Ventilator Management

ATS Virtual Bootcamp 2021

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Course Objectives:

1. The student will be able to distinguish key features of the ventilator interface including input variable and output variables on the display and the function of major knobs/buttons on a ventilator.
2. The student will appreciate the key dependent and independent features between pressure and volume targeted ventilation.
3. The student will recognize basic indications for 3 fundamental modes: Pressure A/C, Volume A/C, Pressure Support

--Supplemental Primer--

Indications for mechanical ventilation support:

1. Unstable/Unprotected Airway.
    a. Decreased aspiration risk (bleeding/vomiting/altered mental state)
    b. Secure airway (laryngeal edema/trauma)
2. Ventilatory Failure (hypercapnea)
    a. Decrease work of breathing and prevention/relief of respiratory muscle fatigue
3. Hypoxemic respiratory failure
    a. Reliably deliver a high inspired oxygen concentration
    b. Improve V/Q mismatch
    c. Decrease shunt by opening collapsed alveoli

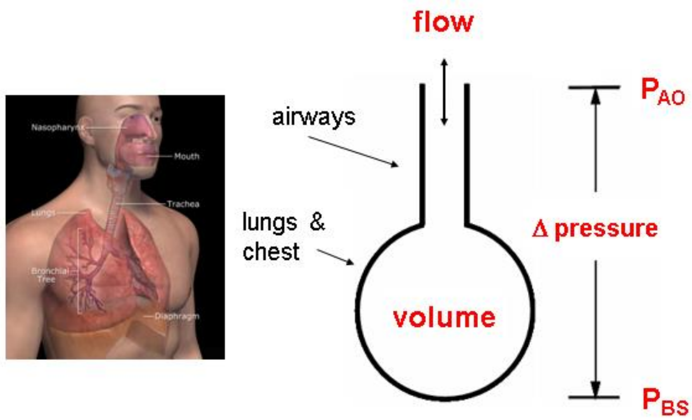
Physiologic changes which occur after initiating mechanical ventilation:

1. Cardiac
    a. Decreased venous return (increased lung volume causes increased pleural pressure and increased intramural pressure on the RA and IVC in the thoracic space - this, causes decreased venous return)
        i. Can cause problems in PE, hypovolemia, tamponade, severe air trapping, right heart failure, pulmonary hypertension
        ii. Give IV fluids or pressors to increase mean systemic pressure and subsequently, venous return.
    b. Decreased afterload (decrease transmural wall tension in LV w/ positive pressure).
        i. Helpful in CHF or possibly MI (better coronary perfusion w/ decreased cardiac O2 consumption).
    c. The sum of these two above processes can result in either increased or reduced cardiac output.
    d. It can also cause hypotension, which needs to be anticipated, especially in states where generous venous return and preload are essential.
2. Pulmonary
    a. May cause:
        i. Barotrauma or volutrauma which can result in pneumothorax or Ventilator Induced Lung Injury
        ii. Air Trapping
        iii. Increased insensible fluid losses
    b. Gas Exchange
        i. May increase physiologic dead space (capillary compression or low Vt)
        ii. High PEEP may worsen V/Q matching when used in unilateral lung disease by causing alveolar overdistention and capillary compression of normal lung, resulting in redistribution blood into non-ventilated areas of lung (diseased lung)

<u>Basic Respiratory Mechanics:</u>

1. Single Compartment Model:
    a. Lung as a single tube (airways) and an elastic compartment (lungs and chest wall)
    b. During a positive pressure breath (inspiration), inward flow occurs when the pressure at the airway opening exceeds the pressure within the elastic compartment.

i. This happens when the ventilator increases the transrespiratory pressure ($P_{AO} - P_{BS}$). Transrespiratory pressure is displayed on the ventilator as airway pressure
ii. Flow in and out of the respiratory system is governed by 2 major properties
1. Resistance: Resistance = Δ Pressure / Δ Flow
a. $\Delta P_{resistive}$ = Resistance*ΔFlow
2. Elastance: Elastance = Δ Pressure / Δ Volume = 1/Compliance
a. $\Delta P_{elastic}$ = Elastance*ΔVolume



2. The Equation of Motion and Newton's 3rd law of motion.
a. Pressure exerted by ventilator at the airway opening (P_{ao} or P_{vent}) is resisted by an equal and opposite pressure generated by the respiratory system ($P_{elastic}$ + $P_{resistive}$).
b. The relationship among the variables pressure, volume, and flow is expressed by the **Equation of Motion** for the respiratory system. A simplified version of the equation for passive ventilation (no inspiratory effort on the part of the patient) is:

$$\mathbf{P_{vent} = P_{elastic} + P_{resistive}}$$

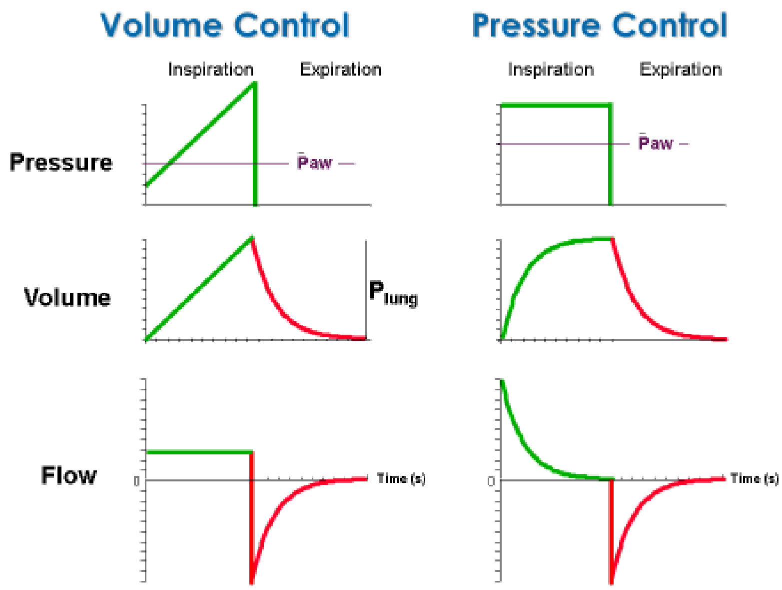
$$\mathbf{P_{vent} = \text{Elastance x Volume + Resistance x Flow}}$$

3. The equation of motion is the basis for defining **pressure control** and **volume control** modes of ventilation.
a. <u>If the ventilator is set to control the pressure:</u> it will control the left side of the equation.
i. As the operator, this means you would define the shape of the pressure waveform ie, inspiratory pressure, rise time, inspiratory time, (LEFT SIDE OF EQUATION)
ii. As a result, the flow and volume delivered are <u>dependent variables</u> (RIGHT SIDE OF EQUATION) and will vary with the elastance and resistance of the respiratory system.
iii. Another version of pressure control is to set the proportionality between the patient's effort and pressure (Proportional Assist Ventilation, Neurally Adjusted Ventilatory Assist etc.). In this case, the ventilator delivers more inspiratory pressure as the patient's inspiratory effort increases.
b. <u>If the ventilator is set to control the volume</u>, it will control the right side of the equation.
i. As the operator, this means you would preset the tidal volume *and* inspiratory flow into the respiratory system. (RIGHT SIDE OF EQUATION)

ii. As a result, the pressure exerted by the ventilator (LEFT SIDE OF EQUATION) is a <u>dependent variable</u> and will change based on the elastance and resistance within the respiratory system.

c. The curves below illustrate the two basic approaches to ventilator control.

i. These are idealized waveforms shown on the ventilator's graphics screen (green is inspiration, red is expiration)



4. The form of the equation above <u>applies to paralyzed patients (no patient effort)</u>. In patients who are not paralyzed, an advanced form of the equation applies which takes into account physical interactions between the patient (effort from inspiratory muscles) and the ventilator (P_{mus}).

$$P_{mus} + P_{vent} = \text{Elastance x Volume + Resistance x Flow}$$

5. We also add a term to the right side of the equation called auto PEEP.

i. This is the pressure above the set PEEP (which to this point we have been using as our reference point) that is associated with trapped gas.

ii. Gas trapping occurs when expiratory time is too short for expiratory flow to naturally decay to zero before the next inspiration begins.

$$P_{mus} + P_{vent} = \text{Elastance x Volume + Resistance x Flow + autoPEEP}$$

<u>Mechanics and Terminology</u>

Key Terminology:

- **Mode:** predetermined pattern of patient-ventilator interaction.
- **Assisted Breath:** ventilator does some work of breathing during breath sequence
- **Trigger:** to *start* inspiration
- **Cycle:** to *end* inspiration
- **Spontaneous breath:** inspiration is both triggered AND cycled by patient
- **Mandatory Breath:** inspiration is triggered OR cycled (or both) by machine

- **Control Variable:** independent variable that the ventilator manipulates to deliver a breath (pressure or volume)
  - Volume control means tidal volume and inspiratory flow are preset.
  - Pressure control means inspiratory pressure is preset OR proportional to inspiratory effort of patient.

Modes of Ventilation:

1. Two Basic Modes: Volume-targeted or Pressure-targeted ventilation
2. There are 2 types of mandatory breaths within these modes: Assisted or Controlled
   a. Controlled means that the machine triggers (initiates inspiration) and cycles (completes inspiration).
   b. Assisted means that patient initiates their own breath (triggers the vent), but the ventilator assists them with the remainder of inspiration and determines breath cycling (completion of inspiration).
      - When a patient initiates a breath, the ventilator generally detects this by noting a change either in the bias flow or a decrease in pressure within the ventilator circuit. (note, there is usually a bias flow through the tubing from the machine, to the t-piece, and back through a separate tube to the machine.)

1. Volume Targeted:
   a. Volume Assist Control Mode **(total support)** (i.e. The goal is safety of patient)
      i. You set:
         1. Tidal volume
         2. Inspiratory flow rate
         3. Two types of inspiratory flow patterns (square wave, decelerating)
         4. Minimum frequency (respiratory rate).
         5. Additional breaths allowed above the minimum frequency, but once triggered, the breath cycle is the same as machine triggered breaths (volume, flow, length of inspiration)
         6. PEEP
         7. FiO2

      ii. Pressure is the dependent variable (depends on physiology)
   b. Synchronized Intermittent Mandatory Ventilation (SIMV)
      i. Patients can initiate breaths beyond the set minimum frequency but do not receive a set tidal volume (these breaths are spontaneous, not mandatory). The delivered volume of the spontaneous breaths varies based on patient strength, neural drives and whether or not pressure support is provided.

3. Pressure Targeted (Pressure Assist Control, Pressure support)
   a. Presssure Assist Control Mode **(total support)** (i.e. The goal is safety of patient)
      You set:
      1. The driving pressure (i.e., the increase in pressure above the set PEEP)
      2. Inspiratory time
      3. Minimum frequency (respiratory rate).
      4. Additional breaths allowed above the minimum frequency, but once triggered, the breath cycle is the same as machine triggered breaths.
      5. PEEP
      6. FiO2

      Tidal volume and flow rate are the dependent variables

   b. Pressure Support Mode (partial support) (the goal is comfort of the patient)
      You set:

1. The driving pressure (i.e., the increase in pressure above the set PEEP)
2. The cycling parameter – breaths cycle at a preset % of the peak flow – usually ~25%. This allows a patient to cycle the ventilator on their own as opposed to waiting for a preset inspiratory time to elapse (as in Pressure A/C)
3. PEEP
4. FiO2

All factors above are the same as Pressure A/C except for 2 things:
-patients must trigger all breaths (there is no preset minimum frequency. This cannot be used in patients who are paralyzed or lack a drive to breathe.)
-the inspiratory time is not fixed – cycling occurs when peak flow drops below a % of the peak inspiratory flow.

Tidal volume and flow rate are the dependent variables (same as pressure A/C)

c. SIMV + PS – mandates a prespecified number of pressure controlled breaths (set by you). Note: SIMV can function in pressure control or volume control mode for the mandatory breaths.

- Additional breaths are initiated by the patient and once initiated can either be pressure supported (in PS mode) or spontaneous (unsupported).
- If the patient is apneic, they will only receive the specified number of mandatory controlled breaths set by you.

a. CPAP- this is just PEEP
b. Bipap- this is essentially PS mode, but non-invasive. The nomenclature for determining inspiratory and expiratory pressures differs though. Bipap 10/5 = PS 5/5.

Scenarios/Application:

Scenario 1: Asthma Exacerbation.

Scenario: 24 year old man with history of poorly controlled asthma with acute onset dyspnea and chest tightness. Patient was emergently intubated in emergency department due to increased work of breathing. They are now heavily sedated with no spontaneous respiratory effort noted.

Initial ventilator settings:

- Mode = Volume Control A/C (classified as VC-CMVs)
- V_T = 500mL Resp rate = 12 (pt breathing at 20)
- Flow Rate = 60 L/min
- FiO_2 = 1.0
- PEEP = 5 cm H_2O

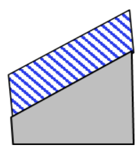
Initial alarm settings: P_{peak} 50 cmH_2O

Your monitor reads elevated peak pressures.

Goal #1- Identify the difference between Peak and Plateau pressures

- The differential for elevated peak pressures:

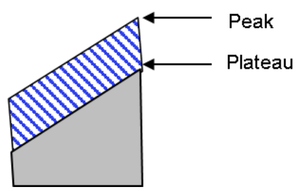
    - Cough
    - Dyssynchrony
    - Bronchospasm
    - Bronchial obstruction (Foreign body, mucous, blood)
    - Biting the tube
    - ET tube kinked
    - Elevated plateau pressure (low respiratory system compliance)
- Patient is being ventilated using a square flow waveform. Using the equation of motion, how does this flow setting affect the pressure waveform?
    - At beginning of breath, there is an immediate increase in pressure from resistive component of equation of motion. (hatched lines below)
    - As lung volume increases, the resistive component remains constant, but the pressure from the elastic component (gray area below) increases.



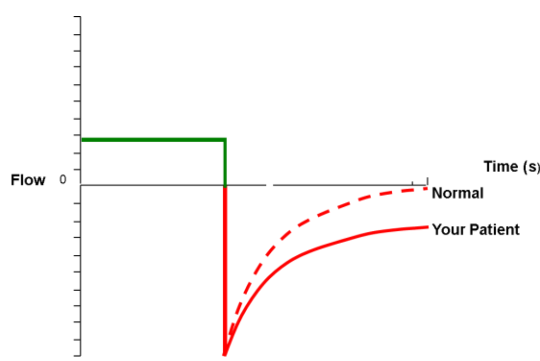
Pressure Waveform

Flow Waveform

-
- Identify difference between Peak and Plateau pressure
    - Because the Plateau pressure occurs at zero flow, it does not include the resistive pressures generated on inspiration. It only accounts for the elastic component of the equation of motion (Volume × Elastance). Therefore, it may be normal despite elevated peak pressure. Understanding the components of peak pressure (resistive and elastic pressure) and the differences between peak and plateau pressure are necessary to determine what changes to the vent are required, if any.



30 minutes later: Patient is now becoming hypotensive. Monitor shows that expiratory flow does not reach 0 prior to next breath.



Goal #2- Identify and manage Auto-PEEP

- Differential diagnosis for hypotension in this setting:
    - Tension pneumothorax

    - AutoPEEP
    - Other shock states (less likely)
- Using an **expiratory hold** (a button on the ventilator) is the best way to identify auto-PEEP. One may suspect it if the expiratory flow waveform repeatedly does not approach zero (see above figure) prior to the next inspiration.
    - Management options for auto-PEEP
        - Acutely, relieve pressure overload by transient disconnection of circuit.
        - Then, relieve air trapping with one or more of the following:
            - Decrease respiratory rate (most effective)
                - Note: you may need to increase the V_T in order to preserve the minute ventilation. In certain situations this is okay, despite what we are taught about the benefits of low V_T ventilation in general.
            - Increase inspiratory flow rate (least effective)
        - Note: use of set PEEP to relieve autoPEEP only works with flow limitation due to collapsible airways.

Scenario 2: – Severe ARDS

Scenario: 40 year-old woman with septic shock and ARDS who was admitted last night with severe hypoxemia requiring intubation. The team is rounding on her in the morning.

Current ventilator settings:

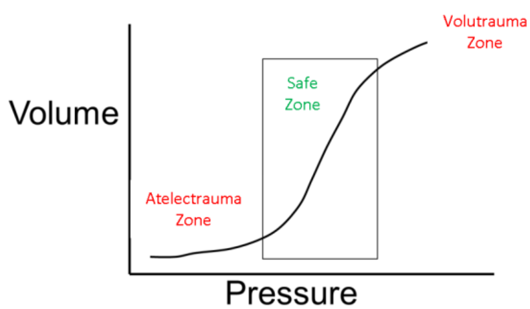
- Mode = Volume A/C (classified as VC-CMVs)
- V_T = 360 mL (6mL/kg IBW)
- Resp rate =24/min
- Inspiratory flow rate 60 = L/min
- F_iO_2 = 1.0
- PEEP = 10 cm H_2O

Vent pressures: Peak pressure 35 cm H_20, Plateau pressure 33 cm H_2O

Vital signs: HR 105 bpm, blood pressure 90/65 (on norepinephrine), RR 26, SpO_2 85%

Physical Examination: Intubated, sedated (RASS -2), crackles bilaterally

Goal #1 – Describe strategies to manage hypoxemia in ARDS.
- Increase FiO_2
- Increase PEEP



    - Decreases atelectasis, improves compliance, increases FRC, and decreases shunt to improve V/Q mismatch – keeps *end expiratory* volume out of atelectrauma zone
    - The optimal PEEP is to get on the steep (high compliance) portion of the PV curve (lowest driving pressure)

    - In volume control modes, high PEEP may put *end inspiratory* volume into the volutrauma zone, lead to ARDS, pneumothorax, worsened RV filling or increased dead space
- Heavily Sedate or Paralyze – Evidence supports using paralysis in severe ARDS within 1st 48 hrs.
- Prone – Evidence supports using this in severe ARDS with PF < 150 and FiO_2 >0.6 until PF >150.
- High Frequency Oscillator Ventilation/ Inhaled Nitric Oxide or prostacyclin (no proven benefit, possible harm with HFOV)
- APRV – No evidence to support improved outcomes, may increase risk of atelectrauma
- ECMO

Goal #2 – Safety: Avoiding Ventilator Induced Lung Injury (VILI) in ARDS

- Current evidence supports tidal volume goals of 6 ml/kg predicted body weight (lower is better!)
- Maintain plateau pressure < 30 cm H_2O (again, lower is better)
    - $P_{elastic}$ depends on two things:
        - Compliance of lung tissue = 1/elastance
            - non-compliant lung usually due to alveolar filling process, interstitial process, or over-distended lung.
        - Compliance of Chest wall.
            - important in kyphosis, burn victim,
            - Obesity - weight of adipose tissue elevates transrespiratory plateau pressure above apparent safe level even if lung is not in danger
    - There is no good way to determine which compliance is predominant (without esophageal pressure monitoring) so clinical judgment is important
- Trade-offs of low V_T ventilation
    - Higher dead space and PCO_2
    - Potential patient discomfort (dyspnea, air hunger)
        - In conventional volume control mode, increased patient effort shifts work from ventilator to patient, exacerbating problem and posing risk of flash pulmonary edema or diaphragmatic injury
        - In pressure control modes, work shifting from high effort can lead to high tidal volumes – worst case scenario
            - Need to monitor this according to ARDS guidelines.

Thank you to Rob Chatburn, MHHS, RRT-NPS, FAARC for assistance in creating this primer.