BUNNELL LIFE PULSE HFJV – 2021

MANAGEMENT STRATEGIES WITH HIGH FREQUENCY JET VENTILATION

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The Bunnell Life Pulse (**www.bunl.com**) is a flow interrupter that uses a pinch valve to generate a stream of high frequency pulses. These rapid pulses of fresh gas generate the tidal volumes, which allow ventilation to occur primarily from flow streaming (Taylor Dispersion), which allows ventilation to occur even with below dead space tidal volumes. The gas is squirted into the lungs at a very high velocity, which produces flow streaming, sending gas via laminar and transitional flow down the core of the bronchial tree minimizing the effect of dead space.

A conventional ventilator is always run in tandem with the jet to generate the PEEP and sigh breaths. **Exhalation on HFJV is passive from elastic recoil.** A special ET adapter is used during HFJV. This adapter has a jet port through which the Jet pulses are introduced and a pressure monitoring port for determining the delivered pressures.

I. INITIAL HFJV SETTINGS

A. RATE (FREQUENCY) and INSPIRATORY TIME

1. **Initial Jet Rate for First Intention Use:**

- **< 24 weeks GA or < 600 grams: 300 BPM (I:E of 1:9)**
- 24-26 weeks GA or 600-1000 grams: 360 BPM (I:E of 1:7)
- ≥ 27 weeks GA or ≥ 1000 grams: 420 BPM (I:E of 1:6)

- **Rate** (Frequency): 300 BPM (5 Hz), 360 BPM (6 Hz) or 420 BPM (7 Hz) are the usual starting Jet rates or frequencies for premature infants (management range of 240 - 660 BPM). Start with the rate as per the above table based on the stage of fetal lung development and/or the risk of PIE. If air leaks or air trapping occurs or is becoming a concern, lower the rate by 60 BPM to increase time spent in exhalation to decrease air trapping. Changes in rate are rarely made in the hour-to-hour management of blood gases. Frequency is ordered as rate in BPM and changes are to be made in 60 BPM (1 Hz) increments. At rates from 240-300 changes can be made by 20 BPM for fine tuning.

2. **I.T. — High Frequency Breath**—always use **20 milliseconds (0.02 sec)** for the inspiratory time (range 20 - 34 milliseconds). The JET I.T. should never be increased above 20 milliseconds (0.02 sec). Any increase in I.T. will greatly increase the risk of air trapping and pneumothorax and should be avoided.

3. **I:E ratio:** The **I:E ratio** is dependent on the frequency. Higher frequencies increase the risk of gas trapping. At 20 milliseconds IT and at 11 Hz (660 BPM), the I:E is **1:3.5** while at 7 Hz (420 BPM) the I:E is **1:6**. The longest I:E ratio is at 4 Hz (240 bpm) = **1:12**.

4. **Decreased Frequencies (4 - 6 Hz) (240-360 BPM)** are used**:**

   a. To treat **air leaks**: PIE, pneumothorax.

   b. To **avoid hypocarbia from excessive ventilation** when at minimum delta P (PIP-PEEP), which is a PIP of 5-6 cm above the PEEP.

   c. To minimize **inadvertent air trapping**, which can be detected when the PEEP measured by the jet exceeds the PEEP set on the conventional ventilator by > 1.5 - 2 cm. Always monitor both PEEP values.

   d. For **First Intention HFJV** if ≤ 26 weeks GA.

5. **Increased Frequency (from 8 Hz up to 11 Hz) (480-660 BPM)**

   a. To increase alveolar ventilation when the patient has severe hypercarbia despite increased PIP, and there is no evidence of significant air trapping.

   b. To improve oxygenation by increasing lung volume from decreased expiratory time (i.e., shorter I:E ratio), leading to increased lung recruitment (**warning: this maneuver may increase the risk of air-leaks**).

   c. To decrease the delta P needed and thus minimize the delivered TV in micro-preemies when air trapping is not a concern and the Jet PIP needed is exceeds 40 cm H_2O .

B. PIP (Peak Inspiratory Pressure)

The jet functions as a pressure limited ventilator. Thus, you set the PIP that you want the jet to achieve. The difference between the **PIP** ordered and the **PEEP** is the **delta P**, which represents the volume of gas generated by each high frequency pulse during the opening of the pinch valve (maximum generated volume occurs with a PIP of 50 cm with a minimum PEEP and an IT of 34 milliseconds). Thus, an increase in **PIP** will increase **delta P** and improve ventilation and a decrease in **PIP** will decrease **delta P** and decrease ventilation.

1. **Tidal volume:** The TV delivered is attenuated by the following: circuit tubing, humidifier, **ET tube diameter** and **length (FLOW is proportional to r^4/L)**, the **patient's airways** and **compliance**. The **TV** delivered is proportional to the **delta P (PIP-PEEP)**.

2. **Initial PIP Settings:** Range (8 - 50 cm H_2O)

   a) **For First Intention HFJV, set the Jet PIP at 22-24 cm H_2O** or high enough to demonstrate good chest wall shake and then adjust based on $PaCO_2$.

   b) If electively converting from **conventional ventilation**, set PIP on the HFJV to a value = to the PIP on the conventional ventilator and titrate.

c) If converting from SensorMedics **3100A HFOV**, then set the PIP equal to the measured PIP that is generated by the HFOV amplitude, which can be measured by monitoring the patient with the jet using the pressure monitoring port of the ET tube adaptor while they are still on HFOV (3100A) prior to conversion. If not ventilating or oxygenating well set the PIP on the Jet above the measured PIP generated by the amplitude of the high frequency oscillatory ventilator.

d) Check gases Q15-20 min, and titrate the PIP based on $PaCO_2$ until stable (e.g., RDS - $PaCO_2$: 45 - 60).

e) **Alveolar Ventilation (Ve)** on HFJV is proportional to the delta P, which is primarily determined by the PIP.

3. **Management of $PaCO_2$ (Alveolar Ventilation (Ve) on HFJV):**
During HFJV, $Ve = (Vt)^2 \times freq$ as compared to CMV in which Ve = Vt x Rate

Thus, $PaCO_2$ is primarily regulated by changes in PIP or delta P (PIP-PEEP), not rate or frequency! Delta P is primarily regulated via changes in PIP. See table below for rough **guidelines on adjusting the PIP**.

a. To change $PaCO_2$ ± 2 - 4 mm Hg adjust PIP by 1-2 cm H_2O

b. To change $PaCO_2$ ± 5 - 9 mm Hg adjust PIP by 3-4 cm H_2O

c. To change $PaCO_2$ ± 10 - 14 mm Hg adjust PIP by 5-6 cm H_2O

d. Check a blood gas 15-20 minutes after any significant change in PIP.

C. PEEP and Sigh Breaths

The PEEP on HFJV is set by using the conventional ventilator placed in-line with the jet; we set it based on the measured value on the Jet. Oxygenation on HFJV is directly proportional to MAP. The MAP is generated by the PEEP with a contribution from the PIP that increases with increased Jet rate. **The greater the delta P, the larger the contribution of the PIP to the MAP. During HFJV: MAP is primarily impacted by PEEP, which can be adjusted to avoid excessive use of PIP, minimizing both volutrauma and hypocarbia as well as overdistention.**

1. **FOR FIRST INTENTION USE OF HFJV FOR EXTREMELY PREMATURE INFANTS WITH RDS (< 27 weeks or < 1000 grams):**

    a. **Use a PEEP of 5 cm** and then titrate, up or down based, on chest radiograph findings (9-ribs) and the ability to oxygenate. Always balancing oxygen toxicity versus risk of mechanical injury from overdistention (PIE).

    b. Purpose for an initial PEEP of 5 cm is to avoid mechanical injury to the extremely immature lung from hyperinflation and overdistention (PIE). Additionally, to avoid impeding venous return impacting preload, cardiac output, and cerebral blood flow.

2. **SIGH BREATHS FROM THE IN-LINE CONVENTIONAL VENTILATOR:**

    a. **Sigh Breaths are** conventional breaths used for recruitment of alveoli to improve oxygenation without need for excessive PEEP. **Normal settings:** Rate = 4, I.T. = 0.4 , PIP = PEEP + 6 cm H_2O (minimal adequate PIP).

    b. **If conventional sigh PIP is higher than jet PIP, then jet breaths the will pause. If sigh PIP is less than jet PIP, then jet breaths will be superimposed over IMV breath.**

    c. **For First Intention**, start with no sighs

    d. Usual settings: PIP set 6 to 10 cm above the PEEP (need to see some visible chest wall excursion). IT = 0.4/0.5 seconds. Rates 4 to 12 BPM

    e. **For Atelectasis**: use for alveolar recruitment for patchy or wandering atelectasis, and usually continue once started, Rate 4 BPM

    f. **For Desaturation Spells**: These are alveolar hypoventilation spells which present with significant desaturations < 80% whenever the spontaneous RR drops (< 15-20 BPM). Need a sigh rate of at least 6-12 BPM to avoid saturations dropping < 80% when infant starts to be become apneic with a decrease in their spontaneous respiratory drive.

    g. If PIE or pneumothorax develops, turn off sigh breaths.

D. CONVERSION TO HFJV from CMV:

1. **Initial PEEP Settings:** Initial PEEP should be 2 cm below the **MAP** on CMV or HFOV. **<u>IMPORTANT POINT – After converting to the Jet, the MAP on the Jet should equal the MAP on either CMV or HFOV prior to conversion.</u>** After conversion, if Jet MAP is > 2 cm above the CMV/HFOV MAP before conversion, then decrease PEEP 1 cm at a time until the MAP on the jet is equal to the MAP before conversion or stop at a MAP 1 cm higher if there is a need to improve oxygenation.

2. **Initial PIP:** If converting from **3100A HFOV**, then set PIP 1 - 2 cm below the measured PIP that is generated by the HFOV amplitude, which can be measured by monitoring the patient with the jet while they are still on HFOV (3100A) prior to conversion. If converting from

conventional ventilation, set PIP on the HFJV to a value that is 2 cm < PIP on conventional ventilation.

3. **Sigh Breaths:** If converting from CMV to HFJV, place the Jet in-line with the patient remaining on their conventional settings and then activate the Jet settings (e.g., 420 bpm, 0.02 sec IT, PIP as previously determined), then increase PEEP by 1 cm while decreasing both conventional rate by 5 bpm and PIP by 2 cm H_2O on the conventional ventilator in order to keep MAP constant during the conversion. Keep decreasing rate quickly and increasing PEEP while decreasing conventional PIP until rate of CMV is 4 BPM (**sighs**) and the MAP on the Jet is the same as the MAP on CMV. For stable patients can just switch the patient directly from conventional ventilation to the previously determined Jet settings. After conversion, the **PIP** of the **conventional sigh breaths** should be 6 cm above the PEEP.
4. It is important to **keep MAP constant during the conversion to HFJV** to avoid excessive atelectasis causing loss of oxygenation.
5. **Obtain a CXR 45-60 min after converting to the jet. Follow CXR closely** to assess for **appropriate lung volume** (around 9 ribs)
6. **Gases: Check within 15-20 min after converting to the jet** and adjust appropriately.

E. Management of ABGs - Oxygenation and Ventilation: Oxygenation is directly proportional to PEEP and MAP — see multiple scenarios below:

1. **Oxygenation Inadequate** - If below optimal lung volume and if FiO_2 0.6 - 0.7, increase PEEP by 1 - 2 cm H_2O. If FiO_2 is 1.0, increase by 2 - 4 cm H_2O. When increasing PEEP, also increase the PIP by the same amount to keep tidal volume constant. **Can also increase the PIP, IT or rate of the sigh breaths to improve alveolar recruitment.**
2. **Oxygenation Inadequate and CO_2 Adequate** — If CO_2 is acceptable but not oxygenating, increase MAP but **keep TV or delta P constant.** Thus, when increasing PEEP, also increase the PIP by the same amount (1 and 1 cm H_2O or 2 and 2 cm H_2O for both PIP and PEEP).
3. **Oxygenation Inadequate and CO_2 Too Low** – Increase PEEP (1-2 cm) but keep PIP constant. This increases MAP, while decreasing the delta P, thus improving oxygenation while decreasing the TV.
4. **Oxygenation Inadequate and CO_2 Too High** – Increase both MAP and delta P by increasing PIP until CO_2 is acceptable. If the oxygenation is still inadequate with an acceptable CO_2, then increase both PIP and PEEP by the same amount to keep TV constant.
5. **Oxygenation Too Good and CO_2 Too Low** – Decrease PIP until CO_2 is appropriate. If oxygenation is still too good with an over-inflated chest X-ray, start decreasing both PIP and PEEP by the same amount to decrease MAP while keeping constant delta P.

6. **Oxygenation Adequate and CO_2 Too Low** – Wean **delta P** by decreasing PIP but increase PEEP as necessary to keep MAP constant. This decreases TV but keeps MAP constant, thus preventing atelectasis with loss of oxygenation.

7. **Oxygenation Too Good and CO_2 Adequate** — If CO_2 is acceptable but FiO_2 is too low or CXR over-inflated, then wean MAP by keeping TV (delta P) constant by decreasing both PIP and PEEP by the same amount (1 and 1 cm H_2O or 2 and 2 cm H_2O).

8. **Warning: Oxygenation is directly proportional to PEEP (MAP) unless lung is over-inflated. If over-inflated, may need to decrease PEEP to improve oxygenation and ventilation. Hyperinflation can increase pulmonary vascular resistance, as well as hypercarbia due to the loss of passive elastic recoil.**

II. MANAGEMENT STRATEGIES

Always place Jet on standby to suction or to give surfactant.

A. RDS:

1. **Surfactant Replacement Therapy:** Can give surfactant while on HFJV, by placing the Jet on standby and bagging in the surfactant.

2. Wean delta P by decreasing PIP to keep $PaCO_2$ 45 - 60 mm Hg.

4. Wean FiO_2 until ≤ 0.40 then decrease MAP by decreasing PEEP and PIP as necessary by the same amount (e.g., 1 cm and 1 cm) as needed to avoid hyperinflation.

5. The lower the FiO_2, the more frequently the PEEP and/or PIP needs to be weaned to avoid over-inflation and volutrauma. Minimal PEEP 4 cm H_2O with $FiO_2 \leq 0.30$-0.40 and appropriate lung inflation on CXR.

B. AIRLEAKS: Pulmonary Interstitial Emphysema (PIE) and/or Pneumothorax:

1. **Minimize** the number and size of IMV breaths. Or, just decrease sigh rate to 0.

2. **Permissive Hypercarbia:** Decrease delta P to keep $PaCO_2$ 55 - 70 mm Hg, by decreasing PIP.

3. **Decrease Jet Rate (Frequency):** Because of the fixed I.T. (0.02 sec) decreasing the frequency will increase the expiratory time, thus minimizing air trapping (e.g., 7 Hz (420 bpm), I:E ratio = 1:6; 6 Hz (360 bpm), I:E ratio = 1:7; 5 Hz (300 bpm), I:E ratio = 1:9; 4 Hz (240 BPM), I:E ratio = 1:12. As more time is spent in exhalation, air trapping and hyperinflation will decrease.

4. **Decrease MAP by decreasing delta P by decreasing both PIP and PEEP.** Transiently tolerate increased FiO_2 requirements (0.5 - 0.75) to heal severe PIE or recalcitrant pneumothoraces.

C. Early BPD (> 28 days of Life to < 34 weeks PMA):

1. The goal is to **minimize barotrauma, volutrauma, atelectatrauma, biotrauma, and oxygen toxicity.**
2. **Minimize delta P** by decreasing PIP to keep $PaCO_2$ adequate (e.g., 50 - 70 mm Hg).
3. **Increase PEEP** as necessary to keep $FiO_2 \leq 0.40$ - 0.50, minimizing excessive PIP and allow the patient to "self-wean by outgrowing the ventilator."
4. **Increase Jet rate** as needed from 300 (1:9) to 360 (1:7) to 420 (1:6) to 480 (1:5) to 540 (1:4.6) or higher as needed to improve overall lung recruitment, increase MAP, and improve alveolar ventilation. Increasing the rate, increases overall time spent in inspiration from a shorter I:E ratio, improving and maintaining alveolar recruitment, which improves oxygenation by increasing total lung volume from decreased expiratory time (shorter I:E ratio). Increasing rate, increases alveolar ventilation when the patient has hypercarbia despite increasing PIP, when widespread air trapping is not an issue.
   a. Remember to increase the Jet rate as the patient's disease transitions from RDS to early BPD after 2-4 weeks of life and instead just increasing the PIP to maintain ventilation
5. Increase sigh breath rate from 4 to 8 and increase conventional IT from 0.4 to 0.5 seconds to improve alveolar recruitment in the presence of heterogenous lung disease with patchy atelectasis
6. Decrease **PIP** and **PEEP by 1 cm H_2O** every 3-7 days once FiO_2 remains < 0.40 - 0.45 after each change.

III. WEANING

A. OXYGENATION: Once oxygenation is adequate and the patient is ready to be weaned, follow these steps:

1. RDS: Wean FiO_2 until ≤ 0.50, unless overinflated then also wean pressures.
2. RDS: Once $FiO_2 \leq 0.40$ and pCO_2 are acceptable, decrease PEEP and PIP by 1 cm H_2O Q4 - 8h, if $FiO_2 \leq 0.30$ - 0.35, decrease PEEP and PIP by 1 - 2 cm H_2O Q2 - 4h to avoid over-inflation.
3. Also decrease PIP of conventional sigh breaths at the same time and by the same amount that you decrease the PEEP (e.g., PIP 16 and PEEP 8 to PIP 15 and PEEP 7).
4. **Minimal PEEP or MAP** ranges from 3 - 7 cm H_2O with $FiO_2 \leq 0.40$. Minimal Jet PIP < 16-20 cm H_2O. At this point one can convert to CMV at low rates (15 - 20 BPM and pressures for central apnea), remain on HFJV while the patient matures and grows (anti-apnea settings), or extubate to Nasal CPAP or Non-invasive ventilation if ready demonstrating a sustainable respiratory drive.

B. VENTILATION

1. Reduce Jet PIP (**delta P**) at least 1-2 cm H_2O per change whenever $PaCO_2$ decreases below threshold, until minimal PIP (< 16-20) is reached, with a delta P < 10.

2. If $PaCO_2$ is still too low **(< 35 mm Hg)** on minimal PIP and minimal delta P (5 cm), and the infant is not ready for extubation, decrease frequency to 5 Hz (300 bpm) and then to 4 Hz (240 bpm) to decrease alveolar ventilation. If $PaCO_2$ is still too low consider conversion to CMV if not ready for extubation.

C. EXTUBATION

Patients are usually ready for a trial of extubation with NPCPAP or Noninvasive ventilation (NIV) when they meet the following respiratory support criteria including evidence of a sustainable respiratory drive:

1. **RDS:** MAP ≤ 8 cm H_2O with FiO_2 ≤ 0.35-0.40 and Jet PIP (< 20 and **delta P < 10-12 cm**).

   a. Extubate to NP-CPAP of 6 - 8 cm H_2O if ≥ 29 weeks GA.

   b. Extubate to Noninvasive Ventilation if < 29 weeks GA

2. **BPD:** PEEP or MAP ≤ 10 - 12 cm H_2O with FiO_2 ≤ 0.45-0.55 and Jet PIP (< 28 and **delta P < 14-16 cm**)

   a. Extubate to NIV with a PEEP at least 1-2 cm H_2O above the PEEP on HFJV.

IV. COMPLICATIONS ASSOCIATED WITH HFJV:

A. ATELECTASIS – increase the PEEP, or increase the PIP, and/or the sigh breath rate, PIP, and IT.

B. HYPOTENSION- decrease PEEP and PIP to decrease MAP and/or decrease the JET rate to minimize air trapping.

C. OVERINFLATION- decrease PEEP and PIP and/or decrease JET rate.

D. APNEA- Increase delta P (Jet PIP if PCO_2 not < 50), increase sighs from 4 to 6-12 BPM, increase sigh PIP to ensure adequate chest wall excursion or consider converting to conventional ventilation. HFJV is not optimal mode for the management of apnea.

V. ALARMS:

A. **Servo Pressure** – Represents the amount of gas flow or tidal volume delivered by the ventilator to achieve the PIP ordered. Maximum servo pressure is 22 PSI.

1. Increase in servo pressure – **Causes:** Compliance has improved, thus a larger TV is being delivered for the same PIP. Check a gas and prepare to wean since the patient is improving, or there may be a leak around the ETT (common in premature infants) or a leak in the circuit requiring an increase in flow to compensate (check circuit).

2. Decrease in servo pressure – Causes: Plugged or obstructed tube, pneumothorax, right main stem intubation, or worsening lung disease. This

worsening of compliance means that it takes very little TV or flow to reach the set PIP. Patient may need suctioning or chest x-ray.

Bunnell Life Pulse High Frequency Jet Ventilator

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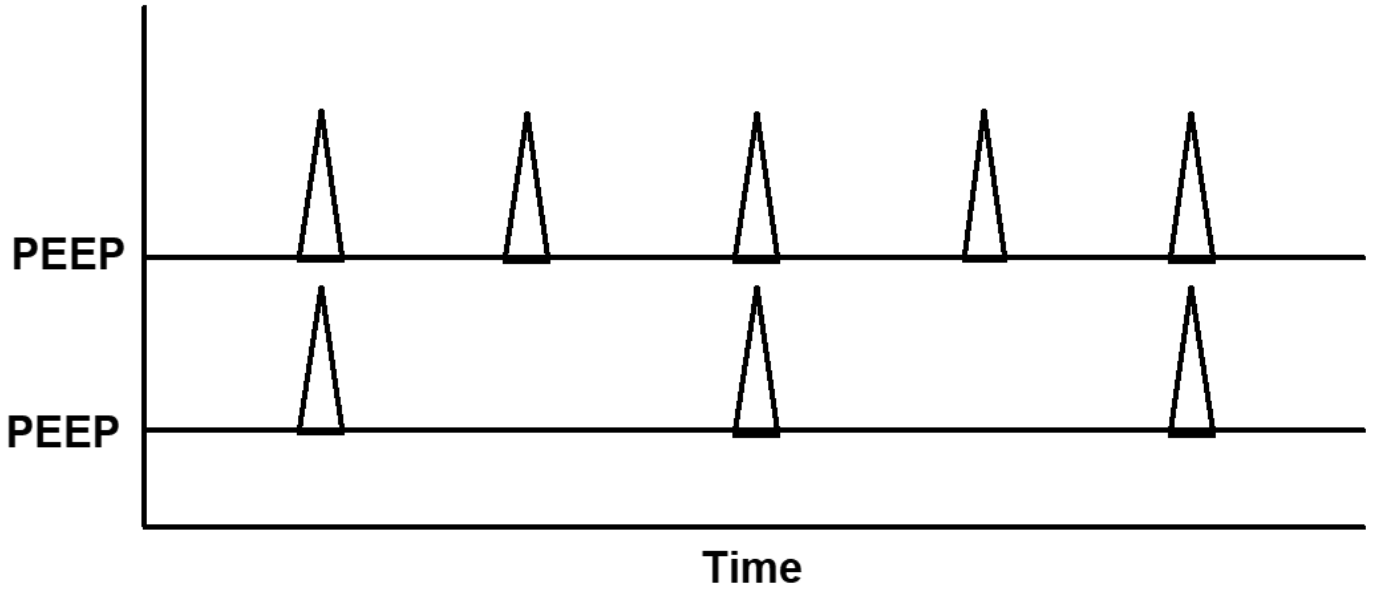
Use I.T. = 0.02 sec (20 milliseconds)



I:E
1:6
420 bpm (7 Hz)

I:E
1:11.5
240 bpm (4 Hz)

* Tidal volume basically doesn't change with the frequency on the Jet ventilator.

Alveolar ventilation = $(TV)^2$ (frequency)

TV - Delta P

Increased alveolar ventilation will increase CO_2 removal

To increase alveolar ventilation, increase the Delta P or increase the rate or frequency (up to 420 bpm or 7 Hz)

<u>Frequency Changes</u>

1. Lower Freq allows increased expiratory time (longer I:E ratio) which minimizes air trapping (use to treat PIE, pneumothorax).

2. Lower Freq will decrease alveolar ventilation (to avoid hypocarbia).

3. A higher Freq > 7 Hz (420 bpm) may improve oxygenation by increasing lung volume from decreased expiratory time (shorter I:E ratio), but increases the risk of air leaks.

High Frequency Jet Ventilation

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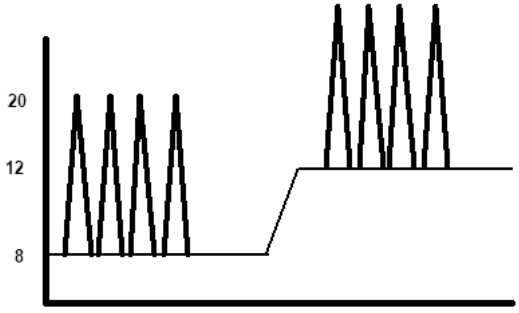
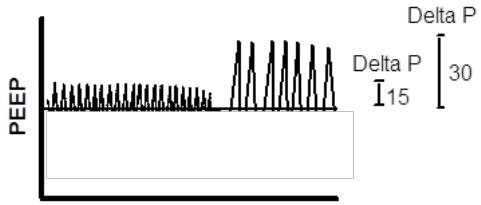
Oxygenation

Increase MAP by increasing PEEP. Improves oxygenation if not overinflated



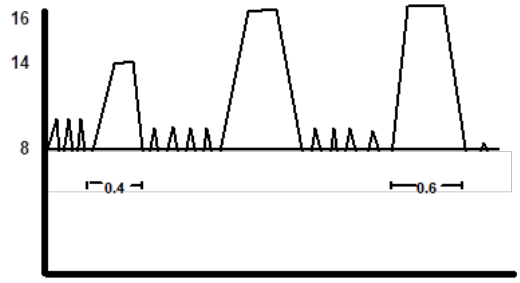
Ventilation

Increase delta P by increasing PIP to increase delivered tidal volume to improve ventilation



Sigh Breaths

Temporarily increase sighs from 3 to 6 BPM to improve oxygenation via alveolar recruitment. Once oxygenation has improved, wean the rate of the sigh breaths back to 3. Can also increase inspiratory time or PIP of the sigh breaths



Oxygenation is determined by the MAP which is regulated by both the PEEP and the PIP.

Ventilation is determined primarily by delta P and the Rate or Frequency