Iowa Approach to First Intention High Frequency Jet Ventilation Management for Extremely Low Birth Weight Infants (<1000 grams or < 27 weeks gestation)

Jet Rate:

1) ELBW Infants < 27 weeks gestation - start with a Jet rate of 300 or 360. The reason to start on a lower Jet rate in this population is to prolong the I:E ratio in order to decrease the risk of developing pulmonary interstitial emphysema (PIE) from inadvertent air trapping.

- **Initial Jet Rate for First Intention Use for RDS:**
  - < 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)

   a. If PIE develops, decrease the Jet rate further and turn off the Sigh Breaths. Most infants improve on a rate of 300. If needed the rate can be lower (280/260/240) with 240 being the lowest Jet rate. At rates from 240-300 changes can be made by 20 BPM for fine tuning. Lower rates can also be used to decrease alveolar ventilation to avoid hypocarbia.

   b. It is important to note that while optimal PEEP is extremely important in these infants, the use of excessive PEEP beyond optimal can result in PIE and/or pneumothorax. PIE results when respiratory and terminal bronchioles become overdistended with resultant tearing of the alveolar ducts, allowing air to escape into the interstitial tissue resulting in the classic "soap bubble" appearance on the CXR. An effective method to treat PIE is to allow the alveoli to partially collapse in order for the epithelial cells to come back into contact with one another and heal the leak. This may require decreasing the PEEP to decrease overdistension along with decreasing the Jet rate to minimize air trapping while remaining on HFV. You should expect an increase in the FiO2 as well as the pCO_2 and may need to transiently tolerate the higher oxygen requirement and relative hypercapnia until the PIE has begun to heal.

2) For worsening late RDS or early BPD, when there are significant issues with pCO_2 retention and the chest radiograph is diffusely hazy (poor aeration between the ribs) despite adequate expansion (inflation, 9 ribs), then consider increasing the Jet rate to improve alveolar recruitment by decreasing the I:E ratio.

   a. Adequate expansion in this population is usually 9 ribs; it may be less for those infants with pulmonary hypoplasia from Preterm Prolonged Rupture of Membranes.
   b. Increasing the Jet rate will increase the mean airway pressure and will help to recruit atelectatic alveoli. A higher rate leads to a decrease in expiratory time (shorter I:E ratio)

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with the I-time constant at 0.02 seconds, so you will need to monitor for potential air trapping (especially if the infant is on high levels of PEEP).

3) Generally, ELBW infants can ventilate on the lower initial rate of 300-360 for the first 5-7 days of life, though this is not always the case.

4) Avoiding overdistension in the ELBW population is critical. Once infants develop mechanical injury from overdistension, treating their lung disease becomes more complex as they are at an increased risk of air trapping leading to cystic BPD.

5) Increased oxygen needs and pCO_2 retention may mean that the infant needs more Jet rate, more PIP, more PEEP or all the above. Increasing the Jet rate to 420/480/540 is not routinely done in the first few weeks of life in the ELBW population unless needed and is used more in infants who are developing early BPD or have established dense BPD.

6) Higher Jet rates are utilized more frequently after the first 2-3 weeks of life:

    a. When the infant's chest radiograph is adequately expanded at 9 ribs but is hazy bilaterally and the infant has increased oxygen needs and pCO_2 retention, then increasing the Jet rate can help with pCO_2 elimination: minute ventilation = rate x $(TV)^2$.
    b. Increasing the Jet rate will also increase mean airway pressure by decreasing expiratory time: MAP = (PIP-PEEP) [Ti/(Ti+Te)] + PEEP, which can help to improve oxygenation. Ti=inspiratory time and Te=expiratory time (of note: you can see the change in the MAP on the Jet, and it is important to always look at what the MAP is reading).
    c. Increasing the PEEP will also lead to improved alveolar recruitment, however if the level of PEEP is excessive the lungs can become hyperinflated leading to increased pulmonary vascular resistance. Alveolar over distention can also lead to a decrease in passive elastic recoil worsening ventilation as well as oxygenation.

7) Sometimes, with an increase in the Jet rate, infants can improve both ventilation and oxygenation, as the increase in rate leads to an increase in MAP without using excessively high levels of PEEP.
    a. Of note, high PEEP (not optimal PEEP) and high Jet rates together can result in air trapping. **Always set the PEEP by using the value measured by the Jet to adjust for inadvertent air trapping; don't set the value by the conventional ventilator even though the conventional ventilator generates the PEEP.**

8) In older infants with severe cystic BPD with hyperexpanded lungs, increasing the Jet rate beyond 420 to 480/540/600 may result in air trapping because it decreases the expiratory time, so this population may not always benefit from the use of a higher Jet rate.

9) If on a Jet rate > 420, as the infant's oxygenation, ventilation and chest radiographs improve, consider weaning the rate as tolerated over days or weeks, back to 420 prior to extubation.

10) Of note, the Jet can go to a rate as high as 660, though this is rarely needed.

Sigh breaths:

1) Sigh breaths are used as a recruitment tool for "wandering" atelectasis, but the purpose of HFJV is to minimize volutrauma, so add sigh breaths in a controlled manner.

2) In general, sigh breaths are not usually started during the first week of life, as sigh breaths may increase the risk of PIE in ELBW infants.
    a. If you notice PIE on your infant's CXR when on sigh breaths, it is important to remove all sigh breaths to help heal the PIE.

3) When you do add sigh breaths, avoid large tidal volumes to minimize volutrauma, but use enough PIP to get above the critical airway opening pressure of the areas of atelectasis. We usually start with a conventional PIP 6-8 cm above the PEEP. For example, if your infant has a PEEP of 6 on the Jet, then you might start your sigh breaths at a PIP of 12-14 cm, PEEP of 6 cm and a rate of 4 BPM. We use an I-time of 0.4 seconds for sigh breaths.

4) Start with a small number of sigh breaths to treat wandering atelectasis: rate of 4, although some infants may require more depending on their degree of lung disease.

5) Once infants require sigh breaths, most should remain on the sighs until extubation due to wandering atelectasis from changes in positioning leading to atelectasis from overly compliant chest walls.

6) If the infant is overdistended on CXR, you may need to wean both the sigh breath PIP, and the PEEP.

7) Sigh breath rate can be increased from 4 up to as high as 12 if the main issue is severe desaturation spells (saturations < 80% for prolonged periods requiring nursing intervention) from alveolar hypoventilation (unresponsive to increase in caffeine) which occurs when the infant slows their spontaneous respiration to < 20 BPM.

Jet PIP:

1) The PIP on the Jet is not equivalent to the same level of PIP delivered by the conventional ventilator in terms of the risk of lung injury due to the minimal tidal volume delivered from the very brief Inspiratory time (0.02 seconds). Therefore, using a higher PIP on an ELBW infant, will not result in the same high degree of volutrauma that is associated with high PIPs (> 30 cm)

during conventional ventilation. The highest PIP on the Jet is 50 cm. The lowest that is used is around 14 cm.

2) Increase the PIP as needed to increase the tidal volume to help with pCO_2 retention and wean the PIP for low levels of pCO_2.

3) If your infant has PIE, you will need to decrease the Jet rate, as you do this, the pCO_2 will may increase so you can compensate for this by increasing the PIP. Infants with severe PIE may require rates of 240-280 and a PIP often > 30 to maintain appropriate pCO_2 values.

4) In the first week of life, pCO_2 goals for these infants are generally 40-55 (50-60 if significant PIE develops). Typically, adjusting the PIP is the primary mechanism used to maintain these goals on your baseline Jet rate of 300 or 360.

5) After the first week of life, allow for more permissive hypercapnia with a pCO_2 goal of 45-60 to continue to reduce the risk of ventilator associated lung injury from volutrauma.

6) Minimize prolonged periods of severely abnormal levels of pCO_2 in the ELBW infants, as prolonged pCO_2 levels > 65 are associated with an increased risk of intraventricular hemorrhages and prolonged pCO_2 levels < 30 are associated with an increased risk of periventricular leukomalacia and IVH.

7) The PIP-PEEP is the delta P which generates the delivered tidal volume.
    a. 1-2 cm change in PIP changes pCO_2 roughly by ± 2-4 mm Hg
    b. 3-4 cm changes in PIP changes pCO_2 roughly by ± 5-9 mm Hg
    c. 5-6 cm changes in PIP changes pCO_2 roughly by ± 10-14 mm Hg

Jet PEEP:

Optimal PEEP minimizes lung damage from both atelectatrauma and overdistension.

1) For ELBW infants, start the PEEP at 5/6 cm H_20 and aim for 9 rib expansion to balance overdistension versus atelectasis to minimize the risk for lung damage.
2) Increase PEEP as needed to improve oxygenation if requiring high FiO_2, and if your pCO_2 is within the acceptable range, also increase the PIP by the same amount to maintain your delta P (the effective tidal volume).
3) The use of higher Jet rates and sigh breaths can minimize the need to use a PEEP level of > 8-9 cm for alveolar recruitment. When adjusting PEEP always follow the chest radiograph to avoid hyperinflation and overdistension as well as using enough PEEP to maintain adequate FRC. Increases in PEEP should proceed in a step wise manner based on the need for high oxygen requirements and radiographs with diffuse atelectasis. This is a general approach to PEEP when using the Jet in ELBW patients.

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Hypoxia: Can also just increase the PIP as a method to improve mean airway pressure especially in the presence of hypercarbia.

1) If pCO2 is adequate, can increase PIP and PEEP by the same amount (1 or 2 cm at a time), keeping delta P constant so TV doesn't change:
    a. Increase one and one (increase PIP by 1 and PEEP by 1) or
    b. Increase one, one and one (increase PIP by 1, PEEP by 1 and sigh breath PIP by 1) or
    c. Increase two, one and one (increase PIP by two, PEEP by one and sigh breath PIP by one (to improve both oxygenation and ventilation)

High Frequency Jet Ventilator: Basic Management Strategies Table:

- Monitor CXR for proper inflation 9-rib expansion
- Most patients should have:

    - Initial High Frequency Rate: 300 BPM <24 weeks GA or <600g; 360 BPM <27 weeks GA or <1,000g; 420 BPM ≥27 weeks or ≥1000g
    - Inspiratory Time on the JET set at 0.02 sec = 20 milliseconds
    - Sigh Breaths: Rate 4 BPM, PIP = PEEP + 6 cm, IT = 0.4 seconds. Increase PIP, Rate, or IT to improve oxygenation (treat atelectasis).
    - Tidal Volume is primarily determined by the ΔP and oxygenation primarily by the MAP.

		Oxygenation		
		Inadequate or Poor (Increase FiO_2)	**Adequate or Good**	**Too Good (Decrease FiO_2)**
Ventilation	**Over Ventilated** **CO_2 is too Low**	Increase PEEP while keeping PIP constant. This increases MAP while decreasing ΔP to prevent hypocarbia.	Decrease ΔP by decreasing PIP and consider increasing PEEP if needed to keep the MAP constant to prevent atelectasis. If over inflated just decrease PIP to decrease TV.	Decrease PIP until CO_2 is acceptable. If still over inflated decrease PIP and PEEP by the same amount.
	Appropriate Ventilation **CO_2 is Adequate**	Increase both PIP and PEEP by the same amount to keep ΔP unchanged while increasing the MAP.	**No Changes**	Decrease PEEP and PIP by the same amount to decrease MAP to avoid over inflation. This keeps ΔP unchanged.
	Under Ventilated **CO_2 is too High**	Increase both MAP and ΔP by increasing PIP until CO_2 is acceptable. If oxygenation is still poor increase both PIP and PEEP by the same amount to keep ΔP constant while increasing MAP.	Increase ΔP by Increasing PIP.	Increase ΔP by decreasing PEEP to avoid over inflation until CO_2 is acceptable. If still over inflated decrease both PIP and PEEP by the same amount to decrease MAP.