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\textsubscript{2}O.

**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 r⁴/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\textsubscript{2}O)
   a) **For First Intention HFJV**, set the Jet PIP at 22-24 cm H\textsubscript{2}O or high enough to demonstrate good chest wall shake and then adjust based on PaCO\textsubscript{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 PaCO₂ until stable (e.g., RDS - PaCO₂: 45 - 60).

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

3. **Management of PaCO₂ (Alveolar Ventilation (Ve) on HFJV):**
   During HFJV, Ve = (Vt)² x freq as compared to CMV in which Ve = Vt x Rate

   **Thus, PaCO₂ 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 PaCO₂ ± 2 - 4 mm Hg adjust PIP by 1-2 cm H₂O

   b. To change PaCO₂ ± 5 - 9 mm Hg adjust PIP by 3-4 cm H₂O

   c. To change PaCO₂ ± 10 - 14 mm Hg adjust PIP by 5-6 cm H₂O

   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 H2O (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. IMPORTANT POINT – After converting to the Jet, the MAP on the Jet should equal the MAP on either CMV or HFOV prior to conversion. 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 H₂O 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 FiO₂ 0.6 - 0.7, increase PEEP by 1 - 2 cm H₂O. If FiO₂ is 1.0, increase by 2 - 4 cm H₂O. 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 CO₂ Adequate** — If CO₂ 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 H₂O or 2 and 2 cm H₂O for both PIP and PEEP).

3. **Oxygenation Inadequate and CO₂ 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 CO₂ Too High** – Increase both MAP and delta P by increasing PIP until CO₂ is acceptable. If the oxygenation is still inadequate with an acceptable CO₂, then increase both PIP and PEEP by the same amount to keep TV constant.

5. **Oxygenation Too Good and CO₂ Too Low** – Decrease PIP until CO₂ 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 CO₂ 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 CO₂ Adequate** — If CO₂ is acceptable but FiO₂ 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 H₂O or 2 and 2 cm H₂O).

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.

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**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 PaCO₂ 45 - 60 mm Hg.

4. Wean FiO₂ 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 FiO₂, the more frequently the PEEP and/or PIP needs to be weaned to avoid over-inflation and volutrauma. Minimal PEEP 4 cm H₂O with FiO₂ ≤ 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 PaCO₂ 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 FiO₂ 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, atelectrauma, biotrauma, and oxygen toxicity.**

2. **Minimize delta P** by decreasing PIP to keep PaCO₂ adequate (e.g., 50 - 70 mm Hg).

3. **Increase PEEP** as necessary to keep FiO₂ ≤ 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 H₂O every 3-7 days once FiO₂ 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 FiO₂ until ≤ 0.50, unless overinflated then also wean pressures.

2. RDS: Once FiO₂ ≤ 0.40 and pCO₂ are acceptable, decrease PEEP and PIP by 1 cm H₂O Q4 - 8h, if FiO₂ ≤ 0.30 - 0.35, decrease PEEP and PIP by 1 - 2 cm H₂O 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 H₂O with FiO₂ ≤ 0.40. Minimal Jet PIP < 16-20 cm H₂O. 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 H2O per change whenever PaCO2 decreases below threshold, until minimal PIP (< 16-20) is reached, with a delta P < 10.
2. If PaCO2 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 PaCO2 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 H2O with FiO2 ≤ 0.35-0.40 and Jet PIP (< 20 and delta P < 10-12 cm).
   a. Extubate to NP-CPAP of 6 - 8 cm H2O if ≥ 29 weeks GA.
   b. Extubate to Noninvasive Ventilation if < 29 weeks GA
2. **BPD:** PEEP or MAP ≤ 10 - 12 cm H2O with FiO2 ≤ 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 H2O 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 PCO2 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

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

* 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 CO₂ removal
To increase alveolar ventilation, increase the Delta P or increase the rate or frequency (up to 420 bpm or 7 Hz)

Frequency Changes
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.
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.