Mechanical Ventilation Basics

Normal Respiratory

v

Mechanical Ventilation

What's different?

Negative pressure

v

Positive Pressure

Respiratory Terminology

- Compliance: $\Delta V/\Delta P$
- Elastance: $\Delta P/\Delta V$
- Dead Space: Portion of each breath not involved in gas exchange
  - Anatomic – conducting airways (volume)
  - Physiologic – anatomic + alveolar dead space
- Functional residual capacity (FRC): Volume air remaining after normal expiration, equilibrium point between lung elastic recoil & expansion of chest wall

Oxygenation v Ventilation

- Oxygenation – O2 exchange
  - How we adjust (simplified)?
    - FiO2
    - PEEP
- Ventilation – CO2 exchange
  - How we adjust (simplified)?
    - TV
    - RR
    - Aka Minute Ventilation (V_e) = TV x RR
      - Target 5-10 L/min

What are the main categories of ventilator modes?

Main Categories

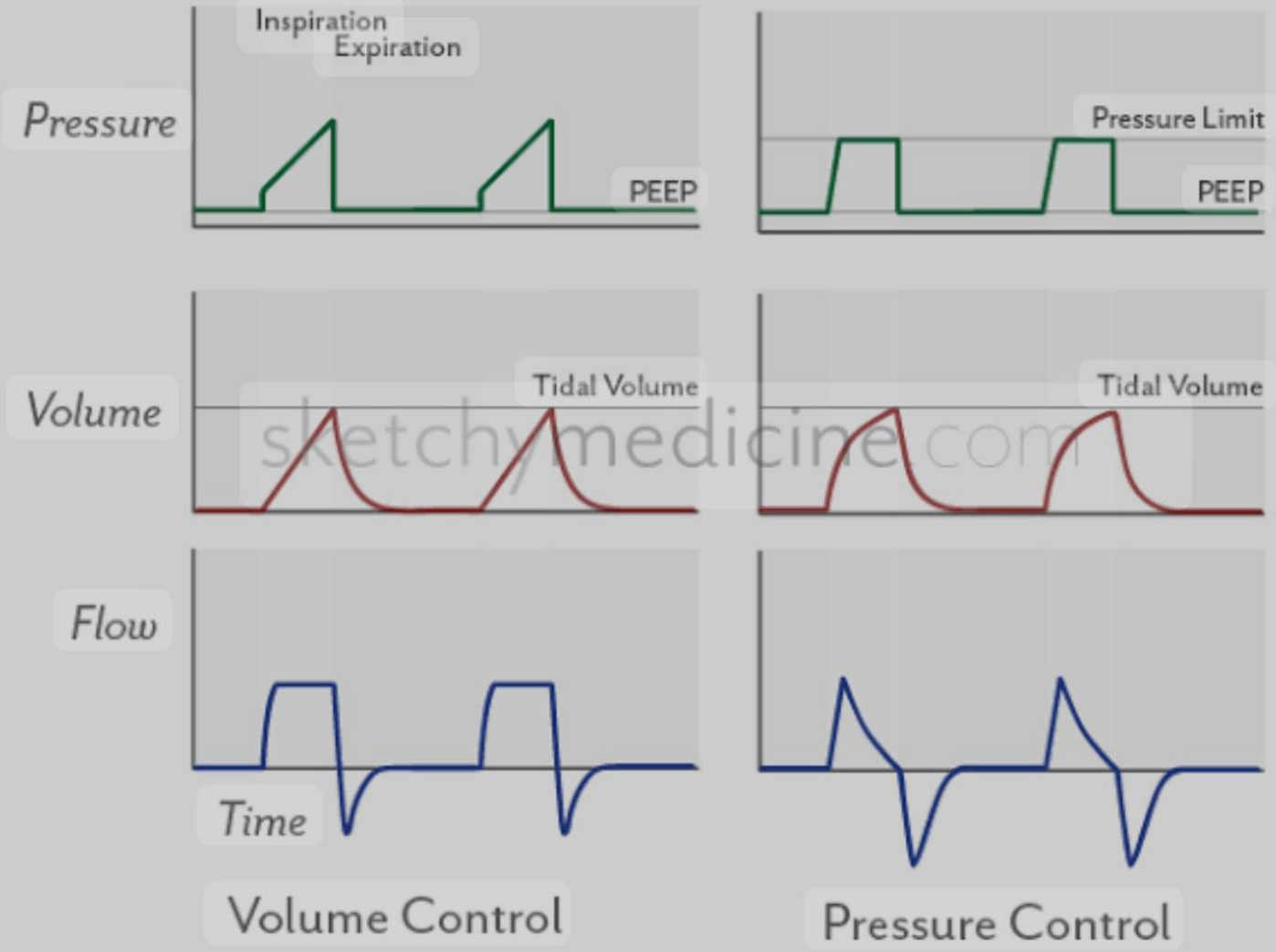
- Volume Modes
  - Set volume of air delivered (constant tidal volume)
  - Pressure variable
- Pressure Modes
  - Set pressure delivered
  - Volume variable

Changes patient to patient, breath to breath:

- Anatomy/habitus
- Pulmonary factors (i.e. resistance/compliance)
- Position

*Some advanced modes a hybrid of both

Common Ventilator Modes



Settings (aka things we control)

- Tidal Volume (TV)
  - How obtained depends on mode
  - 6-8ml/kg in nml lungs (IBW)
- Respiratory rate (RR) – frequency, breaths per minute
- Oxygen Concentration (FiO2)
- Positive End Expiratory Pressure (PEEP)
  - Constant pressure applied during expiration
  - Increases FRC
- I:E
  - Typically 1:2
- Inspiratory flow

Other setting terms

- Trigger – initiator of breath
  - Machine (time)
  - Person (effort based)
- Target – Variable that regulates gas delivery during inspiration
  - flow for volume
  - Inspiratory pressure for pressure
- Cycle goal - What terminates inspiration
  - Volume
  - Time
  - Flow

A little more on FLOW:

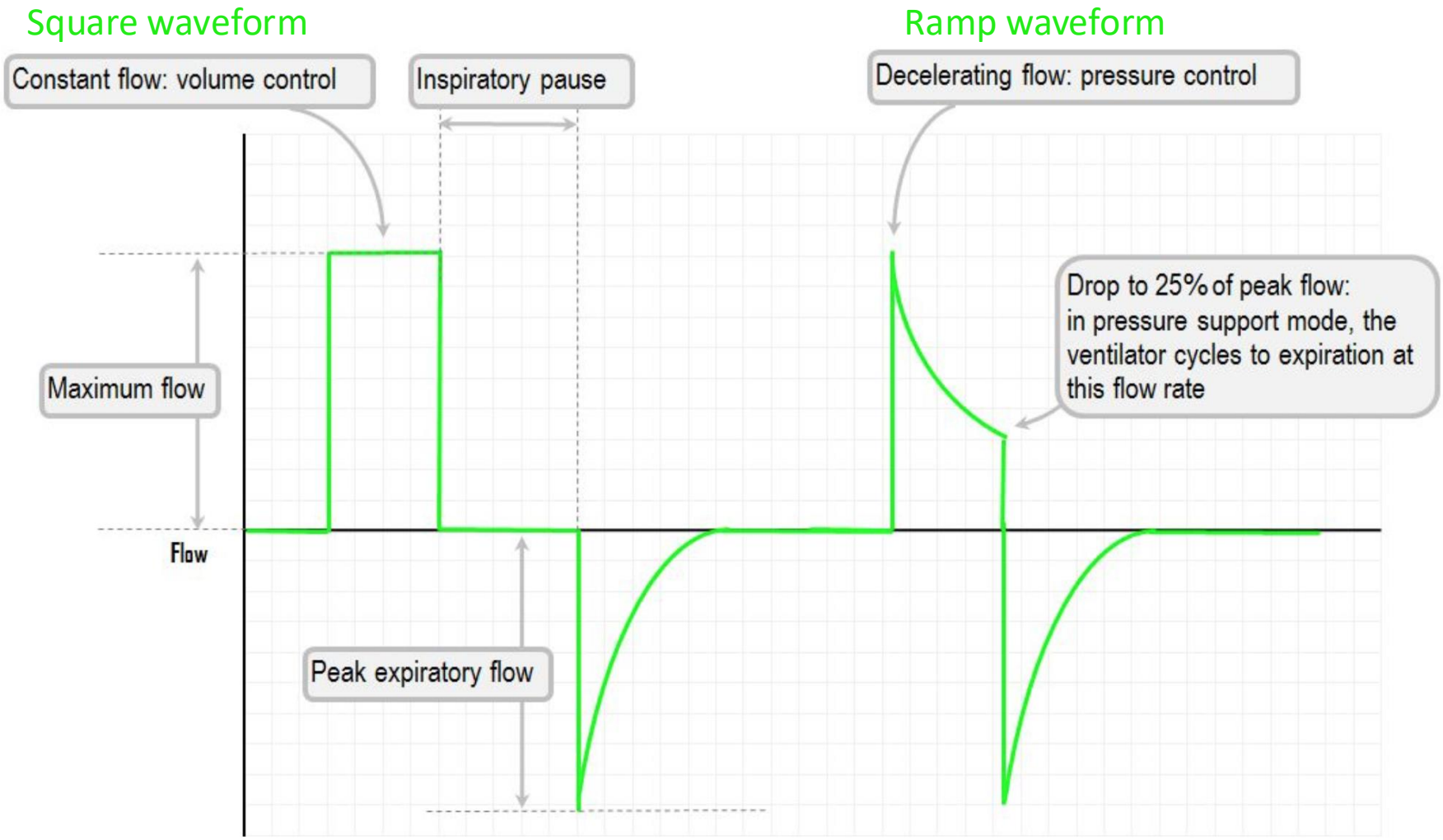
- Can be constant through inhalation = square waveform

OR

- Decelerating as breath delivered = ramp waveform

- Square waveform: faster delivery of inspiration, decreasing inspiratory time, increasing expiratory time
  - Useful when longer expiration needed:
    - Asthma, COPD
    - High RR (encourage full exhalation)
- Ramp waveform: Decrease the flow as delivered volume increases
  - More comfortable
  - Better volume distribution and equalization heterogeneous lungs (i.e. ARDS)

A little more on FLOW:



Back to Ventilator Modes

Types of Volume Modes?

- Assist Control Volume Control (ACVC)
- Synchronized Intermittent Mandatory Ventilation (SIMV)

Volume Modes: ACVC

- What do you set?
  - TV
  - RR
  - FiO2
  - PEEP
- More advanced
  - I:E
  - Flow

Volume Modes: ACVC

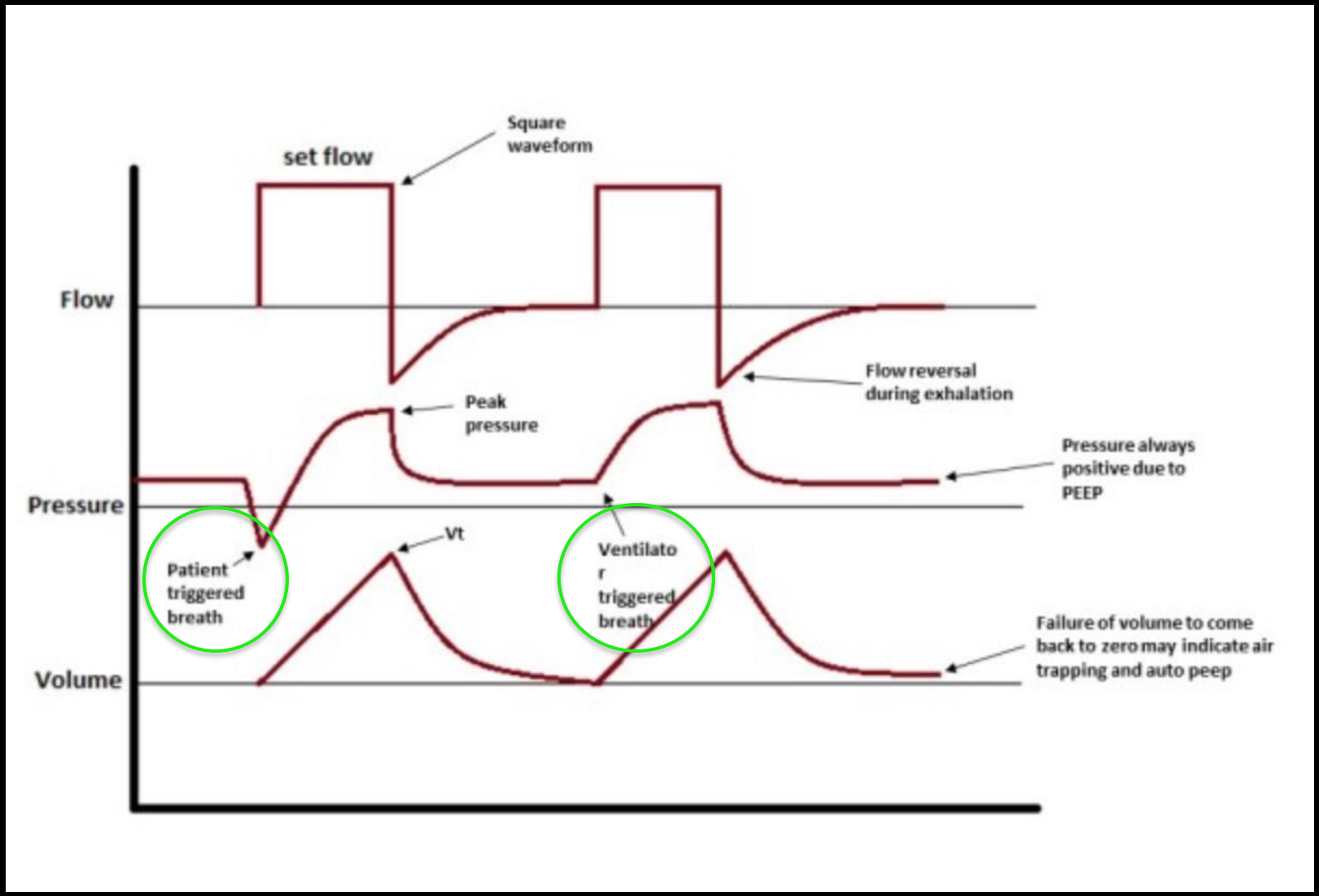
- Assist Control?
  - Adjusts trigger (breath initiator)
    - NO spontaneous breath – time initiated breath
    - Spontaneous breathing – senses negative inspiratory effort & gives breath
  - Example: RR set to 15
    - No spontaneous breathing – RR=15
    - Spontaneous breathing – RR=15 *plus* patient breaths above this rate
- Gives full preset TV regardless of trigger

Volume Modes: ACVC

- Gives full preset TV every breath
  - Full control of minute ventilation
  - Useful to manage respiratory/metabolic acidosis
  - Barotrauma risk
    - Uses whatever pressure needed to get volume
    - Non-compliant (“stiff”) lungs
  - Tachypneic patients
    - Reduced expiration time – breath stacking, auto-PEEP

      -> hyperinflation, increased pulmonary pressures
    - Hyperventilation - respiratory alkalosis
- Recruitment may be poorer in poor compliance
- Discomfort – vent synchrony

ACVC


set flow
Square waveform
Flow
Flow reversal during exhalation
Peak pressure
Pressure always positive due to PEEP
Pressure
Vt
Patient triggered breath
Ventilator triggered breath
Failure of volume to come back to zero may indicate air trapping and auto peep
Volume

Volume Modes: SIMV

- Combines mandatory breaths w/ patient initiated breaths
- What do you set?
  - TV
  - RR
  - FiO2
  - PEEP
  - +/- PS (assist with self initiated breaths)

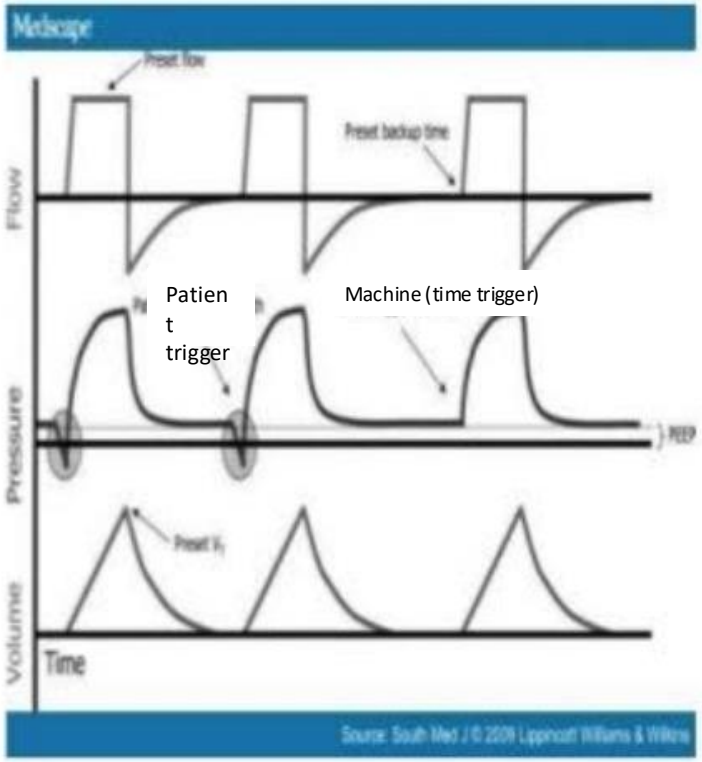
Volume Modes: SIMV

- How is this different from ACVC?
  - Set mandatory breaths (RR) synchronized to patient effort
  - Mandatory breaths give full preset TV (same as ACVC)
  - Spontaneous breaths patient determined TV (different than ACVC)
    - Can add PS
- If NO spontaneous breathing same as ACVC

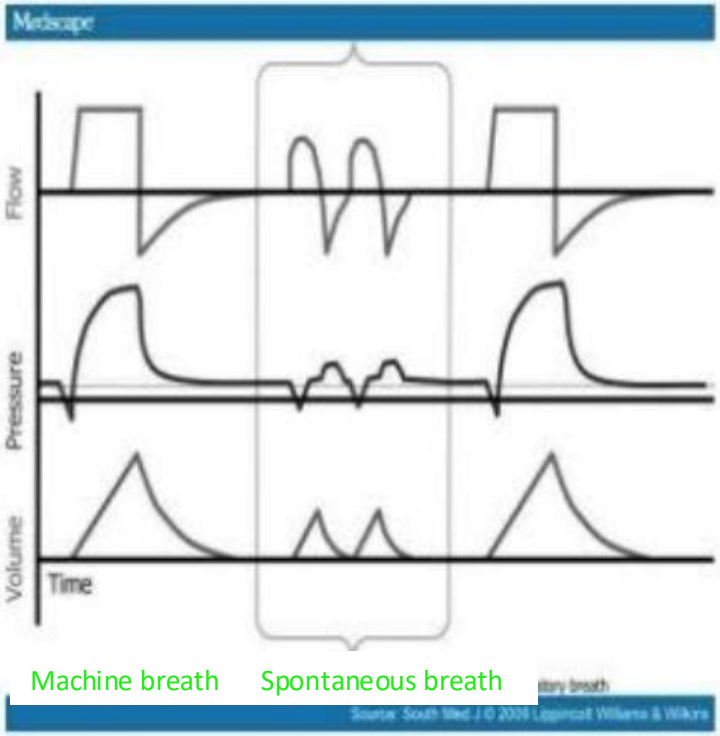
Volume Modes: SIMV

- Guarantees minimum RR with set TV
- Patient can trigger additional breaths (can adjust degree of support)
  - Can increase work of breathing
  - Avoid respiratory alkalosis (tachypneic patient)
- Improved patient comfort (synchronization)?
- Weaning mode?

Assist Control



SIMV



Types of Pressure Modes?

- Pressure Control (PC)
- Pressure Support (PS)
- Airway Pressure Release Ventilation (APRV)

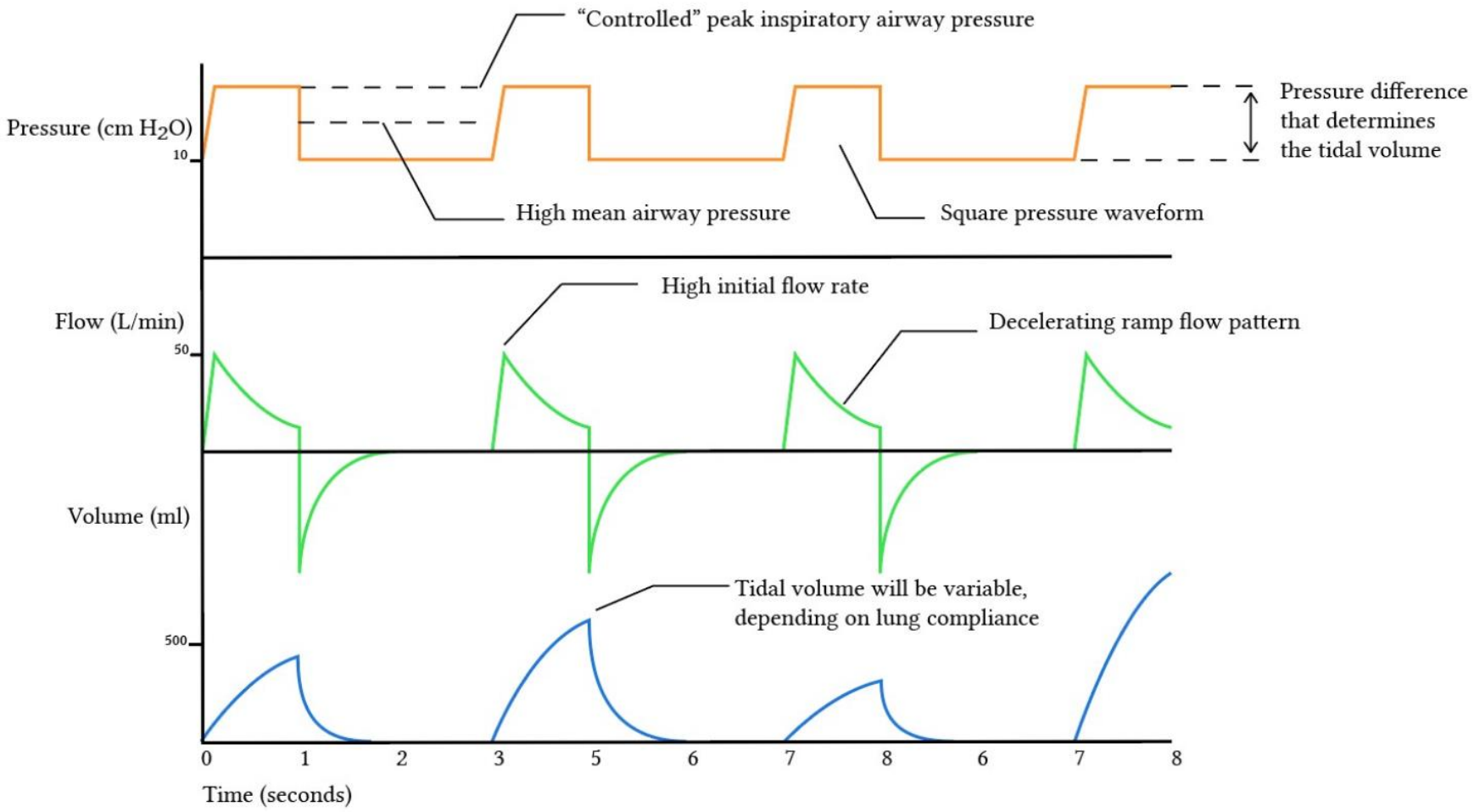
Pressure Modes: PC

- What do you set?
  - Pressure
    - Set to target goal TV range (i.e. 6-8ml/kg)
  - RR
  - FiO2
  - PEEP
- More advanced
  - I:E

Pressure Modes: PC

- Volume is variable – TV can change with airway resistance (aka peak airway pressure) & compliance (aka plateau)
  - *Needs close monitoring*
  - *Risk of hypoventilation* (low TV)
  - Risk of *volumtrauma* (high TV)
- Barotrauma protection (non-compliant lungs)
- Constant airway pressure
  - Improved alveolar distention/recruitment –> oxygenation & dead space ventilation
- Improved patient tolerance/vent synchrony
  - Flow rate variable to patient needs

PC


"Controlled" peak inspiratory airway pressure
Pressure (cm H_2O)
10
Pressure difference that determines the tidal volume
High mean airway pressure
Square pressure waveform
High initial flow rate
Flow (L/min)
50
Decelerating ramp flow pattern
Volume (ml)
Tidal volume will be variable, depending on lung compliance
500
0
1
2
3
5
6
7
8
6
7
8
Time (seconds)

Pressure modes: PS

- Spontaneous breathing
  - Does have a back up RR for apnea
- What do you set?
  - Pressure (inspiratory pressure)
    - Set to target goal TV range
  - FiO2
  - PEEP
- Pressure delivered until inspiratory flow drops below a determined threshold (i.e. 25% of peak flow)

Pressure modes: APRV

- High continuous airway pressure (oxygenation) with brief pressure releases (ventilation)
- Unrestricted spontaneous breathing throughout
- What you set?
  - Pressure high (25-30)
  - Time high
  - Pressure low (0)
  - Time low
  - FiO2
- (I:E usually 7:1 or 10:1)

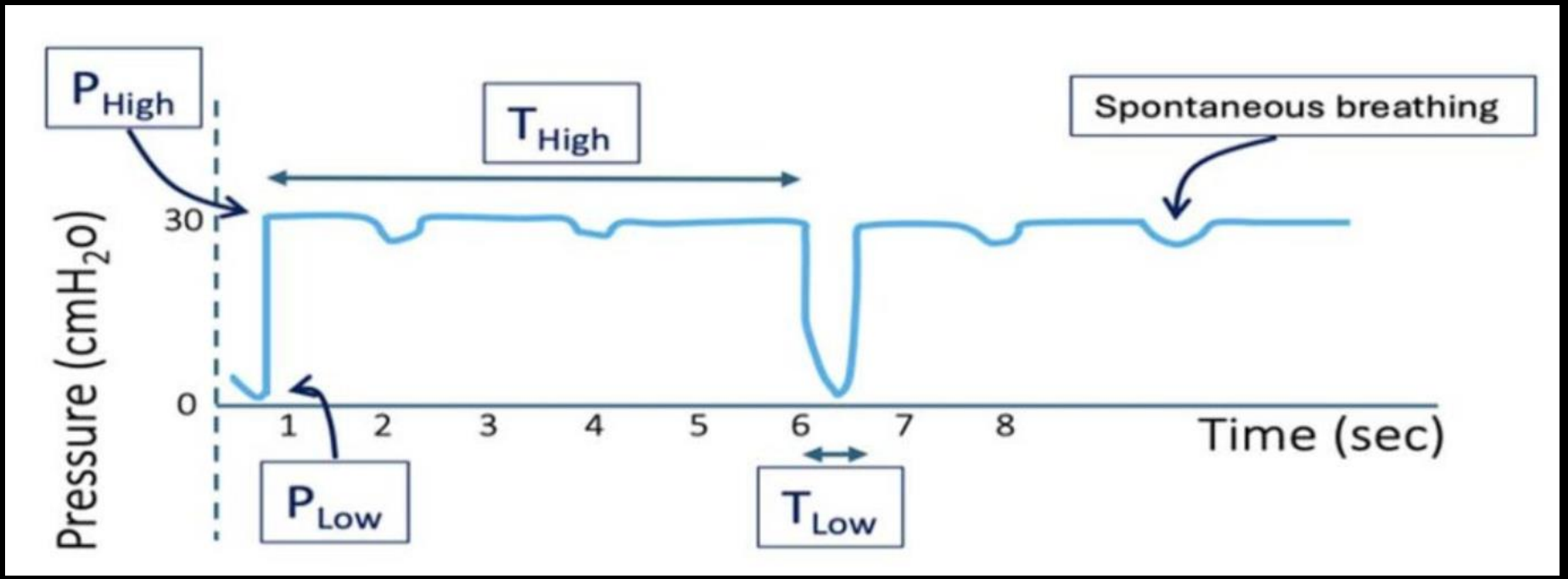
Pressure modes: APRV

- Improved oxygenation
  - Improved mean airway pressures
  - Alveolar recruitment
- Spontaneous respirations
  - Facilitates gas exchange – CO2 clearance
  - Maximizes continued recruitment
  - Ventilation of dependent areas
- Reduced sedation

Pressure modes: APRV

- Requires spontaneous breathing
  - i.e. neuro intact, not on chemical paralysis
- Hypotension with initiation (usually transient)
  - Reduced venous return (Phigh)
  - Patient needs to be fully resuscitated prior
  - Avoid in hemodynamically unstable
- Risk volutrauma
- Can increase work of breathing

APRV


P High
T High
Spontaneous breathing
30
0
Pressure (cmH2O)
1
2
3
4
5
6
7
8
Time (sec)
P Low
T Low

Hybrid Mode: PRVC

- Pressure Regulated Volume Control (PRVC)
  - Lowest inspiratory pressures to achieve set TV
    - Adjusts pressure to achieve TV target
    - Feedback method breath-to-breath
- What you set?
  - TV
    - Uses plateau pressure from previous breath to calculate inspiratory pressure need to reach set TV for following breath
  - RR (same as VC)
  - FiO2
  - PEEP

Hybrid Mode: PRVC

- Best of both worlds???
  - Change in resistance or compliance, pressure will adjust to deliver the desired TV
- PC benefit - improved mean airway pressure -> better alveolar distention/recruitment –> oxygenation & dead space ventilation
- VC benefit - guaranteed minute ventilation
- Can increase work of breathing in patients with high respiratory drive

Other things

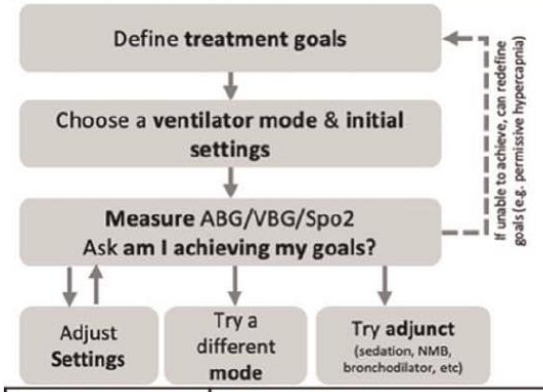
- Peak Inspiratory Pressure: Highest pressure recorded at peak inspiration
  - Plateau p *plus* additional pressure applied to overcome flow resistance & elastic recoil of the lungs/chest wall
- Plateau pressure: Alveolar pressure applied during the majority of the breath cycle
  - Measure via inspiratory hold
  - Goal ≤30 cm H2O
- Driving pressure: Plateau p – PEEP
  - Lung strain
  - 14-18cmH20
- Auto/intrinsic-PEEP: Residual pressure in the circuit at end expiration = Total PEEP (measured with expiratory pause) in the circuit – set PEEP

Causes of increased peak airway pressure

Increased Peak to Plateau Pressure Gradient	Increased Plateau Pressure
	Decreased lung compliance
Increased resistance in the ventilator circuit	• ARDS
• Kinked ventilator tubing	• Pneumonia
• Biting on the endotracheal tube	• Pulmonary edema or hemorrhage
• Obstructed endotracheal tube	• Interstitial lung disease
	• Atelectasis
Increased resistance in the large airways	**Decreased pleural space compliance**
• Mucous plug	• Pneumothorax
• Central airway mass or foreign body	• Pleural effusion
Increased resistance in the small airways	**Decreased chest wall compliance**
• Bronchospasm	• Obesity
• Asthma	• Musculoskeletal restriction
• Chronic obstructive pulmonary disease	• Abdominal distension

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

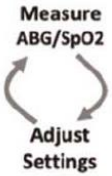
Ventilator Modes:

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 **Pros** and **Cons** 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	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