_2$ normal or baseline (except for permissive hypercapnia).
- ☑ Patient is able to initiate an inspiratory effort.

Cardiovascular Criteria:

- ☑ No evidence of myocardial ischemia.
- ☑ Heart rate ≤ 140 beats/minute.
- ☑ Blood pressure normal without vasopressors or with minimum vasopressor support (e.g., dopamine < 5 μg/kg/min).

Adequate Mental Status:

- ☑ Patient is arousable, or Glasgow Coma Score ≥ 13.

Absence of Correctible Comorbid Conditions:

- ☑ Patient is afebrile.
- ☑ There are no significant electrolyte abnormalities.

Weaning
How?

Spontaneous Breathing Trial (SBT)

- Check respiratory system compliance and resistance before SBT

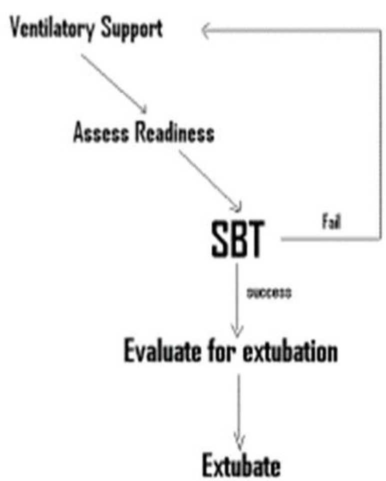
30 -120 minutes

- T-piece
- PSV 5-7 CmH2O
- CPAP 5-7 CmH2O
- ATC
- Smart Care ?
- PAV ?

~~SIMV~~

Weaning & Liberation

Weaning



Weaning

Weaning & Liberation

Weaning
causes of failed SBT

Factors that can lead to weaning failure due to the imbalance between ventilatory needs and respiratory capacity

Factors that increase the load

Increased resistive loads	Increased chest wall elastic loads	Increased lung elastic loads
Bronchospasm	Pleural effusion	Hyperinflation (auto-PEEP
Airway edema, secretions	Pneumothorax	Alveolar edema
Upper airway obstruction	Flail chest	Infection
Obstructive sleep apnea	Obesity	Atelectasis
Endotracheal tube kinking	Ascites	Interstitial inflammation and/or edema
Secretions encrustation	Abdominal distension	
Ventilatory circuit resistance		

Factors that result in decreased neuromuscular competence

Decreased drive	Muscle weakness	Impaired neuromuscular transmission
Drug overdose	Electrolyte derangement	Critical illness polyneuropathy
Brain-stem lesion	Malnutrition	Neuromuscular blockers
Sleep deprivation	Myopathy	Aminoglycosides
Hypothyroidism	Hyperinflation	Guillain–Barré syndrome
Starvation/malnutrition	Drugs, corticosteroids	Mysthenia gravis
Metabolic alkalosis	Sepsis	Phrenic nerve injury
Myotonic dystrophy		Spinal cord lesion

Weaning
Patients who fail SBT

- Correct underlying reason for failure
- Daily SBT
- At least 24 hours of rest in between trials

Thank You