Ventilation & Beyond for Anesthesia

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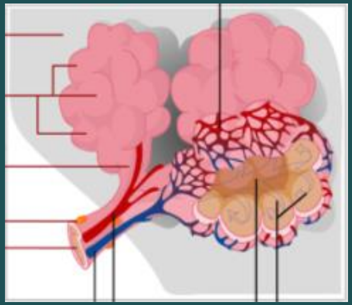
Objectives:

1. Understand various respiratory functions & mechanics.
2. Know how to alter ventilator settings to achieve desired ventilatory status
3. Understand the various modes of ventilation
4. Explain which modes are beneficial based on patient and/or procedure
5. Discuss airway devices and modes of ventilation to use

Respiratory System Functions

- **Passageway:** Airways **a**llow air to reach the lungs.
- **Oxygen supply:** The respiratory system keeps the body supplied with 0xygen.
- **Elimination:** Elimination of carbon dioxide.
- **Gas exchange:** The respiratory system oversees the gas exchange occurring between the blood and the external environment.
- **Humidifier:** Purify, humidify, & warm incoming air.



Respiratory Regulation

- **Phrenic and intercostal nerves:** Regulate the activity of the respiratory muscles, the diaphragm, & external intercostals.
- **Medulla and pons:** Neural centers that control respiratory rhythm & depth.
  - Medulla – pacemaker - sets the basic rhythm of breathing.
  - Self-exciting inspiratory center
  - Expiratory center that inhibits the pacemaker
  - Pons centers smooth out this basic rhythm

Mechanics of Breathing

Rule to Remember: Volume changes→ Pressure Changes →

Inspiration: Air flows into lungs, chest expands, rib cage elevates & the diaphragm is flattened; intrapulmonary pressure falls = air flow into the lungs.

Expiration: Air leaves lungs; chest dimension reduced; diaphragm elevated, intrapulmonary pressure increases = air flow out of the lungs.

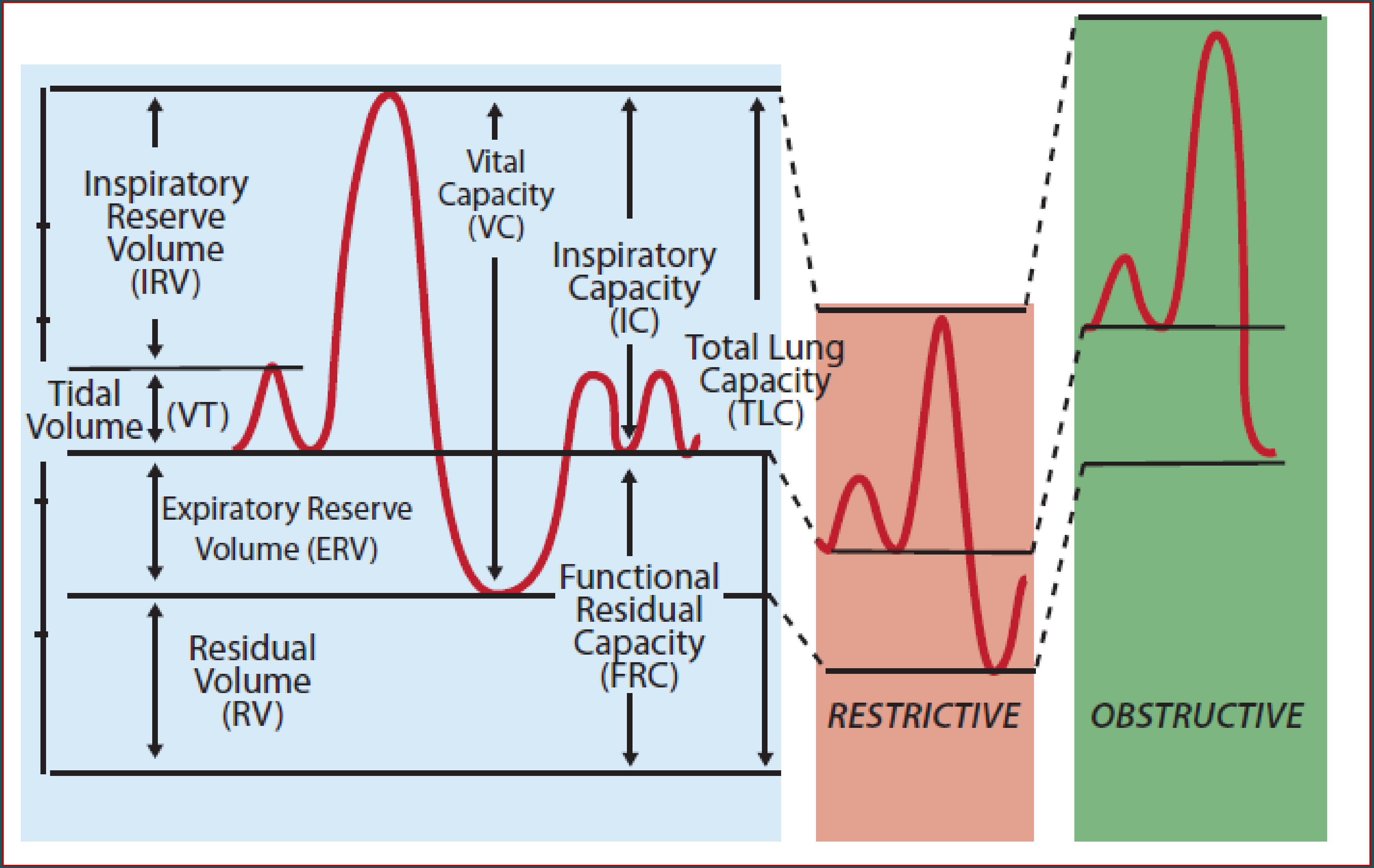
Intrapulmonary Volume: Volume within the lungs.

Intrapleural pressure: Normal pressure within the pleural space – *always negative* – prevents lung collapse

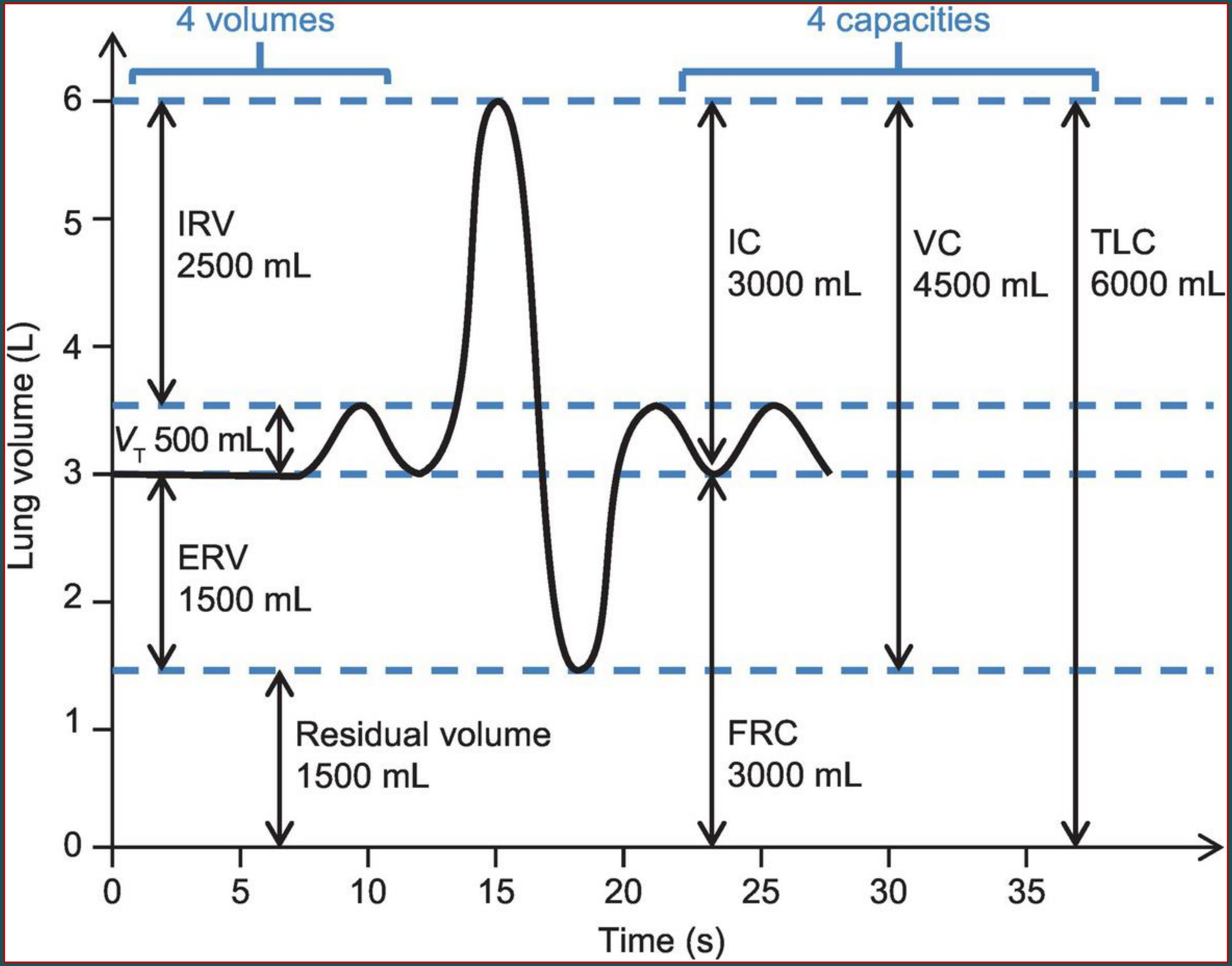
Non- Neural Factors Respiratory Regulation

- **Physical factors:** talking, coughing, laughing, temperature
- **Emotional factors:** hypothalamus
- **Chemical factors:** C02, pH & 02
  - Influenced by hyperventilation & hypoventilation → alterations in the respiratory rate

Lung Volumes and Capacities



Lung Volumes and Capacities



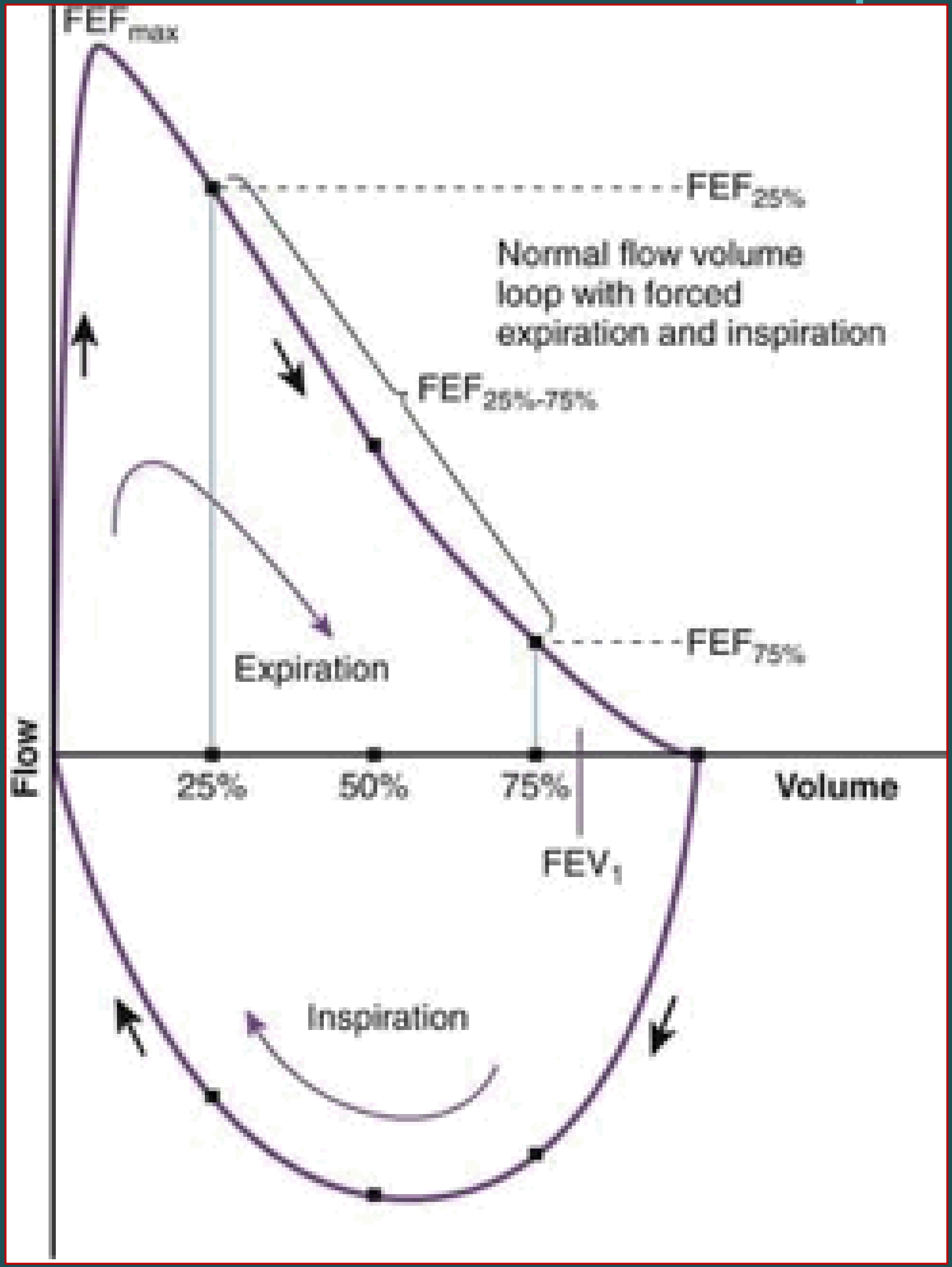
Normal Lung Volumes

Volume	Value (litres)	
	In men	In women
Inspiratory reserve volume (IRV)	3.0	1.9
Tidal volume (TV)	0.5	0.5
Expiratory reserve volume (ERV)	1.1	0.7
Residual volume (RV)	1.2	1.1

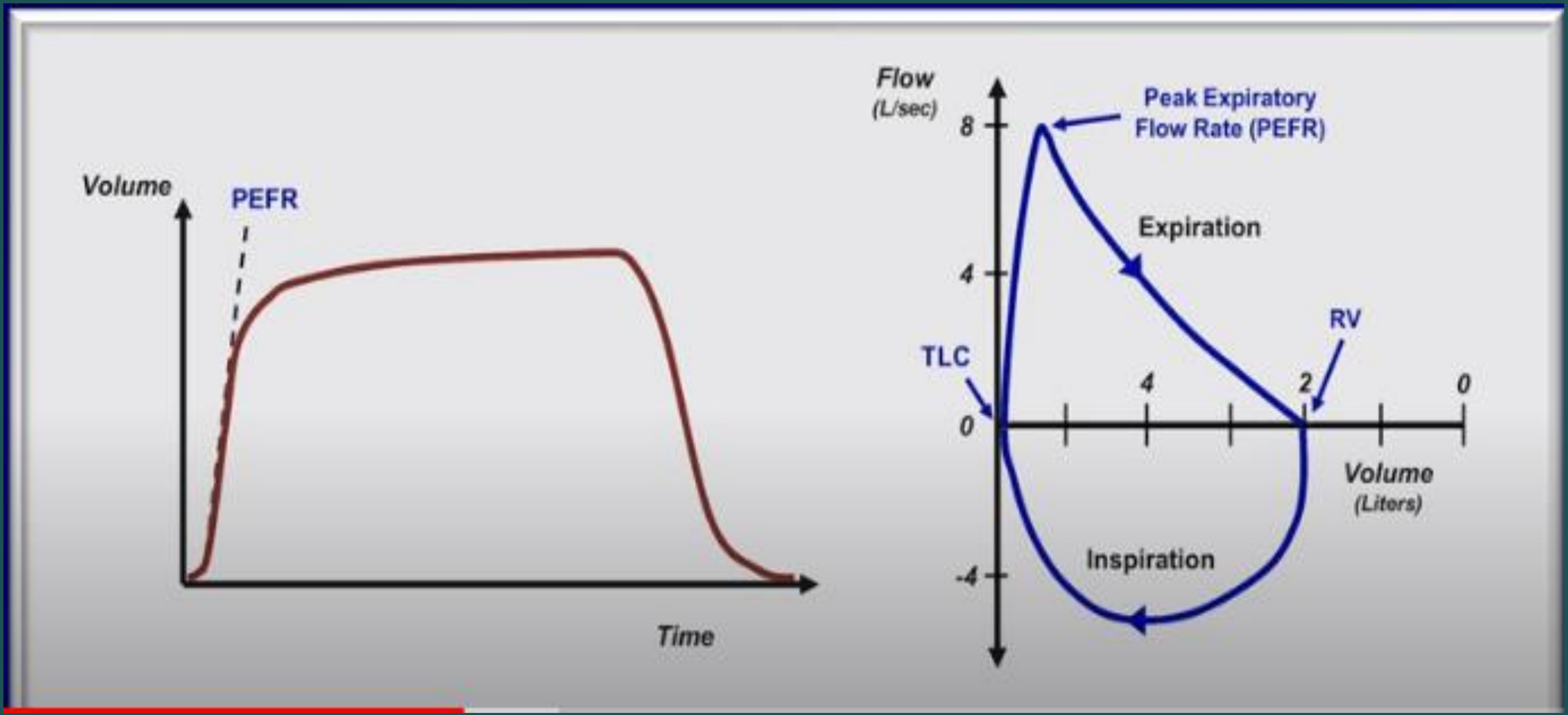
Normal Lung Capacities

Volume	Average value (litres)		Derivation
	In men	In women	
Vital capacity	4.6	3.1	IRV + TV + ERV
Inspiratory capacity	3.5	2.4	IRV + TV
Functional residual capacity	2.3	1.8	ERV + RV
Total lung capacity	5.8	4.2	IRV + TV + ERV + RV

Flow Volume Loops

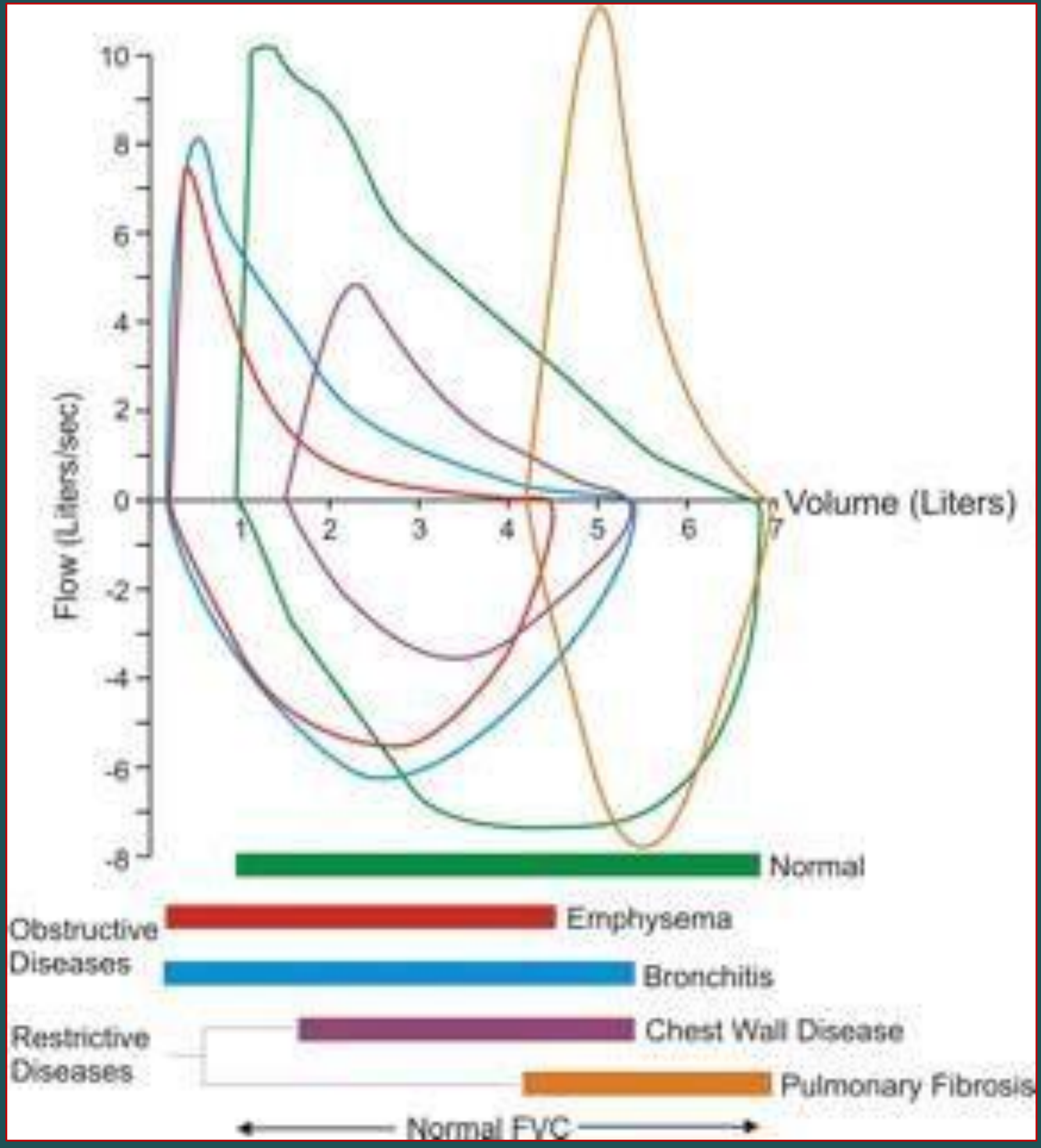


Flow Volume Loops

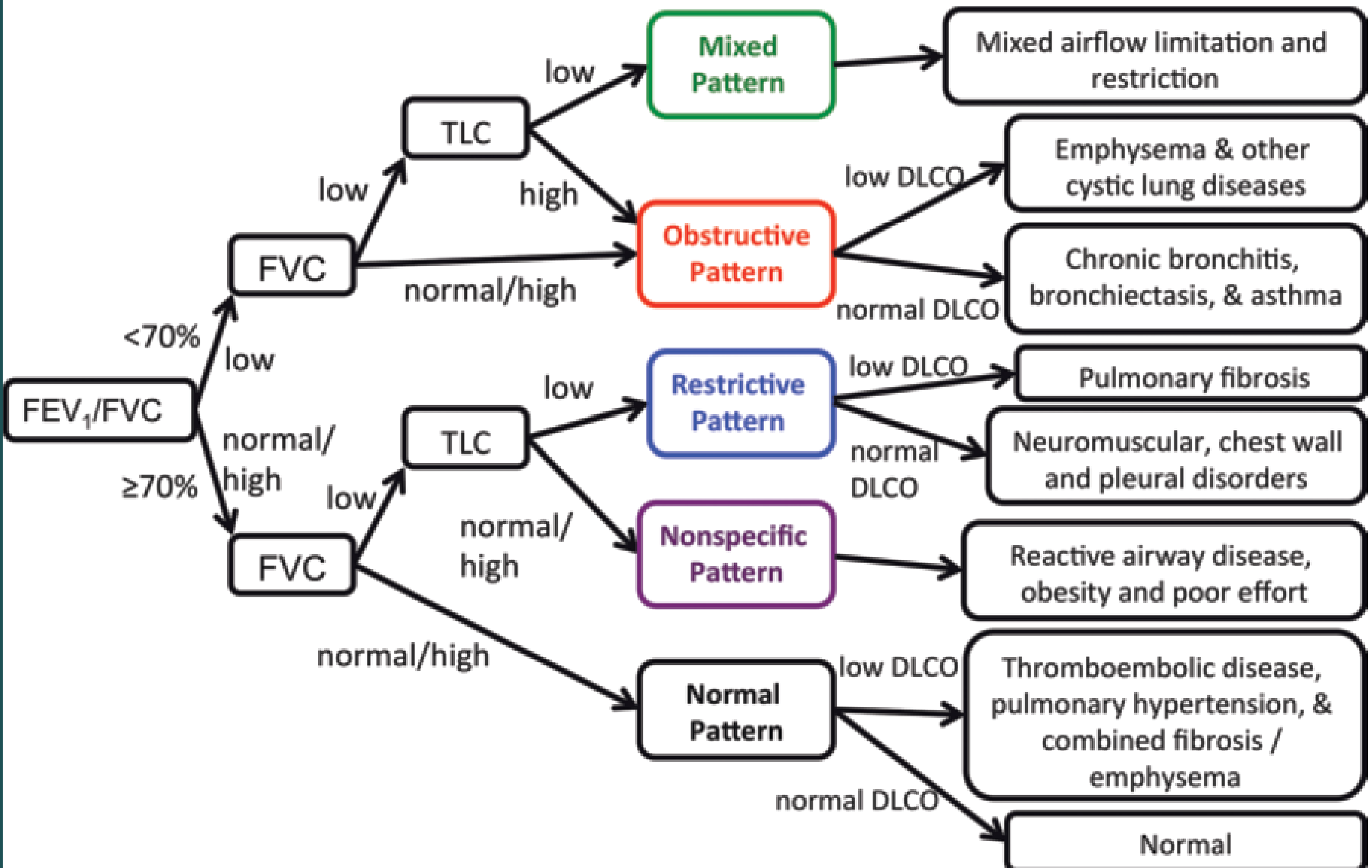


Flow = Volume/Time

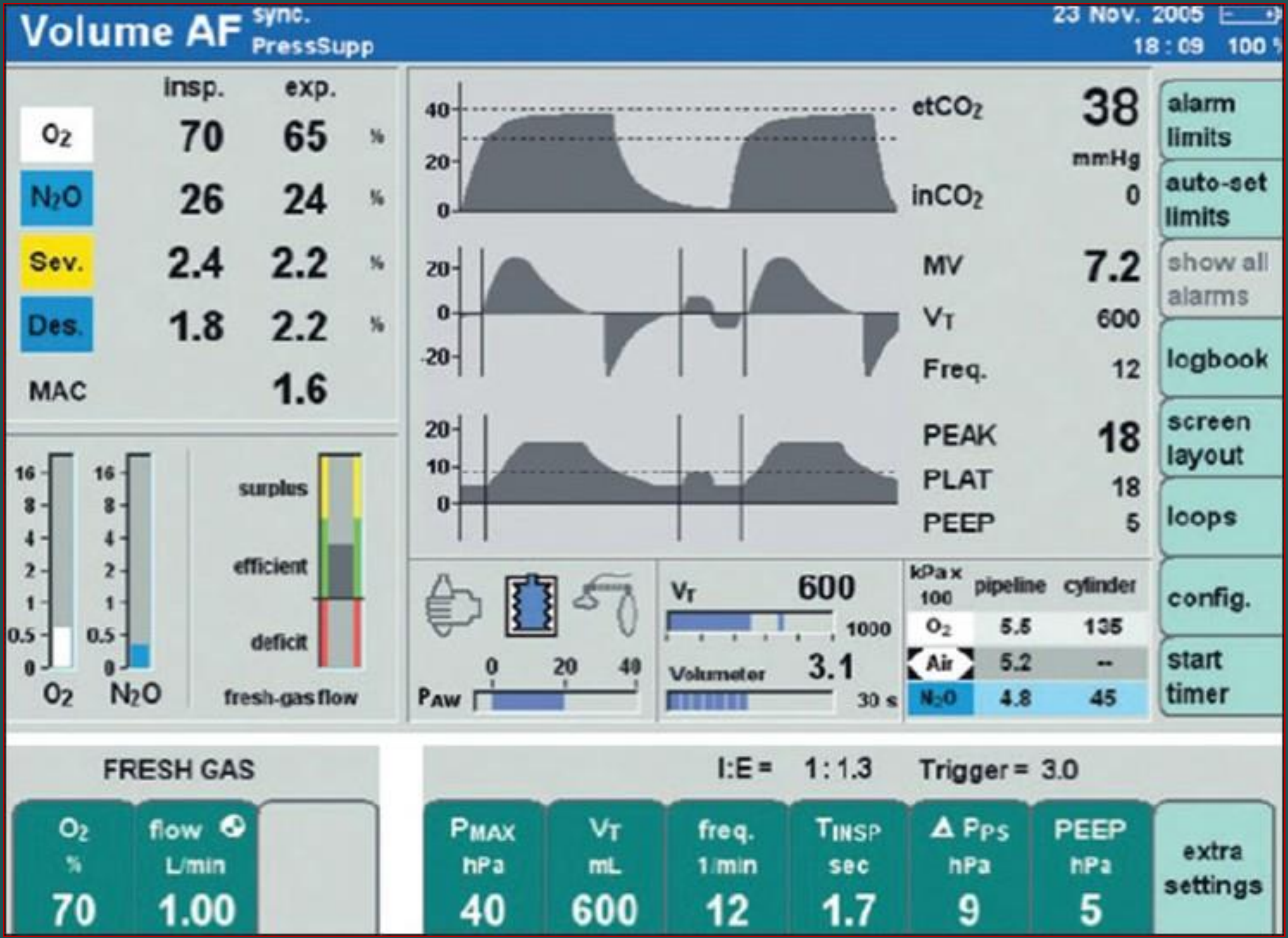
Abnormal Flow Volume Loops



Lung Function Algorithm



Anesthesia Ventilatory Graphics

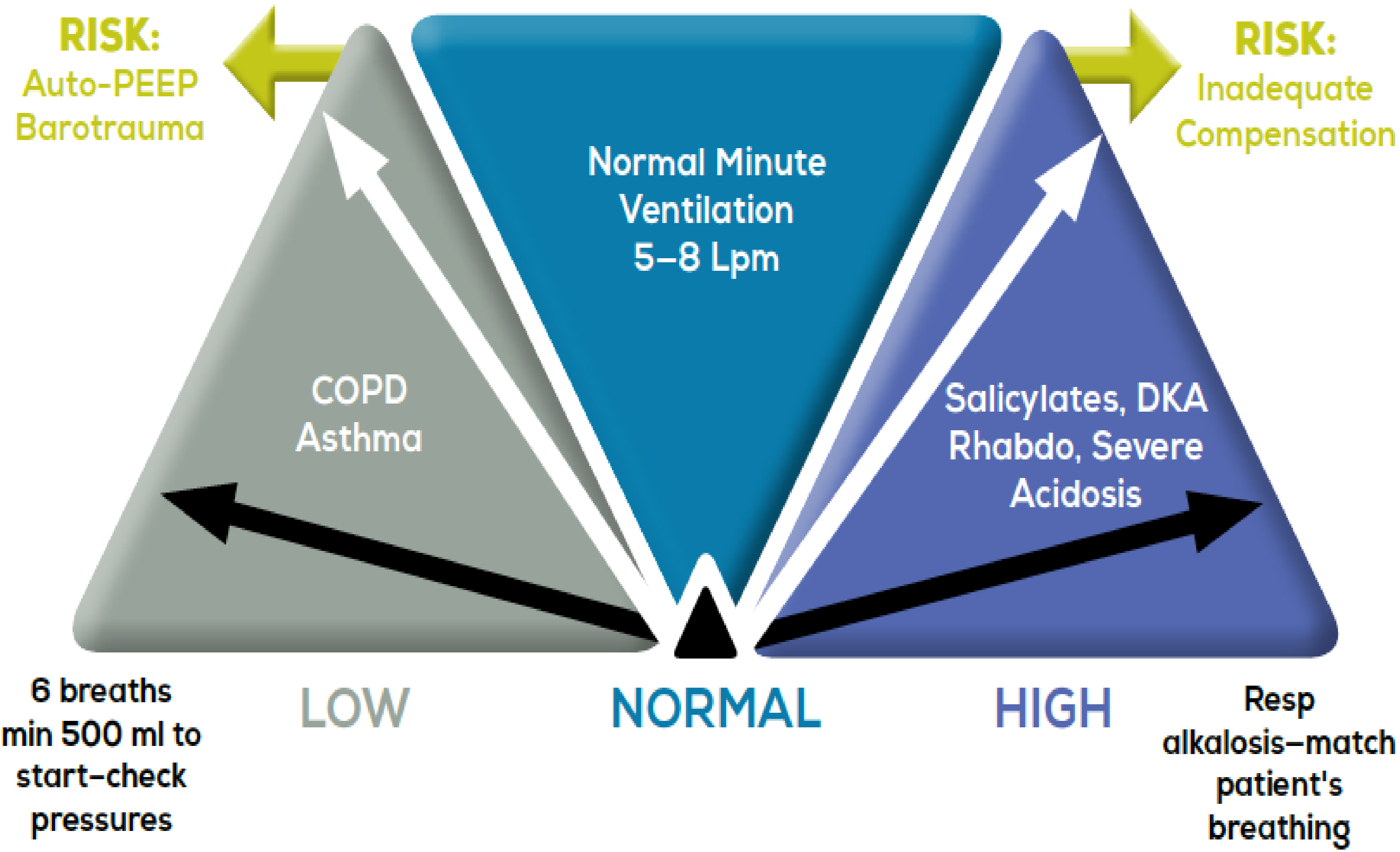


Respiratory Calculations

- **Tidal Volume** = **V_T :** volume of gas entering (or leaving) patient with inspiration or expiration (6-8 cc/kg
- **Tidal Volume** (VT) = Respiratory Rate (RR) X Minute Ventilation (VE) minus dead space
- **Minute Ventilation** (MV) = Rate x V_T
- **Minute Volume:** Sum of all tidal volumes in a minute (RR x V_T) 70 kg, 12 – 20 bpm x 500mL = 6-10 L/Min

Minute Ventilation at the Extremes: Preintubation

What will happen when you take control the patient's respiratory drive?



Definitions:

Compliance: ratio of change in volume to change in pressure. Dynamic!

Peak Inspiratory Pressure (PIP): Maximum pressure during inspiration

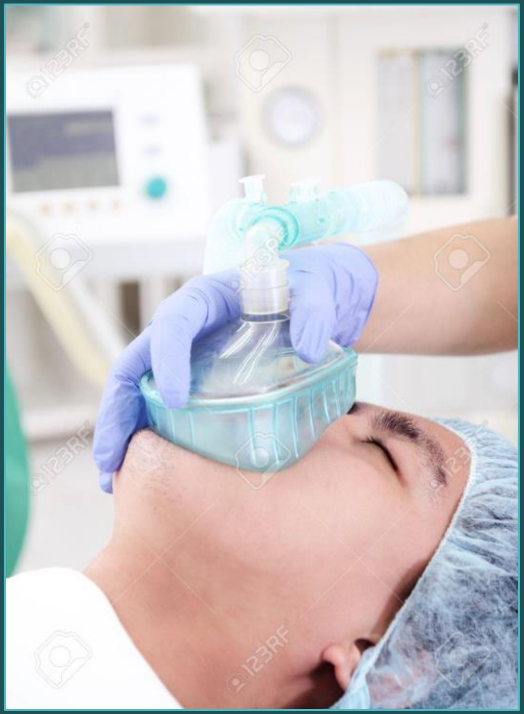
PEEP: Positive End Expiratory Pressure. Maintains alveolar expansion

I:E ratio (Inspiratory to Expiratory ratio): Normally 1:2

- Inspiratory phase is one third of ventilatory cycle time

- **Continuous Positive Airway Pressure** (CPAP): airway pressure maintained above ambient pressure
- **Sigh**: deliberate increase in tidal volume for one or more breathes (Normally 9-10 per hour). Maintains pulmonary compliance. Releases and evenly distributes surfactant.

Work of Breathing



- Energy expended by patient and/or ventilator to move gas in and out of the lungs.
- Includes work need to overcome elastic & flow-resistive forces of respiratory system & breathing system (Machine)
  - Position
  - Type of surgery
  - Airway

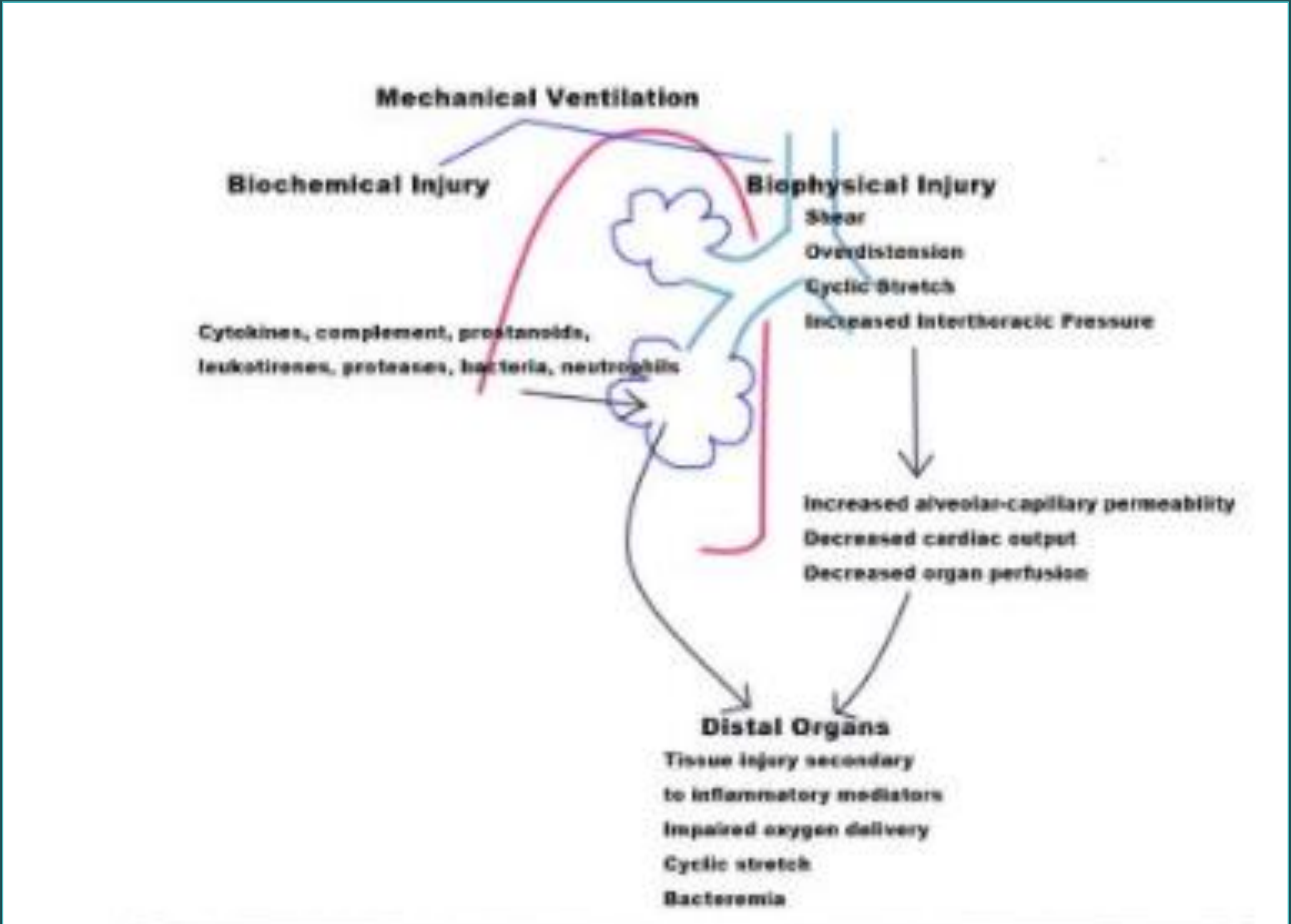
Complications of Mechanical Ventilation

- **Barotrauma**: Injury from high airway pressure
- **Volutrauma**: Injury from lung over distention

Complications of Mechanical Ventilation

- ***Atelectotrauma:*** Repetitive alveolar collapse & reopening of the under recruited alveoli
- ***Barotrauma***: Injury from high airway pressure
  - Keep plateau pressure < 30 cmH20
- ***Volutrauma***: Injury from lung over distention
- ***Biotrauma:*** Sheering, aspiration
- ***Oxygen Toxicity:*** Oxygen is a drug. Weaning patients form high Fi02s is vital.
  - High FiO2 concentration accelerates onset and amount of atelectasis, using
  - 50% FiO2 is recommended to optimize oxygenation in obese patients

Complications of Mechanical Ventilation



Compliance

- **Total Compliance:** reflects elastic properties of the lungs, thorax, abdomen, & (breathing system -corrugated tubing, reservoir bag)
- **Static Compliance:** Calculates pressures needed to overcome elastic resistance to ventilation without flows. Normal Adult: 35-100 mL/cm H_2O
- **Dynamic Compliance:** monitors both elastic and airway resistance; radius of the airways with gas flows.

Compliance

Clinical Significance

1. Paralytics increase chest wall compliance but **lung** compliance will be unchanged.
2. Emphysema or COPD – poor elastic recoil; increased compliance
3. Pulmonary Fibrosis – decreases elastic recoil & compliance
4. Atelectasis/ARDS – Collapse of lung alveoli. Often after surgery. Compliance decreases and pressure required to reinflate increases.

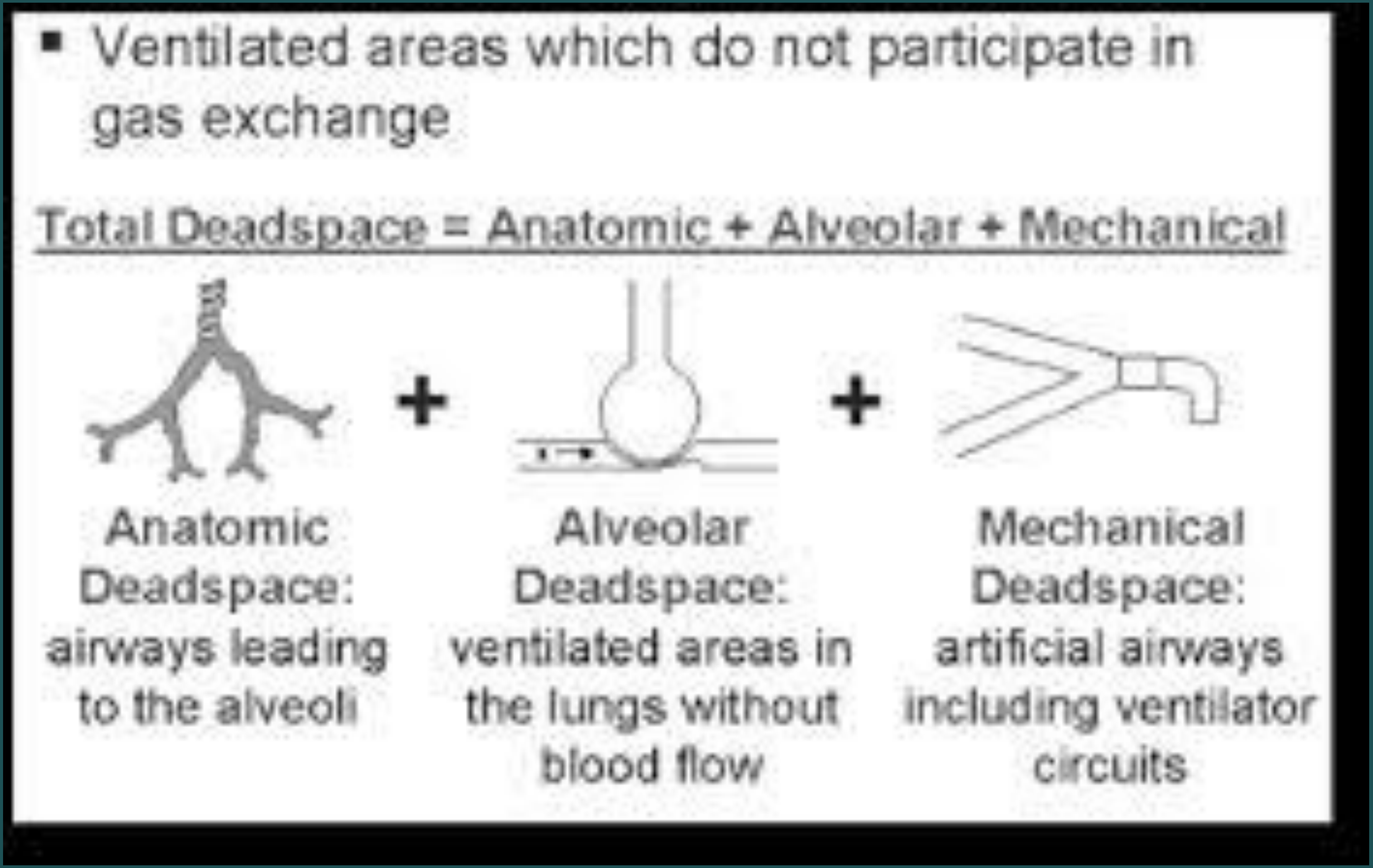
Resistance:

- May differ on inspiration and exhalation
- Determining Factors:
  - Patient's airway, airway adjunct, and breathing system
    - Endotracheal tube resistance primarily from internal diameter (I.D.).
  - Increased with bronchoconstriction, secretions, tumor, edema, foreign body, airway closure
  - Breathing system resistance: affected by length, I.D. of circuit, sharp bends, or constrictions
- Increase airway resistance requires higher pressure for a given V_T
- Higher resistance=higher peak pressure to produce same tidal volume and flow
- For a given V_T resistance may decrease if using a lower flow for a longer time (I:E ratio)

I:E Ratios

- Normally 1:2
- COPD patients may require longer expiratory time due to loss of elasticity → hyperinflation
  - 1:3
- 1:1 Inspiratory: Expiratory ratio allows longer time for inspiration & decreases PIP
- Inverse ratios - 2:1 ARDS
  - Keeps alveoli expanded to reduce edema
  - Can lead to "*stacking*"

Dead Space



Ventilated areas which do not participate in gas exchange
Total Deadspace = Anatomic + Alveolar + Mechanical
+
+
Anatomic Deadspace: airways leading to the alveoli
Alveolar Deadspace: ventilated areas in the lungs without blood flow
Mechanical Deadspace: artificial airways including ventilator circuits

Dead Space

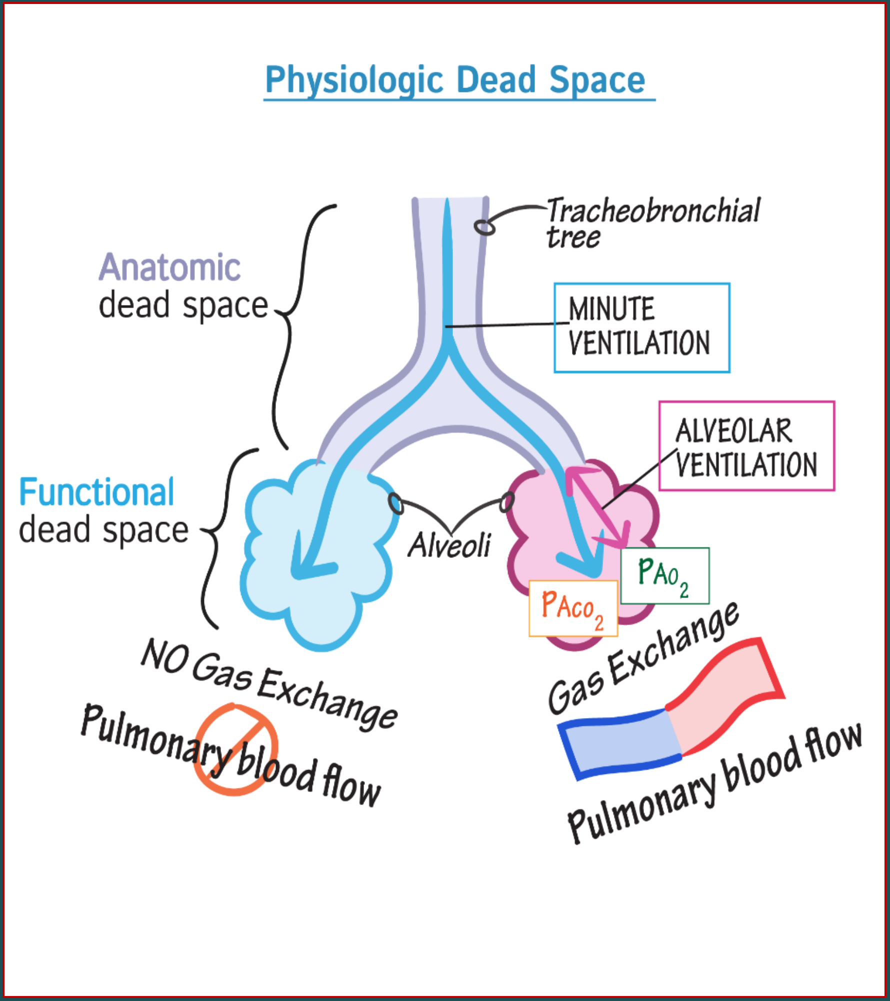
Anatomic: Nose to terminal bronchi (2mL/kg)

- ETT, (LMA, Circuit and/or mechanical

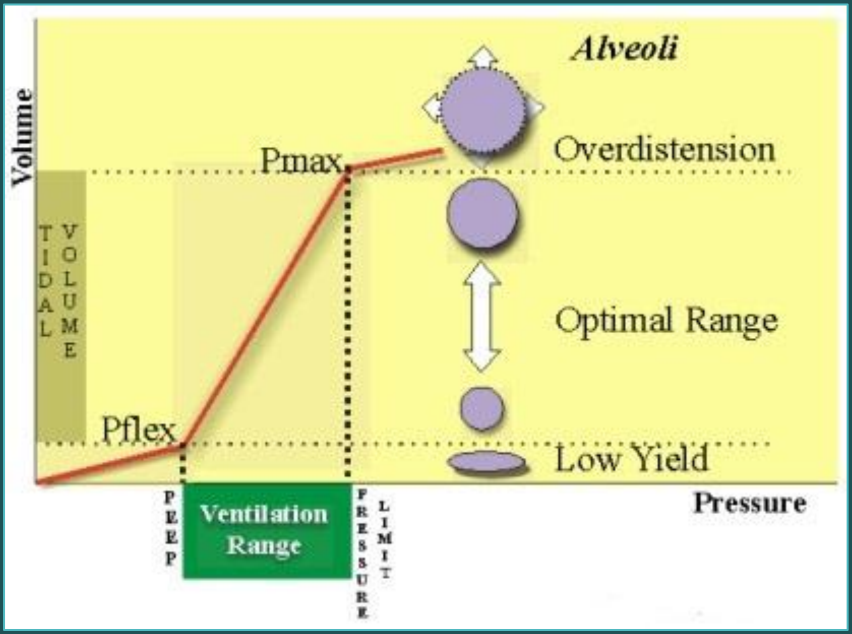
Alveolar: alveoli ventilated by not perfused (V/Q)

Physiologic: Anatomic + Alveolar deadspace

- Bohr Equation – VD = (PaC02 – PEC02)/PaC02
- What is a normal alveolar ventilation?
- Vt – 500 mL minus (2x 70 kg) or 140 mL = 360 mL



PEEP – Positive End Expiratory Pressure



- Increased alveolar recruitment
- Expands functionally collapsed alveoli
- Physiologic PEEP – 3 cmH20
- 5-10cmH20 helpful in mechanical ventilation
- Decreased venous return
- Cardiac compromise
  - Decrease ventricular compliance
  - Decreased contractility
  - Increased RV Afterload

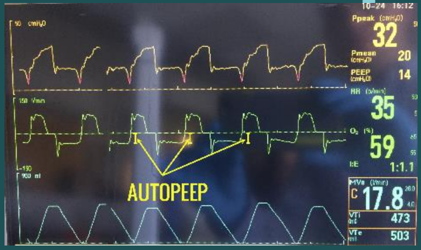
PEEP

PEEP (Extrinsic)

- Allows more even distribution of V_T and increases FRC (Functional Residual Capacity)
- Displaces lung water from alveolar space

Increased compliance = alveolar recruitment

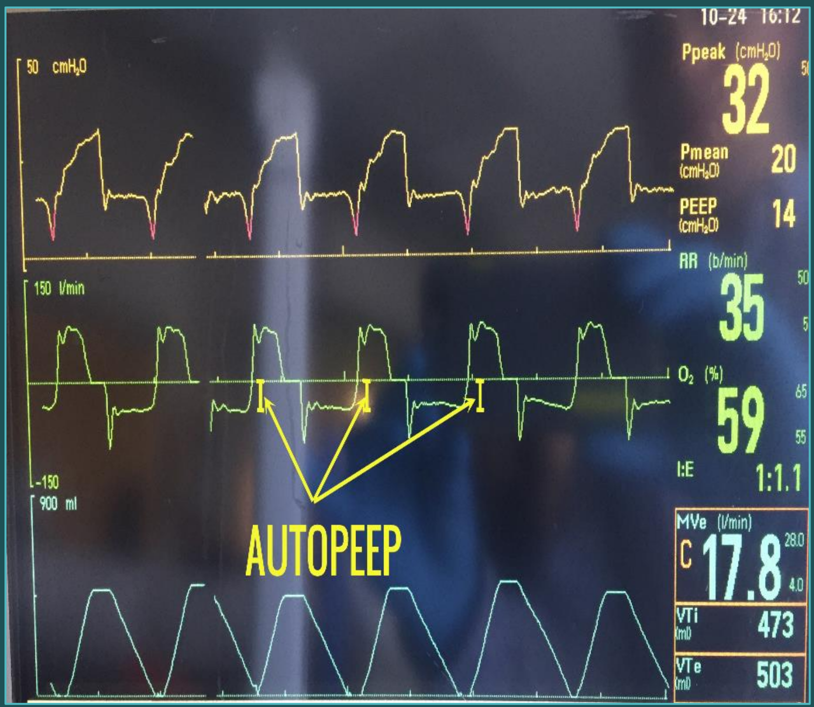
Decreased compliance = over distention



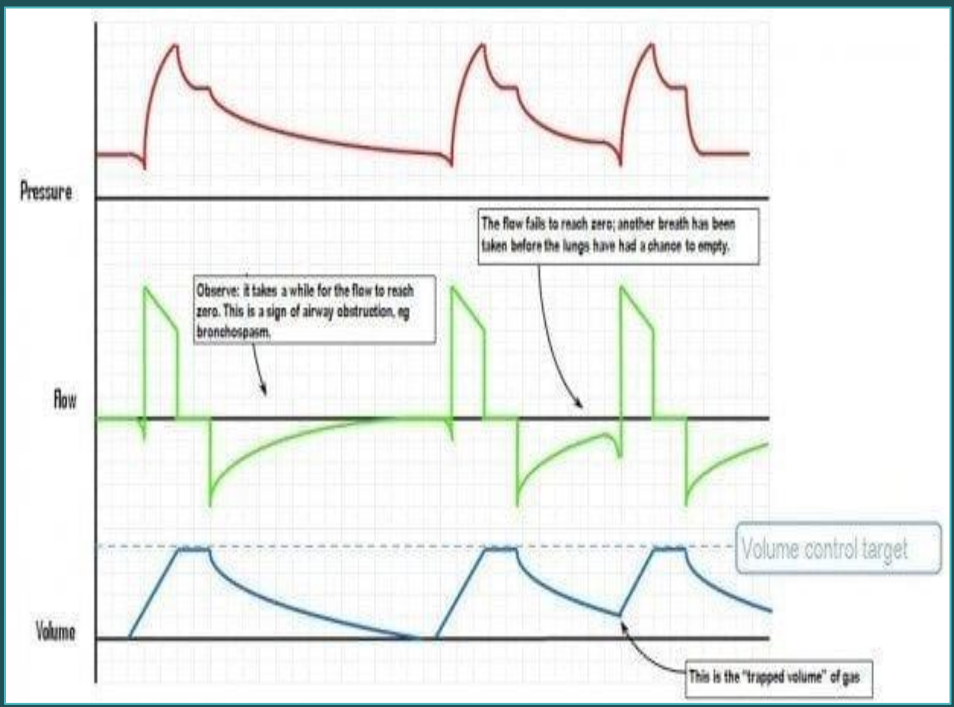
PEEP (Intrinsic)

- AUTO PEEP
- Incomplete expiration prior to the initiation of the next breath = progressive air trapping/ hyperinflation → increased alveolar pressure.
- Common causes:
- Hyperventilation
- Obstructed Airway
- Expiratory resistance (narrow airway – ETT)

AUTO PEEP



10-24 16:12
50 cmH2O
Ppeak (cmH2O)
32
Pmean (cmH2O)
20
PEEP (cmH2O)
14
150 l/min
RR (b/min)
35
O2 (%)
59
-150
I:E
1:1.1
900 ml
AUTOPEEP
MVe (l/min)
C
17.8
VTi (ml)
473
VTe (ml)
503



Pressure
The flow fails to reach zero; another breath has been taken before the lungs have had a chance to empty.
Observe: it takes a while for the flow to reach zero. This is a sign of airway obstruction, eg bronchospasm.
Flow
Volume control target
Volume
This is the "trapped volume" of gas

Pulsus Paradoxus

- Some variation in Systolic Blood Pressure (SBP) with inspiration and Expiration is normal
  - **Spontaneous Ventilation:** Inspiration decreases SBP, expiration increases SBP
  - **Mechanical Ventilation:** Inspiration increases SBP, expiration decreases SBP
    - High inspiratory pressures and PEEP can exaggerate
- Plethysmograph (SpO2) tracing & arterial line tracing Stroke Volume Variation
- Change in SBP > 10 mmHg with inspiration
- Consistent with hypovolemia, cardiac tamponade


HR
150
70
150
SpO2
100
93
96
ABP
105/74
CVP
(22)
Different Sweep Speed for RESP trace
40
7
25

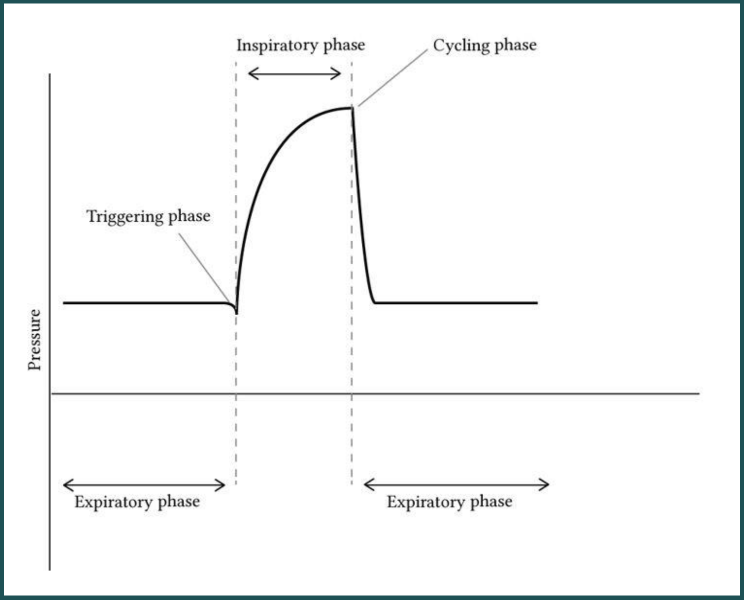
Modes of Ventilation

Modes of Ventilation

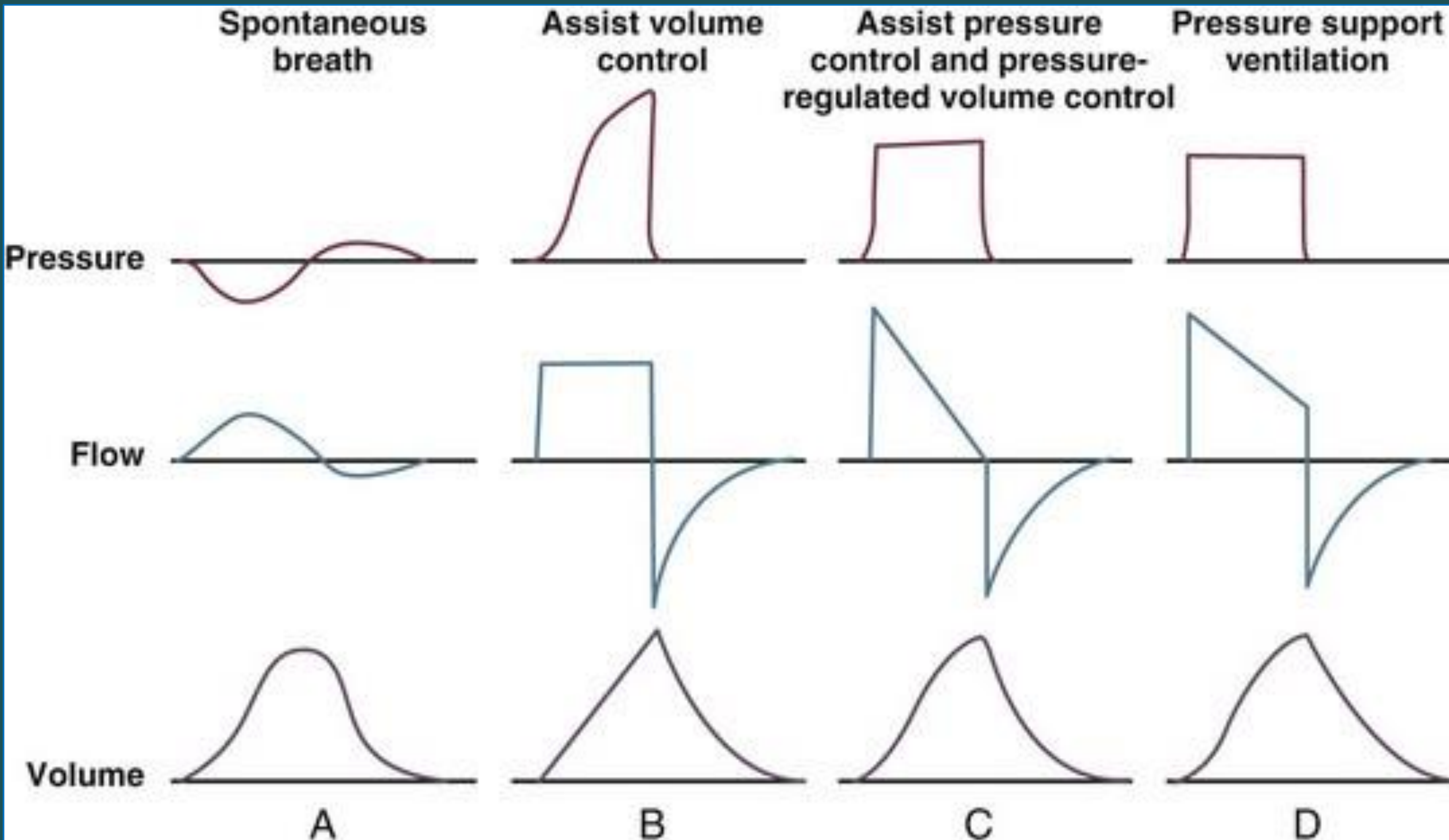
Mode	Description	Pros	Cons	Major settings / example	Monitor
VC Volume Control (a.k.a. assist control volume)	Every breath delivered (mandatory and patient triggered) is the same set **volume (TV)** T – time/pressure/flow, C – volume, L – volume	Good general-purpose mode; Ensures a minimum MV is achieved. 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 (mandatory & patient triggered) is a set **pressure (IP)** for a **set time (T_i)** 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+, APV, Autoflow)	***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 (e.g. high WOB) this mode 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% *($T_{High/low}$ – time high/low, $P_{High/low}$ – pressure high/low, also note that Plow is analogous to PEEP)*	Volumes & gas exchange PCO2 / EtCO2

Modes of Ventilation

- Fall into 2 categories – Pressure & Volume
  - Trigger (T) – What Initiates the breath
  - Cycle (C) – What ends the breath
  - Limit (L) – What stops the breath early/determines the size of the breath



Waveform Comparisons



Modes of Ventilation

Volume Modes

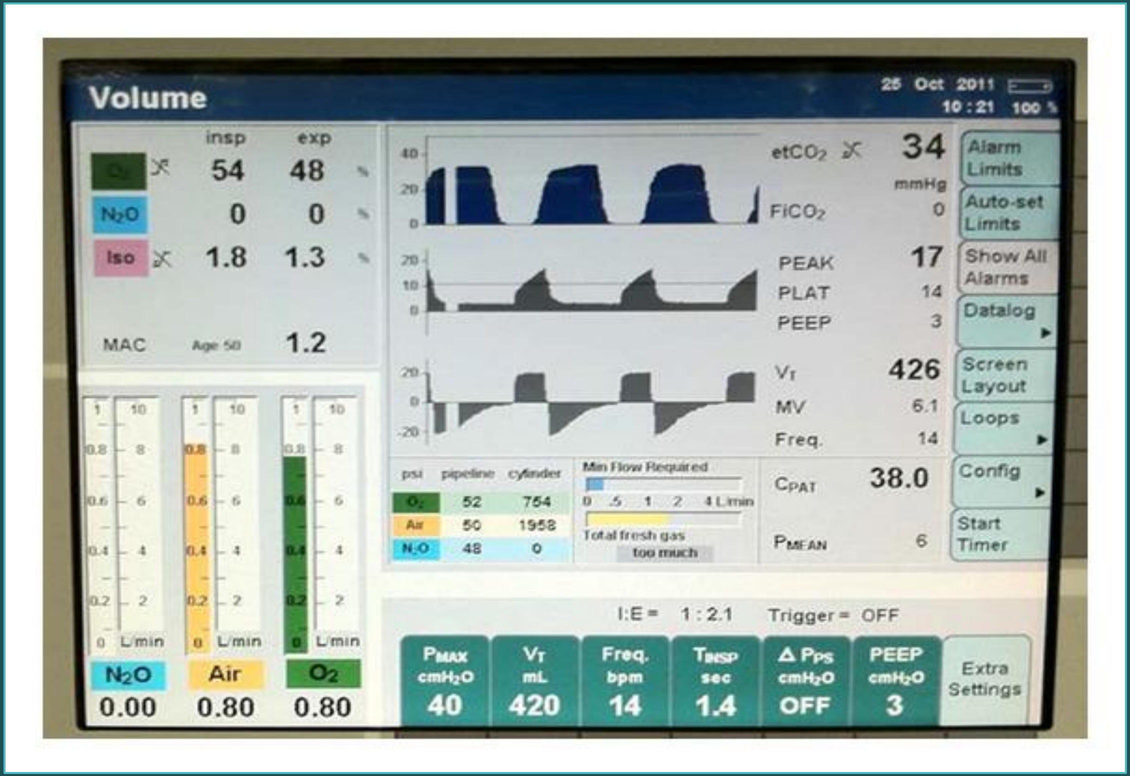
- Volume Control
- Assist Control
- SIMV

Pressure& Dual Modes

- Pressure Control
- Pressure Support
- APRV
- PRVC/PRV-VG

Volume Control - VC

- Most Commonly used
- Set tidal volume (Vt) delivered; constant flow during inspiration
- Ventilator calculates flow based on set V_T and length of inspiratory time
- Ensures minute ventilation despite changes in airway compliance



Volume Control

Advantages

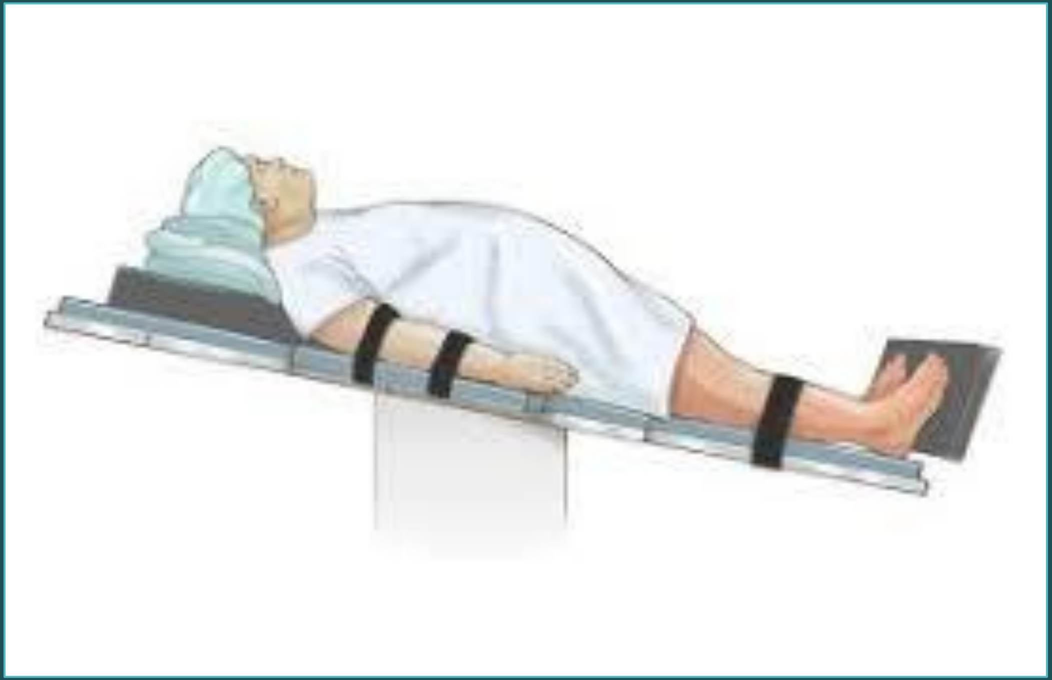
- Easy
- Standard mode
- Patients under anesthesia, paralyzed & compliant lungs.
- Ventilator adjusts output to compensate for compressed volume
  - System compliance of
  - FGF
  - Small leaks

Disadvantages

- Asynchronous → patient unable to alter ventilatory cycle
- Highest peak pressures; default is 40 cmH20 to prevent barotrauma
- if patient has spontaneous ventilations - “bucking”
  - Hyperventilate, Deepen anesthetic, Paralyze

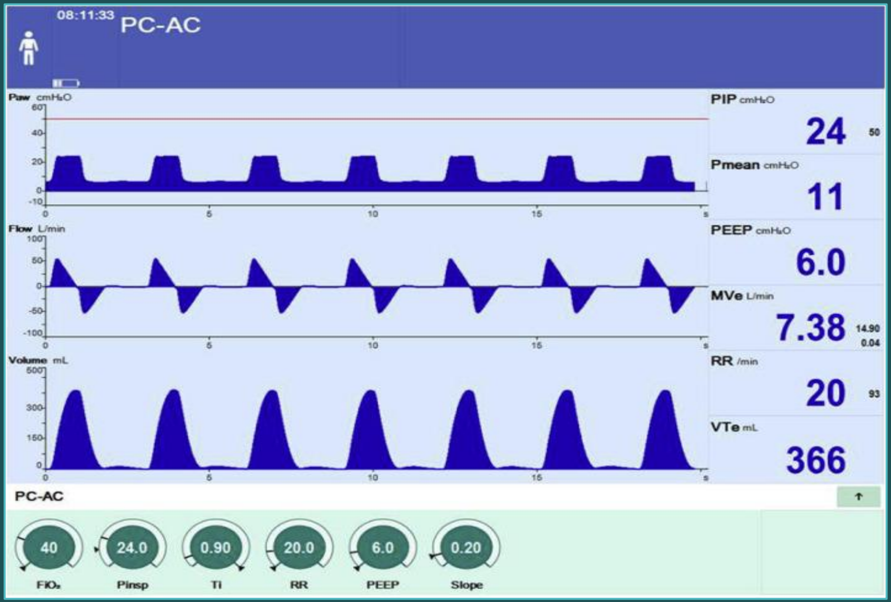
Volume Control - Anesthesia

- Good for Reverse Trendelenburg → due to the lack of cephalad displacement of the diaphragm high inspiratory pressures are not anticipated.
- Good for Supine cases without compliance concerns



Pressure Control - PC

- Most commonly used mode in ICU
- High Initial flow in circuit builds PRESSURE quickly to preset level & maintains it to end of inspiratory phase
- **Pressure** is constant throughout inspiration
- **VOLUME** is dependent variable
- Every breath delivered



Pressure Control - PC

Advantages

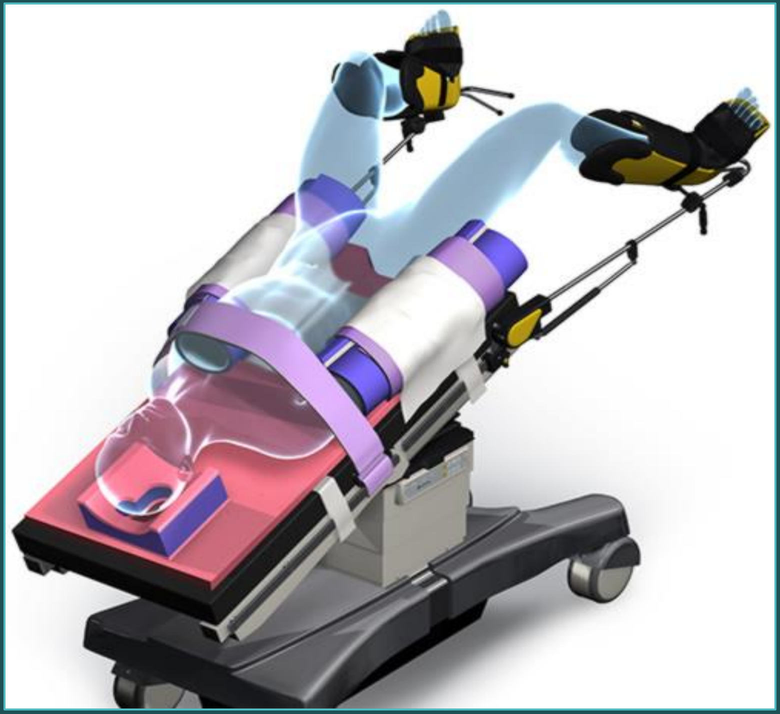
- Increases alveolar recruitment
- Increased distribution of ventilation
- Flow decreases as pressure in lung increases
- Utilizes low peak pressures - prevent barotrauma
- Inspiratory phase time is calculated from rate and I:E ratio
- PC may decrease intraoperative blood loss by decreasing airway pressures compared to volume ventilation (El-Seyed et al., 2019)

Disadvantages

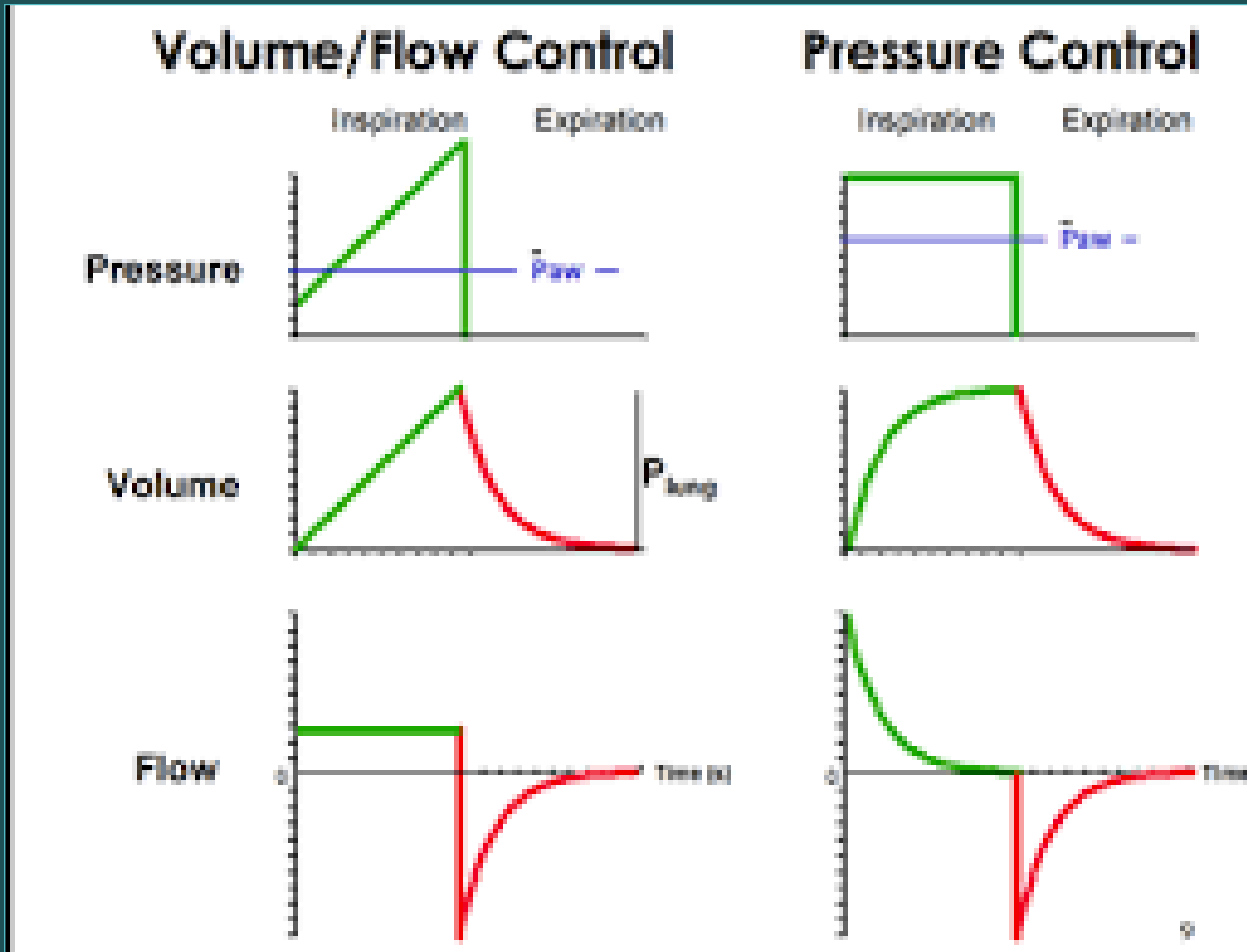
- Asynchronous → patient unable to alter ventilatory cycle
- Changes in compliance can greatly effect TV
- Potential for “stacking”
- Must adjust Pressure with changing compliance to prevent extremes in TV – Requires extra vigilance.

Pressure Control - PC

Due to reduced FRC, lung volumes, diaphragmatic movement, pulmonary compliance from ***Steep Trendelenburg***, a pressure control setting is the best choice. (Heiner, 2018) (Macksey, 2012).



Comparison of VC to PC



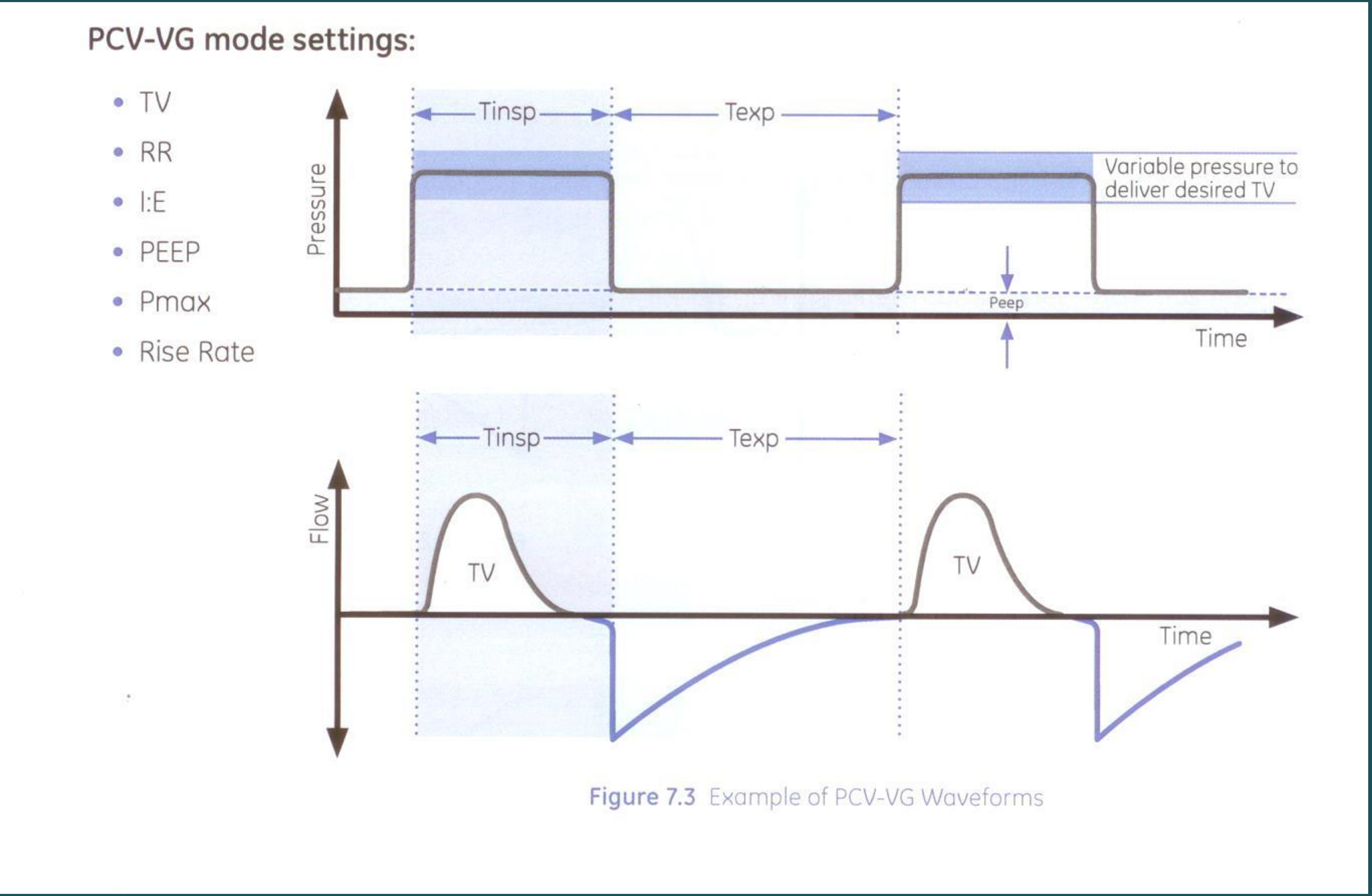
Pressure-Regulated Volume Control/Pressure Control Ventilation – Volume Guarantee

- Pressure controlled ventilation regulated with volume guarantee.
- Allows the benefit of lower airway pressures offered by pressure controlled ventilation, but each breath will end at a set tidal volume
- Set desired V_T : ventilator will adjust pressure with each breath to achieve set V_T at lowest pressure. Senses and adjust for changes in compliance.
- Initial breath is given at set V_T. Compliance is determined and subsequent pressure is adjusted

Efficient & Safe

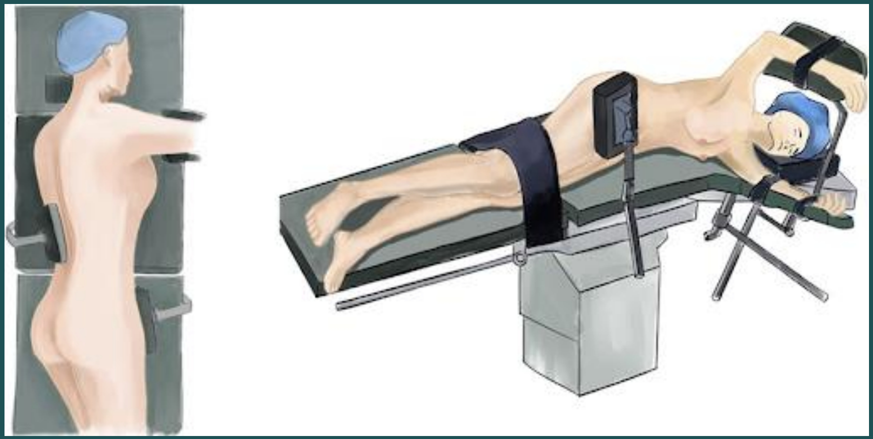
- helps maintain tidal volume in the face of changing lung compliance

PRVC / PCV-VG



Pressure Control mode that changes inspiratory pressure for a set time

PRVC or PCV - VG



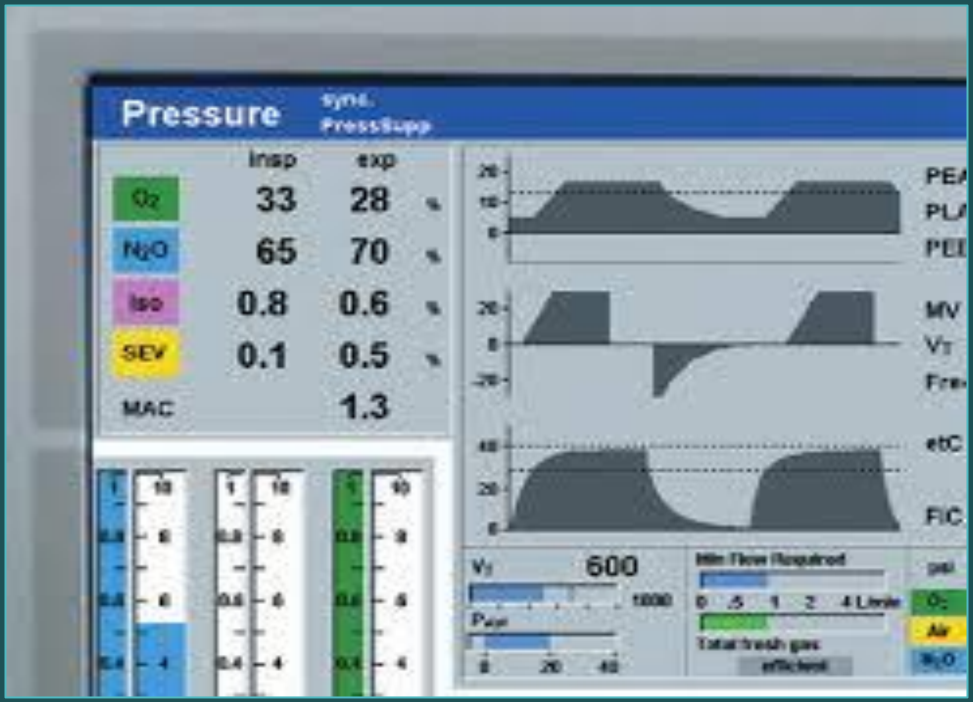
Some regions suffer atelectasis, which leads to the nondependent lung > Ventilation

Low risk for causing volume lung injury

PRVC / PCV-VG

- Adapts to changes in lung compliance-intra-abdominal pressure expected in a prone position.
- Allows for minimal pressure while guaranteeing the patient is receiving appropriate volumes.
- Adjusts inspiratory pressure based on the last breath and reaches the target volume with lowest inspiratory pressure possible.
- Delivers a set volume with lower peak pressures than VC for patients in the prone position

Pressure Support Ventilation - PS



PS is useful to augment tidal volumes of spontaneously breathing patients during maintenance or emergence

Pressure Support - PS

Advantages

- Supports the spontaneously breathing patient
- Overcomes resistance to airflow created by anesthesia machine, valves, circuit, airway
- Increases alveolar recruitment - VT
- Decreased work of breathing

Disadvantages

- Patient spontaneously breathing
- Non-paralyzed
- Limited peak pressures

Pressure Support - PS

- Applies pressure plateau to airway of the spontaneously breathing patient .
- Any case - supine patients, LMAs or weaning off the ventilator – expedites readiness for extubation.
- Helps to adapt to changes in airway compliance and changes associated with positive pressure ventilation.
- This mode allows patient to maintain spontaneous respirations and avoids barotrauma.

SIMV

- Synchronized Intermittent Mandatory Ventilation
- When ventilator senses start of spontaneous inspiration it synchronously delivers the set mandatory V_T
  - If patient fails to spontaneously inspire the ventilator will deliver the set rate and V_T
  - Example: V_T 600, RR 4, PEEP 5 cmH_2O and patient spontaneously breathing at a rate of 14 bpm.
  - Patient receives 4 breaths at 600ml/5 PEEP and 10 breaths as their inspired breath + PEEP
  - Synchronous Volume mode

SIMV

Advantages

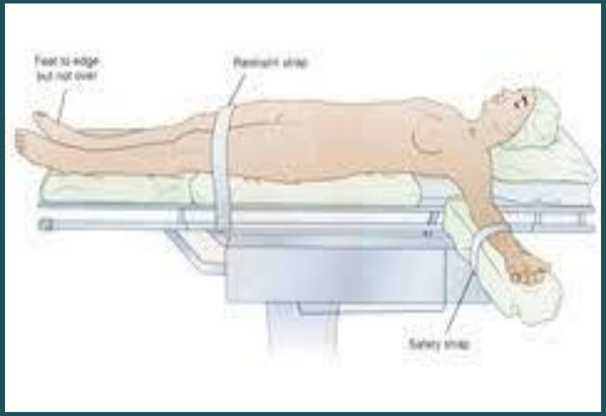
- Set volume is delivered at set intervals - like VC but synchronized with patient effort.
- Between mandatory breaths patient can take spontaneous breaths. Can set Pressure support (PSV) to pressurize circuit with each spontaneous breath.
- Appropriate for **weaning**, spontaneously ventilating, or apneic patient
- May reduce muscle atrophy

Disadvantages

- More commonly used in the ICU
- increased WOB at low rates
- May cause respiratory alkalosis → *air-trapping, autoPEEP at rapid RR possible
- PIP variable

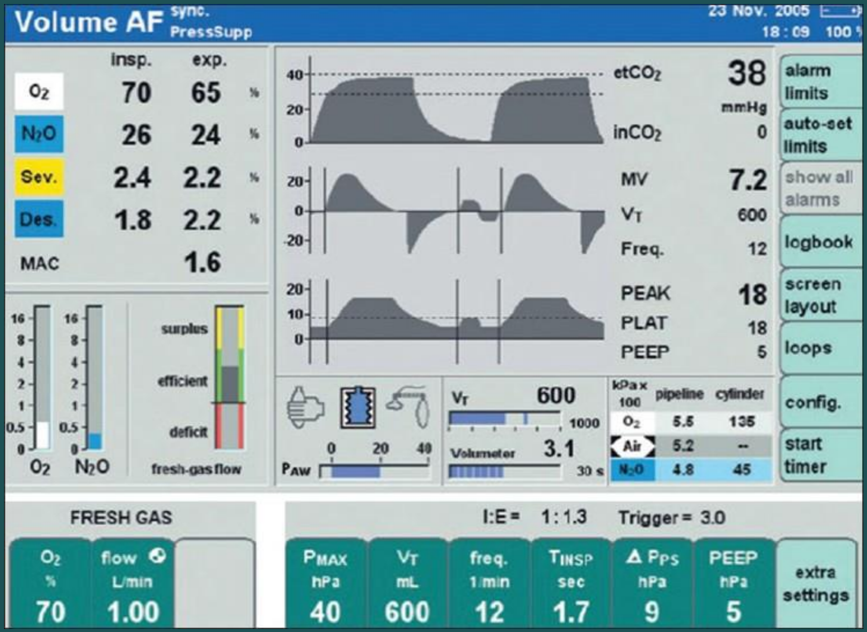
SIMV

- If patient fails to spontaneously inspire the ventilator will deliver the set rate and V_T
- Synchronous Volume mode



Volume Control Auto Flow -VCAF

- Volume Control Mode
- AutoFlow is an adjunct to volume control
- Minimal flow required to deliver the set volume within the set inspiratory time → end inspiratory pressure is used as the inspiratory pressure for the next breath.

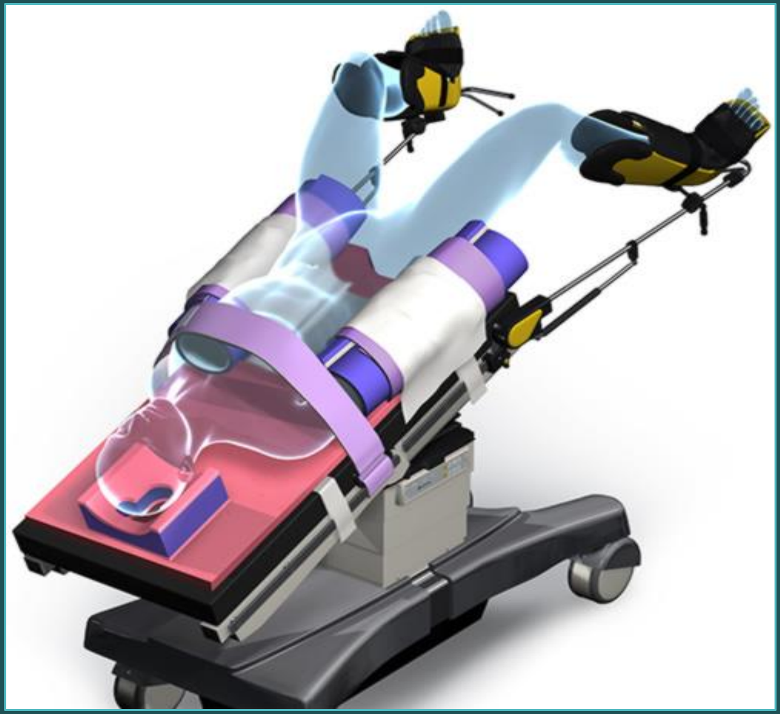


Volume Control Auto Flow -VCAF

Morbidly obese patients in steep Trendelenburg.

Delivers the set tidal volume at the lowest possible inspiratory pressure.

Reduces peak airway pressures.



Volume Control Auto Flow

Advantages

- Patients may increase RR
- Low work of breathing
- Lower Transpulmonary Pressure
- Enabling spontaneous breathing throughout the respiratory cycle which facilitates stress-free volume controlled ventilation.

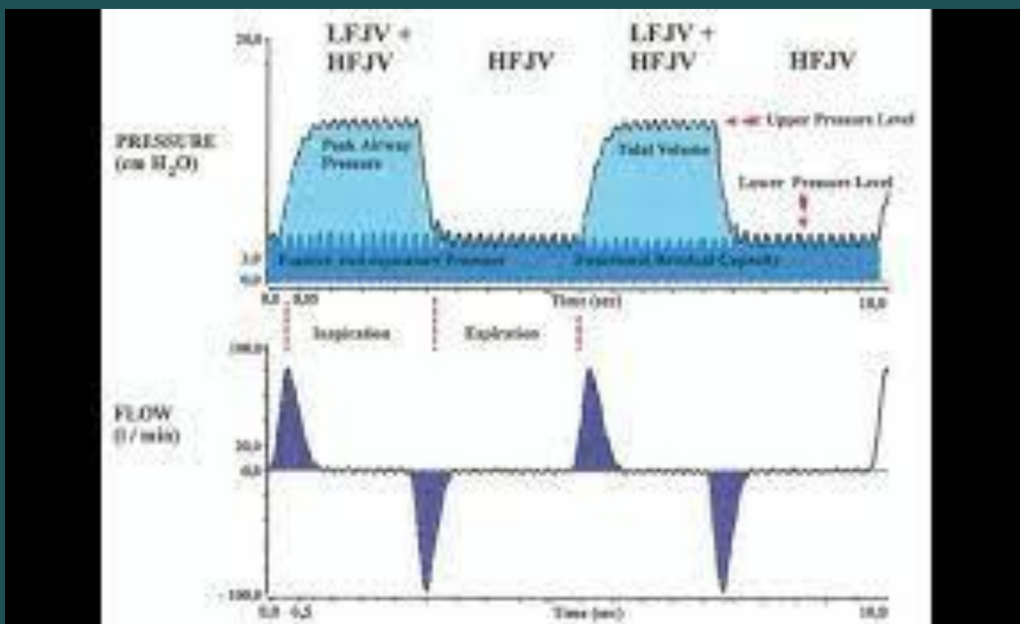
Disadvantages

- Spontaneous breathing may cause fluctuations in the tidal volume

Advanced Ventilator Modes

- SIMV+PS: Adds Pressure support to SIMV
- SIMV-PC: SIMV in Pressure Control Mode
- SIMV-VC: SIMV in Volume Control Mode
- APRV – Airway Pressure Release Ventilation

High Frequency Oscillatory Ventilation



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