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. 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 CO2 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 H2O higher than the MAP used during CMV for low lung volume strategy or 3 - 5 cm H2O 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 in 30 minutes 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 ΔP to achieve desired level of ventilation. Once adequate ΔP achieved, consider decreasing the frequency by 1-2 Hz.
4. If severe hypercarbia persists despite maximum 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 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 may not be seen for several hours*.
3. Wean ΔP by 2-4 as ventilation improves.

HIGH FREQUENCY JET VENTILATOR

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 420 bpm is the recommended rate for patients ≤ 2000 grams. 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. It is recommended that changes in rate be made in increments of 60 bpm.
- Increases in the rate generally improve ventilation, unless air trapping occurs.

Mean airway pressure (MAP)

- The MAP is a calculated value derived from peak inspiratory pressure, peak end expiratory pressure, inspiratory and expiratory time.
- There is a direct correlation between MAP and PaO2 except when the lungs become over distended.

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.

Inspiratory time (I-time)

- Short inspiratory times provide two of 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 are necessary to maintain an adequate I:E ratio.
- Adjust the I-time by increments of: 0.02, 0.026, 0.03, 0.034 seconds. The maximum I-time is 0.034 seconds.
- The HFJV utilizes a ***passive*** exhalation process.

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 initiate at 2 bpm and then increase to a maximum of 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

VENTILATOR SETTINGS

Initial Settings:

1. A rate of 420 bpm is the recommended for patients 2000 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 on the HFJV.
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 conventional mechanical ventilator MAPs are achieved.
5. Continue conventional ventilation at a PIP 30-50% less than the HFJV PIP, and an I-time between 0.33-0.45 seconds.
6. Minimize the rate (0-4 bpm) on the conventional mechanical ventilator and find the optimal PEEP.
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.
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. Adjust the I-time when PIP increases of 8-10 cm H_2O no longer affect the $PaCO_2$.

GENERAL CONSIDERATIONS

1. Repeat chest radiographs as needed 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, check CXR and/or increase I:E ratio by decreasing rate in 60 bpm increments. Additionally, consider decreasing the "sigh" rate on the conventional mechanical ventilator to 2 or 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, the rate on the conventional mechanical ventilator can be decreased or turned off. Also, consider decreasing the HFJV rate/frequency.

References:

Bunnell Website - HFJV

CareFusion Website - HFOV

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