Newborn Critical Care Center (NCCC) Clinical Guidelines

High Frequency Ventilation

BACKGROUND

One mechanism for ventilator-induced lung injury is over-distention of the lung during mechanical ventilation at high lung volumes (volutrauma). High frequency ventilation (HFV) is a strategy of ventilation that was developed with the purpose of avoiding the use of high tidal volumes, while achieving adequate minute ventilation and oxygenation. HFV achieves those goals by generating tidal volumes that are typically smaller than anatomic dead space delivered at rates in excess of 260 breaths per minute.

Though the HFJV/HFOV uses a set pressure that is greater than conventional ventilation, the set pressure attenuates as the breath travels down the airways resulting in lower overall pressure at the alveolar level.

Advantages of HFJV/HFOV include the following

- Reduced risk of volutrauma and prevention ventilator-induced lung injury.
- Assists maintenance of constant alveolar inflation, prevents the inflation-deflation cycle (atelectrauma) and improves oxygenation
- Improves the ventilation/perfusion(V/Q) ratio by allowing uniform aeration of the lungs

Despite the theoretical advantages of HFV, the efficacy of this therapy compared to conventional mechanical ventilation (CMV) in the prevention of the consequences of ventilator-induced lung injury (e.g., bronchopulmonary dysplasia) has not been proven in randomized controlled trials.

INDICATIONS

High frequency ventilation is typically reserved for two settings in the NCCC:

- Failure of oxygenation and/or ventilation despite high airway pressures with conventional ventilation
- Severe pulmonary air leak (pulmonary interstitial emphysema, and/or bronchopleural fistula) or high risk of air leak syndrome

EQUIPMENT

There are two types of HFV routinely utilized:

- High frequency oscillatory ventilation (HFOV)
- High frequency jet ventilation (HFJV)

PATIENT PREPARATION

- Suction the airway
- Ensure adequate sedation / analgesia
- Assess patient’s intravascular status and give a fluid bolus, if needed, to increase preload

HIGH FREQUENCY OSCILLATOR VENTILATOR (HFOV)

Rate/Frequency

- The ventilator rate is expressed in Hertz (1 Hz = 60 breaths/minute).
- In general:

  Infants ≤ 1000 grams: 15 Hz
  Infants > 1000 grams: 10-12 Hz
  Term infants: 8-10 Hz

Mean airway pressure (MAP)

- The MAP (expressed in cm H_2O) is the baseline pressure around which the small oscillations occur.
- The MAP is adjusted by a single setting.
- There is a direct correlation between MAP and PaO_2 except when the lungs become overdistended.

Amplitude (ΔP)

- The amplitude is the setting that determines the magnitude of diaphragm excursion and hence the volume of gas that is pushed in and out of the airway during each ventilated breath.
- The amplitude creates the visible vibration of the chest wall which should propagate from the shoulders to the umbilicus.
- The ΔP is an arbitrary value that does not correspond to a physiologic unit.
- Increasing the amplitude will increase the tidal volume and improve CO_2 removal.

Inspiratory time (I-time)

- The I-time is set to 33% on the HFOV.
- Increasing the % I-time may increase gas trapping.
- The HFOV utilizes an **active exhalation** process.

VENTILATOR SETTINGS

Initial Settings:

1. Set the MAP 1 - 2 cm H_2O higher than the MAP used previously on CMV for low lung volume strategy or 3 - 5 cm H_2O higher than the MAP on CMV for high lung volume strategy.
2. In general, a frequency of 15 Hz (≤ 1000 grams) and 10-12 Hz (> 1000 grams) should be used.
3. Set the amplitude (ΔP) to achieve gentle vibration from the shoulders to the umbilicus.
4. The inspiratory time is fixed at 33%.
5. Obtain an ABG 30 minutes following and a chest x-ray 1-2 hours after beginning HFOV.
6. Watch for evidence of decreased cardiac output as HFOV can impair venous return and impair cardiac output.

Adjustments:

1. Adjust the MAP to achieve optimal lung inflation (right diaphragm at 8th to 9th rib posteriorly).
2. Within these limits of inflation, adjust MAP to achieve desired level of oxygenation.
3. Adjust the Amplitude (ΔP) to achieve desired level of ventilation.
4. If severe hypercarbia persists despite maximum Amplitude (ΔP), consider the following:
    a. Suction and provide PPV to rule out obstruction and/or dislodgement of ETT.
    b. Obtain a CXR and consider transillumination to evaluate for pneumothorax.
    c. Verify all equipment is functioning appropriately.
    d. Lower frequency by 1-2 Hz.

Weaning/extubation from HFOV:

1. Once adequate oxygenation is achieved, decrease FiO_2 to maintain saturations in the desired range.
2. Wean MAP by 1-2 after weaning FiO_2 to 0.60, or earlier if hypotension is an issue.

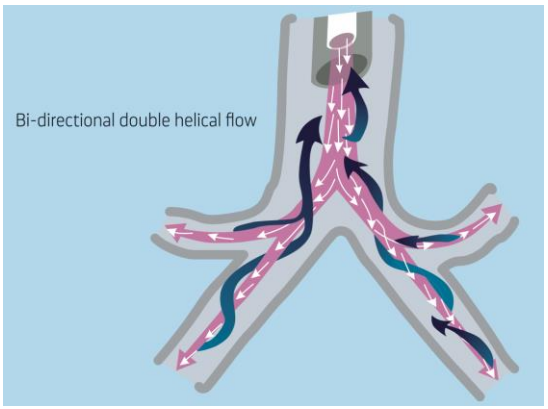
    Note: *The full effects of decreasing the MAP likely will not be seen for several hours*
3. Wean Amplitude(ΔP) by 2-4 as ventilation improves.
4. Infants can be extubated from HFOV once MAP is minimal; or infant can be switched to CMV for further weaning (typical process if sedation needs to be weaned).

HIGH FREQUENCY JET VENTILATOR

High Frequency Jet Ventilator Management Algorithm

Mechanism of Action

- The HFJV contains a jet port nozzle that allows breaths to travel rapidly through the center of the airways, penetrating through dead space gas instead of pushing it ahead of fresh gas. Therefore, smaller volumes are required to deliver fresh gas, resulting in lower overall pressure at the alveolar level.
- Exhalation is passive and is aided by the natural recoil of the chest. During exhalation slower moving exhaled gas moves out along the airway walls in a counter-current helical flow pattern around the inspiratory Jet pulses. Therefore, inspiration and exhalation occur simultaneously.



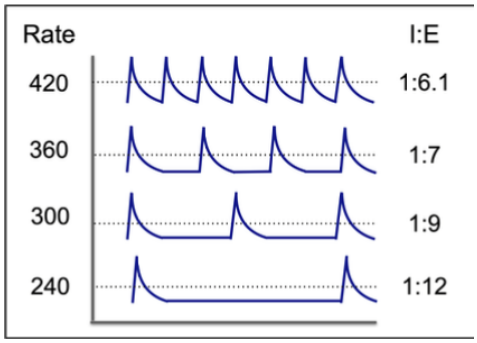
Rate/Frequency

- The ventilator rate is expressed in breaths per minute (bpm).
- The rate can range between 240-660 bpm. Infants with pulmonary hyperinflation, severe PIE and other lung conditions in which exhalation is compromised by airway inflammation or obstruction may benefit from lower rates. Typically, a rate of 360 bpm is the recommended rate for patients ≤ 1000 grams with RDS. Higher rates can be selected in situations with very low lung compliance.
- Manipulating the rate during HFJV can have a significant effect on minute ventilation. If air leaks or air trapping occurs, lower the HFJV rate in increments of 60 bpm to increase time spent in exhalation.
- Increases in the rate generally improve ventilation, unless air trapping occurs.

Inspiratory time (I-time)

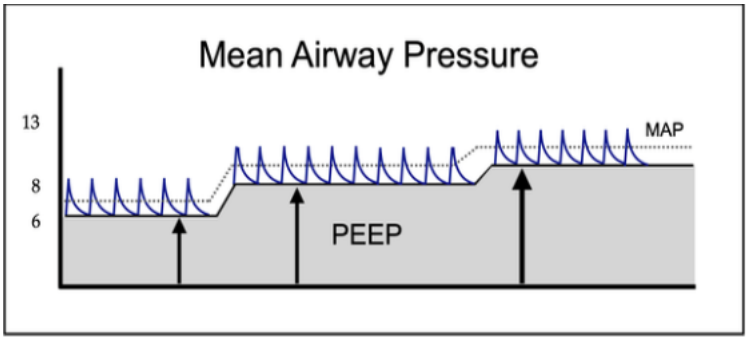
- Short inspiratory times provide the most important benefits of HFJV – small tidal volumes and low alveolar peak pressures.
- Unlike HFOV, where the I-time is set as a percentage of the respiratory cycle (33%), the HFJV has an adjustable inspiration: exhalation ratio (I:E). The jet ventilator has a set I-time (0.02 sec); therefore, as the rate is adjusted, the only parameter that changes is exhalation time (E-time). The I:E ratio varies from 1:3.5 at 660 bpm to 1:12 at 240 bpm, however the typical I:E ratio is 1:6. A prolonged E-time is critical for patients with hyperinflation or excessive secretions.

- Increasing the I-time can aid in CO_2 removal by providing a small increase in tidal volume (Vt) delivered over a longer period of time.
- Longer I-time should be considered once it is established that increasing the PIP by 8-10 cm H_2O is ineffective for controlling the $PaCO_2$ and all other settings are optimized. Since lengthening the I-time will shorten the exhalation times, lower rates may be necessary to maintain an adequate I:E ratio.
- Adjust the I-time by increments of: 0.02, 0.024, 0.026, 0.028, 0.03, 0.034 seconds. The maximum I-time is 0.034 seconds.
- The HFJV utilizes a **passive exhalation** process.



Mean airway pressure (MAP)

- The MAP is a calculated value derived from peak inspiratory pressure, peak end expiratory pressure, inspiratory and expiratory time.
- The small, rapid breaths from the HFJV contribute little to the overall MAP, therefore MAP is best controlled with PEEP (set on the conventional ventilator)
- There is a direct correlation between MAP and PaO2 except when the lungs become over distended.
- Constant PEEP throughout the lungs maintains airway patency during exhalation



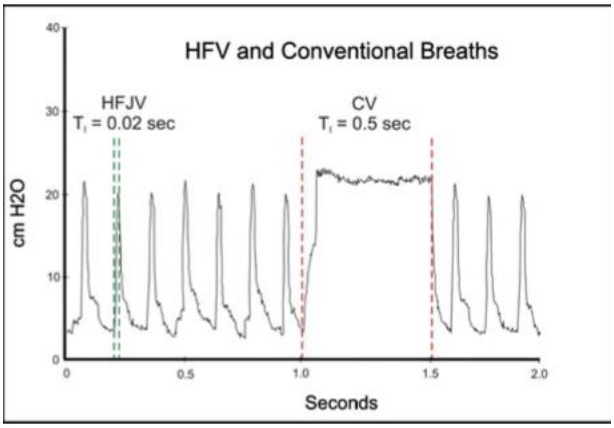
Peak inspiratory pressure (PIP) and peak end expiratory pressure (PEEP)

- The pressure amplitude (PIP-PEEP) produces the tidal volume (Vt) which controls the $PaCO_2$.
- Tidal volumes are extremely small (Vt ~1 mL/kg)

- High PIPs are commonly used with the expectation that alveolar pressures will not be correspondingly high because of the short I-time.
- It is not unusual to use PEEPs in the 7-12 cm H_2O range.
- The greater the ***ΔP*** (PIP-PEEP), the larger the contribution of the PIP to the MAP. HFJV MAP is primarily impacted by PEEP, which can be adjusted to avoid excessive use of PIP minimizing volutrauma, hypocarbia, and overdistention.

Conventional Mechanical Ventilation in Conjunction with HFJV

- A conventional mechanical ventilator is required for maintaining PEEP and providing "sigh" breaths.
- The breath rate (sigh breaths) ranges between 0-5 bpm and is utilized for alveolar recruitment. Typically in the NCCC if sigh breaths are needed, we use at 4 bpm.
- The rate should be minimal to avoid high frequency flow interruption and inadvertent PEEP.



Air Trapping

- Air trapping may be present if the PEEP measured by the HFJV is higher than the PEEP set on the conventional mechanical ventilator by > 1.5 - 2 cm H_2O OR if the CXR shows overinflation.
- Air trapping may occur if longer valve times are used with higher rates.
- If air trapping is noted, consider:
    - Decreasing the jet rate/frequency
    - Decreasing the conventional mechanical ventilator rate (sighs)

Servo Pressure

- Servo Pressure is a representation of flow through the Jet circuit needed to establish and maintain a set Jet peak inspiratory pressure (PIP). The Servo Pressure is automatically determined and adjusted by the ventilator.
- Changes in Servo Pressure:
    - Trending Servo pressure can be useful in detecting changes in lung compliance and resistance when no adjustments have been made to the ventilator.

- Increased Servo Pressure
    - Signifies more flow is required to fill a larger space while maintaining the same set PIP.
    - May indicate improved compliance, less airway resistance, increased ETT leak, leaks in Jet or CMV system.
- Decreased Servo Pressure
    - Signifies less flow is required to fill a smaller space while maintaining the same set PIP.
    - May indicate worsening compliance or increased resistance leading to a decrease in delivered Vt, kinked or obstructed ETT or Jet Circuit, right mainstemed ETT.

VENTILATOR SETTINGS

Initial Settings:

1. A rate of 360 bpm is recommended for patients 1000 grams or less. Lower rates are preferred for obstructive pulmonary disease and air leak syndromes.
2. The inspiratory time is initiated at 0.02 seconds.
3. Typically start the HFV PIP 2-4 cm H_2O higher than the conventional mechanical ventilator, unless you are concerned for air trapping (i.e. PIE) in which case you might start the HFV PIP 1-2 cm H_2O lower than the CMV.
4. Increase the PEEP until the HFJV MAPs are achieved.
5. For patients with atelectasis/underinflation on CXR and/or with FiO2 >0.6, use sigh breaths at a PIP 6-8 above PEEP and I-time between 0.4-0.5 seconds.
6. Once the lungs are recruited, eliminate the sigh breath rate (0 bpm) on the CMV and find the optimal PEEP by increasing the PEEP 1-2 cm H20.
7. Obtain an ABG and a chest x-ray approximately 30 minutes after beginning HFJV.

Adjustments:

1. Adjust the MAP to achieve optimal lung inflation (right diaphragm at 8th to 9th rib posteriorly) by controlling the PEEP. Note: MAP is typically ordered.
2. Within these limits of inflation, adjust the MAP to achieve desired level of oxygenation.
3. Adjust the ΔP to achieve desired level of ventilation (increase the PIP).
4. The HFJV rate is utilized to increase the expiratory time affecting ventilation.
5. Consider adjusting the I-time when PIP increases of 8-10 cm H_2O no longer affect the $PaCO_2$.

HIGH FREQUENCY VENTILATION GENERAL CONSIDERATIONS

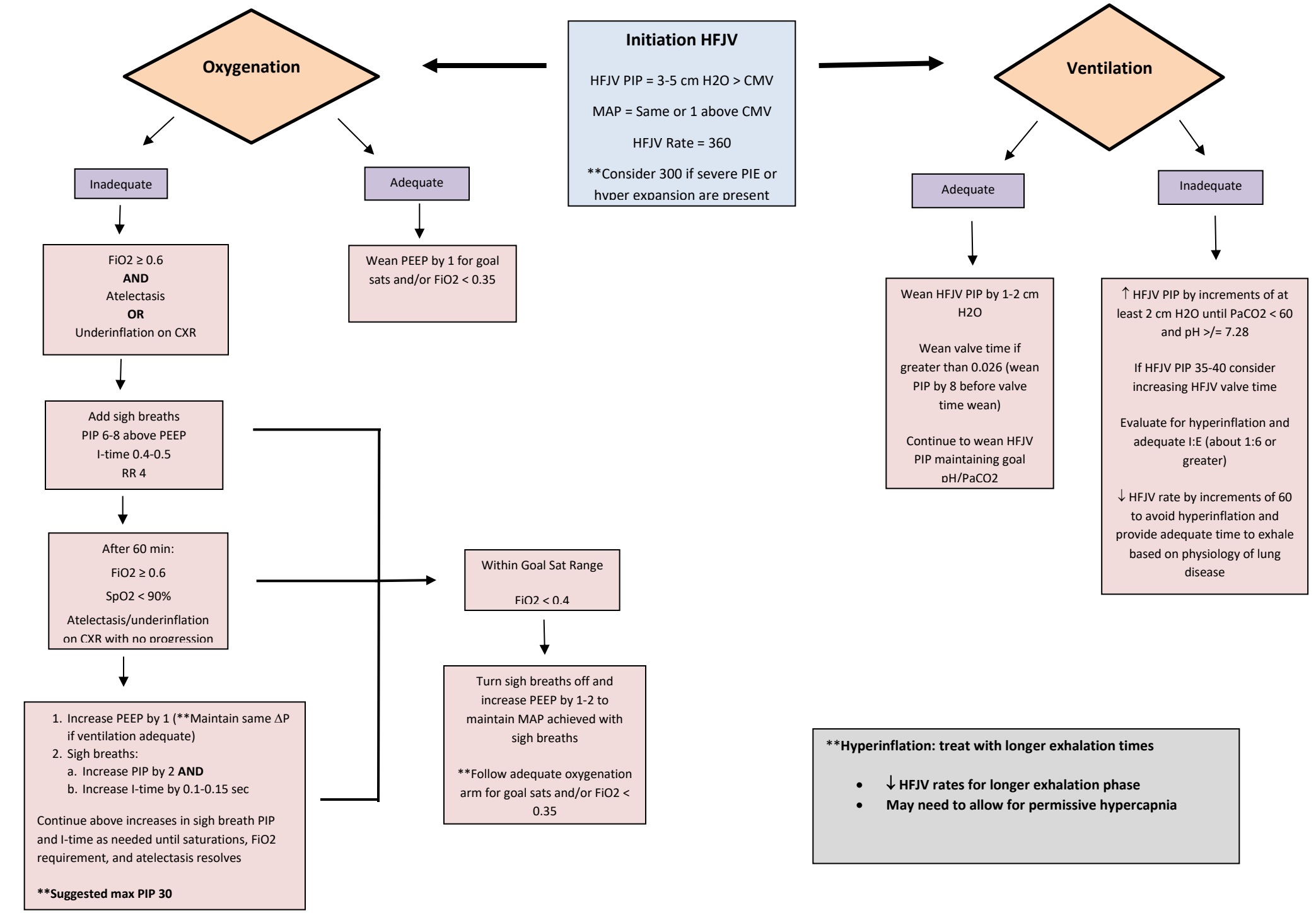
1. Repeat chest radiographs as needed (setting change) during dynamic periods of disease.
2. Avoid disconnecting infant from the ventilator, as this can lead to de-recruitment.
3. Permit a period of at least 30 minutes to elapse before assessing the impact of a change in MAP (usual time of recruitment or de-recruitment).
4. If an increase in MAP does not result in an increase in PaO_2 (or results in a decrease), consider the possibility of overinflation. If there is concern for air trapping on HFJV check CXR and/or increase I:E ratio by decreasing HFJV rate in 60 bpm increments. Additionally, consider removing "sigh" breaths (change rate on the conventional mechanical ventilator to 0).
5. The use of HFV may impair cardiac output by diminishing venous return or possibly through other mechanisms. Be prepared to administer vascular volume expanders and inotropic medications. Impaired cardiac output can also occur with overinflation (see #4 and #8.)
6. Transcutaneous CO_2 monitoring is extremely helpful in preventing hyperventilation and hypocarbia.
7. The recruitment process takes longer with the HFOV as compared to the HFJV. Weaning should be approached at a slower rate with the HFOV compared to the HFJV.
8. Overinflation will occur more readily in smaller infants (≤ 1000 grams) as compared to larger infants with the HFJV. To reduce overinflation, consider decreasing the HFJV rate/frequency. There should be no sigh breaths utilized unless CXR demonstrates atelectasis or underinflation (4 sigh breaths may be used to recruit the lung).
9. Positioning patients on HFV consists of rotating head and circuit, micro side tilts, proning.

Table 1: Comparison of HFJV vs HFOV

	HFJV	HFOV
Mechanisms	Utilizes a pneumatic valve, short jets of gas are released into the inspiratory circuit	Through movement of an electromagnetic diaphragm (piston pump) pressure is generated in the ventilator circuit
Type of exhalation	Passive	Active
Settings to adjust **ventilation**	PIP, Valve time, Rate	Amp, Frequency
Settings to adjust **oxygenation**	FiO2, MAP, Sigh breaths	FiO2, MAP
I:E ratio	Adjustable I:E ratio (with changes in rate/valve time)	Fixed (normal 33%)
Assessing MAP changes	Shorter time frame required	Longer time frame required
Sigh breath capability	Yes	No

References:

Bunnell Website - HFJV
CareFusion Website - HFOV



Reviewed July 2023 - Nora Norwood RTT / Karen Wood MD