

JOHNS HOPKINS ALL CHILDREN'S HOSPITAL

High Frequency Jet Ventilator (HFJV) for Neonates Clinical Pathway

Johns Hopkins All Children's Hospital

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Owner and Primary Author: Drifa Freysdottir, MD

This pathway is intended as a guide for physicians, physician assistants, nurse practitioners and other healthcare providers. It should be adapted to the care of specific patient based on the patient's individualized circumstances and the practitioner's professional judgment.

High Frequency Jet Ventilator (HFJV) for Neonates Clinical Pathway

Rationale

High frequency jet ventilation is one mode of ventilation used to support breathing in neonates that can possibly be of additional benefit to some subgroups of neonates compared to other modes of ventilation. This clinical pathway is intended to give guidelines as to initial settings for this mode of ventilation as well as recommendations of adjustments for different clinical scenarios after starting ventilatory support with HFJV, to have a synchronized approach among different practitioners and decrease variability of management.

Background

1. The ventilator

The Model 203 Life Pulse High Frequency Ventilator, (Bunnell, INC. Salt Lake City, Utah, U.S.A.) was granted premarket approval by the FDA in 1988 for the clinical use of High Frequency Jet Ventilation (HFJV) for the treatment of RDS complicated by pulmonary air leaks. Additionally, the HFJV has been used frequently for conditions with high risk of air leaks, such as lung hypoplasia, meconium aspiration, and CDH, among others. (5,6,9)

The LifePulse from Bunnell is a pressure-limited/ time cycled ventilator with adjustable PIP and rate. It is used simultaneously with a conventional ventilator to provide PEEP and, sometimes, a backup rate. (1,2)

2. Key components of the HFJV

Inspiratory time (I-time) is kept as short as possible (0.02 sec.)

Exhalation is passive: That means that airway pressure at end-exhalation, PEEP, is constant throughout the lungs, as long as the rate is set slow enough to avoid gas trapping.

Exhaled gas moves out in a counter-current helical flow pattern around the gas jetting in, which helps secretion clearance in the airways. Tidal volumes (VT) are delivered at rapid rates and at very small volumes of about 1 ml/kg, which is about half of the anatomic dead space. This is done via a special ET tube adapter with built-in jet adapter that connects to the device delivering the Jet breaths.

PIP along with the ΔP (PIP-PEEP) is the biggest determinant of TV. PIP may be set as high as that used during CMV. However, delivered PIP falls quickly as it progresses down the bronchial tree due to the high rate and low inspiratory time. As a result, peak alveolar pressure is much lower than peak airway pressure.

Gas flow is feedback-controlled by matching monitored PIP with set PIP.

Servo Pressure

Monitored servo-controlled driving pressure (Servo Pressure) is used to detect changes in lung compliance and resistance

Rising servo pressure is concerning for Increased compliance / Decreased resistance

- Accidental extubation,
- Air leak / Disconnected tube

Decreasing servo pressure is concerning for:

- Worsening compliance
- Increased resistance, such as with bronchospasm
- Tension pneumothorax
- Tube obstruction, i.e., due to secretions
- Tube malposition, such as right main stem

Published Data and Levels of Evidence

1. High Frequency Jet Ventilator in neonates

There is a scarcity of randomized controlled trials of HFJV use. Most trials mix different HFV modalities and many of them were done in the pre-surfactant era and prior to current volume targeted ventilation and the optimal lung volume strategy that has become the standard of care. The most recent Cochrane review was only able to include one trial stated that "The overall quality of evidence is affected by limitations in trial design and by imprecision due to the small number of infants in the included study.

The benefit of HFV (High frequency ventilation) is believed to be a function of reduced pressure and volume swings transmitted to the periphery of the lungs (1,7), allowing for better oxygenation and ventilation at lower MAP (6). A few early animal studies demonstrated decreased acute lung injury with HFV using an optimal lung volume strategy (12,13)

2. Use of high-frequency jet ventilation as rescue therapy in preterm infants

a. HFJV versus CV

The most recent Cochrane review comparing use of high-frequency jet ventilation (HFJV) versus conventional ventilation (CV) in preterm infants with severe pulmonary dysfunction was assessed. Subgroup analyses included trials with and without surfactant replacement therapy, trials with and without strategies to maintain lung volume, trials with infants of different gestational ages and birth weights (specific subgroups to include < 28 weeks' gestation and < 1000 grams), trials with and without adequate humidification of inspired gases. Only one trial met criteria to be included. Keszler 1991 reported data on 144 infants; and permitted cross-over to the alternate treatment if initial treatment failed. Investigators found no statistically significant differences in overall mortality (including survival after cross-over) between the two groups (RR

1.07, 95% confidence interval (CI) 0.67 to 1.72). In a secondary analysis of infants up to the time of cross-over, rescue treatment with HFJV was associated with lower mortality (RR 0.66, 95% CI 0.45 to 0.97). Researchers reported no significant differences in the incidence of CLD among survivors at 28 days of age, nor in the incidence of intraventricular hemorrhage, new air leaks, airway obstruction and necrotizing tracheobronchitis. The authors conclusion to the Cochrane review was that existing evidence does not support the use of high-frequency jet ventilation as rescue therapy in preterm infants, however they acknowledged that the overall quality of evidence is affected by limitations in trial design and by imprecision due to the small number of infants in the included study. (14)

b. HFJV versus HFOV

There were no studies meeting inclusion criteria for comparison at the only published Cochrane systematic review published in 2016 .(14)

A retrospective analysis of chart records on demographics, ventilator settings, blood gas analysis and calculated oxygenation index prior to and during the first 7 days of high-frequency jet ventilation in ten consecutive infants reported improvement of oxygenation in patients transitioned from HFOV to HFJV. Despite sustained improvement for 7 days after the transition, there were no significant changes in pH, pCO₂, or pO₂ before or during high-frequency jet ventilation (15)

3. Use of HFJV as primary mode of ventilation to extremely premature infants

There is no Cochrane review of use of HFJV as primary mode of ventilation, and no trials using HFJV as primary mode of ventilation published for this patient population. However, there are single center experiences published, the most recent coming from the University of Iowa and published in J.Peds 2020 (Watkins et al) on use of HFJV as primary mode of ventilation for 255 periviable infants 22-25 weeks of GA. Survival was 78% for 22-23 week GA infants and 89% for 24-25 week GA, BPD rate was 95%.(16)

4. Use of HFJV for air leak syndromes

a. HFJV versus CV

Newborns with pulmonary interstitial emphysema (n=144) were stratified by weight and severity of illness, and randomly assigned to receive treatment with high-frequency jet ventilation (HFJV) or rapid-rate conventional mechanical ventilation (CV) with short inspiratory time. If criteria for treatment failure were met, crossover to the alternate ventilatory mode was permitted. Overall, 45 (61%) of 74 infants met treatment success criteria with HFJV compared with 26 (37%) of 70 treated with CV (p less than 0.01). Eighty-four percent of patients who crossed over from CV to HFJV initially responded to the new treatment, and 45% ultimately met success criteria on HFJV. In contrast, only 9% of those who crossed over from HFJV to CV responded well to CV (p less than 0.01), and the same 9% ultimately met success criteria (p less than 0.05). Therapy with HFJV resulted in improved ventilation at lower peak and mean airway pressures, as well as more rapid radiographic improvement of pulmonary interstitial emphysema, in comparison with rapid-rate CV. Survival by original assignment was identical. The incidence of chronic lung disease, intraventricular hemorrhage, patent ductus arteriosus, airway obstruction, and new air leak was similar in both groups. We conclude that HFJV, as used in this study, is safe and is more effective than rapid-rate CV in the treatment of newborn infants with pulmonary interstitial emphysema. (17)

b. HFJV versus HFOV

No studies were found comparing the two types of ventilation strategies

5. Possible adverse effects of HFJV

Risks of HFJV mirror those of CMV, i.e. tracheal trauma, alveolar injury, air leaks, infections etc. One study by Wiswell et al published in 1996 (18) showed increased risk of PVL in a subgroup analysis, but that risk has not been shown in other trials. (Bhuta et al: Cochrane Database of Systematic Reviews 1998, Issue 2.)(19)

Clinical Management

HFJV can be used as either the primary mode of ventilation or as rescue therapy. At the outset, we expect that HFJV will be primarily utilized as a rescue management for neonates with hypoxemic respiratory failure who have or are at high risk of air leaks, such as pneumothorax or pulmonary interstitial emphysema.

1. Initial settings for rescue HFJV

- a. **Inspiratory Time (IT)** - High Frequency Breath - always use 0.02 sec for the IT (range 0.02-0.034 seconds). Changing the IT should be an **exception**. Any increase in IT will increase the risk of air trapping and pneumothorax. Specifically, any increase in IT above 0.02 at jet rates over 300 will markedly increase risk of air leak due to rapidly shortening I:E ratios.
- b. **Rate**: The typical starting rate will be 360. Rates might range from 240-660, however rates above 540 should be an exception. Rates are adjusted by 60 at a time, i.e. 240-300-360-420-480, etc. Lower rates **240-360 BPM** is used: To treat air leaks, e.g., PIE or pneumothorax. To avoid hypocarbia from excessive ventilation when at minimum ΔP (delta P) (PIP-PEEP), which is a PIP of 3 - 6 cm above the PEEP. Higher rates 420-540 are used to increase alveolar ventilation when the patient has severe hypercarbia despite increased PIP, when there is no evidence of air trapping.
- c. **PIP**: If converting from conventional ventilation, the initial PIP should be set on the HFJV to a value that is 2-4 cm higher than the PIP on the conventional ventilator. If the infant is



not ventilating well on this setting, then the PIP on the Jet can be set 4+ higher than the PIP on the conventional ventilator.

- d. **PEEP:** PEEP should be adjusted to optimize lung expansion and needs to consider lung compliance as well as oxygenation. Initial settings usually range from 6-12 (we recommend starting at 8-10) depending on clinical condition. If converting from CMV or HFOV, then the initial PEEP should be 2 – 4cm below the MAP on either CMV or HFOV; it can then be adjusted up or down, as indicated.
- e. **Back-up rate:** CMV rate should not be used routinely, and its only role is as sigh breaths to avoid atelectasis and atelectotrauma. Overuse of CMV increases the risk of air trapping, air leak and delay healing of previous air leaks. Sigh breaths, when used, should be between 2-5 bpm with CMV with the CMV breaths' PIP set at or 6-8 above the PEEP and IT set at 0.35-0.5 seconds. The most common reason for desaturations when taking back up rate off is inadequate PEEP. However, BUR of 2-5 may be necessary in an infant with poor cardiac output, that cannot tolerate optimized PEEP settings.

A blood gas should be obtained within 20-30 minutes after placing the infant on HFJV and repeated frequently until stable gases on stable settings have been demonstrated.

As a general rule, it is not recommended to decrease PEEP for over expansion. Air trapping is best addressed by decreasing or discontinuing the backup rate. If there is no back up rate used or this change is not sufficient, then the HFJV rate should be incrementally decreased by 60 bpm each time and can go as low as 240 bpm.

Goal expansion by CXR is approximately 9 ribs expanded. Frequent CXRs are indicated in the first 12-24 hrs. after placing on HFJV with the first one within 2-4 hrs. of initiating HFJV.

Complications associated with HFJV

- ETT obstruction (same as CV)
- Tracheal injury (same as CV)
- Hypercarbia due to inadequate TV consequent to:
 - *Inadequate HFJV PIP
 - *Inadequate HFJV rate
 - *Insufficient inspiratory time

- Hypocarbica resulting from excessive TV consequent to:
 - * Excessive HFJV PIP
 - * Excessive inspiratory time
 - * Excessively high HFJV rate

The highest risk of hypocarbica is during initiation of HFJV (due to unrecognized increased efficiency of gas exchange) or during periods of rapid improvement / lung recruitment when delivered

-Hyperinflation and/or Inadvertent PEEP (air trapping) and potential development of air leak syndrome (pneumothorax, pneumomediastinum, pulmonary interstitial emphysema) consequent to:

- * Inappropriately long IT
- * Inappropriately high ventilator rate

* Excessive PEEP (hyperinflation without gas trapping)

-Atelectasis with risk of hypoventilation and lung injury consequent to:

* Inadequate PEEP

Troubleshooting:

Anticipated unwanted problems associated with the ventilation mode and proposed solutions

- **Endotracheal plugs**
 - Pay attention to changes in wiggling, decrease of Servo pressure or gradual increase in oxygen requirement, suction ETT and pay attention that plug sometimes just below the ETT.
- **Position of the ETT**
 - Pay attention to position of bevel and depth of ETT, readjust to ideal position as per previous CXRs
- **Use of a backup rate, harm to the lung**
 - Backup rate increased risk of shearing injury to lung parenchyma and overdistention of alveoli. It is counter to the goal of gentle ventilation with very low tidal volumes.
 - Backup rate at 2-5 can be helpful as sigh breaths in infants that do not have air leak or hyper-expansion on CXR and in infants with lung atelectasis
- **Hyperventilation**
 - Frequent gases are needed initially to avoid hyperventilation with subsequent risk of decrease in cerebral blood flow.
 - Other option is to utilize end tidal CO₂ monitors
- **Interference with other equipment**
 - The HFJV box if placed in isolette/radiant warmer can interfere with aEEG/EEG tracings. Placing folded towels beneath the box to raise from base of bed by 4-5 inches decreases this effect.

Failure of the ventilation mode - criteria

- **Include time frame for evaluation**
 - Keep in mind that the goal for HFJV is not necessarily rapid decrease in pCO₂/FiO₂ although often desired and obtained, but to achieve acceptable gas exchange while minimizing ongoing injury to the lung.
 - It can take several hours to see improved gas exchange once overinflation diminishes and alveolar capillaries of those areas can participate in gas exchange
 -
- **Maximum settings**
 - PIP can be incrementally increased to 50, if not sufficient to improve ventilation, then increase rate incrementally, but needs to be done in context of expansion and air leak. Rates above 360 should be avoided in presence of air leaks.

- PEEP can be increased every few minutes by 1-2 until oxygenation stabilizes/improves, as long as it does not adversely affect cardiac output. Increasing PEEP without increasing PIP simultaneously will decrease delta P and alveolar ventilation, unless there are significant atelectasis that are driving the need for increased PEEP.
- Maximum rate on the Jet ventilator is 660 but rates above 360 should only be used in absence of air leak/hyperexpansion.
- For continued atelectasis and hypercarbia despite optimal adjustment of the HFJV settings, consideration could be given to increase the PIP on the back up conventional breaths (the rate, however should not be increased)

Extubation criteria from HFJV

- Peep of 8 or less
- PIP of 20 or less
- FiO2 or 30% or less
- Infant with good respiratory effort or PCO2 lower than desired on minimal settings
- Normal gases for age/condition
- air leak/PIE has resolved or improved substantially
- Suggested PEEP level for CPAP is close or equal to MAP at time of extubation

Summary

HFJV has place in both primary and rescue ventilatory strategies. Air leaks and high risk of air leaks is the most common utilization of this ventilatory mode

High Frequency Jet Ventilator (HFJV) for Neonates Pathway

HFJV Initial settings (table 1)

HFJV Vent Settings	Initial settings	Conventional Ventilation (CV) Settings	Initial Conventional Ventilation (CV) settings
Jet PIP	<p>Converting CV, the initial PIP should be set on the HFJV to a value that is 2-4 cm higher than the PIP on the CV</p> <p>Converting from HFOV use delta P as initial Jet PIP</p>	PEEP	<p>Initial PEEP should be 2 – 4cm below the MAP on either CV or HFOV</p> <p>If not already on CV or HFOV, start at 8 – 10 cm H2O</p>
Jet Rate	<p>Start at 300</p> <p>Use 360 in high risk patients if no air leak or hyper-expansion present</p> <p>Consider rate 240 for severe PIE or hyper-expansion</p>	PIP (for back up rates on CV)	CV breaths' PIP set at or 5-8 above the PEEP and IT set at 0.35-0.5 seconds.
Jet Insp. Time	.02 sec	IMV rate (for back up rates on CV)	<p>Sigh breaths, when used, should be between 2-5 bpm to reverse atelectasis (should be unnecessary if PEEP is optimized)</p> <p>Use CPAP preferentially and especially with air leaks</p>

HFJV Algorithm / Pathway (table 2)

HFJV Vent Settings	Range of settings	When to Increase	When to Decrease
Jet PIP	<p>Variable depending on desired PCO2</p> <p>Minimum 18</p> <p>Maximum 50</p>	To lower PCO2	To raise PCO2 (1 st line attempt) (If PO2 is compromised by lowering PIP, can increase PEEP simultaneously to keep MAP constant however this might lead to even greater increase in PCO2)
Jet Rate	<p>240-540 (neonates)</p> <p>Rates affect ventilation and expiratory times. (Recommend starting at 300 or 360). <i>Lower rates may be used for air leaks</i></p>	<p>To decrease PCO2</p> <p>To increase MAP</p>	<p>To eliminate inadvertent PEEP by lengthening exhalation time.</p> <p>To increase PCO2 (last step in correcting for hypocarbia)</p> <p>To avoid air trapping/hyperexpansion</p>
Jet Insp. Time	<p>.02 – 0.034 sec</p> <p>Changing the IT should be an exception as it will increase the risk of air trapping and pneumothorax. Specifically, any increase in IT above 0.02 at jet rates over 300 will markedly increase risk of air leak due to rapidly shortening I:E ratios.</p>	Usually kept at .02	Usually kept at .02
IMV Rate/IT/PIP	<p>Rate: 0 – 5 bpm (0 = CPAP)</p> <p>IT: 0.35-5 sec</p> <p>PIP: Start at 5-8 above PEEP May increase PIP to improve CO2 or reverse atelectasis if all other settings have been optimized</p>	To reverse atelectasis (only reason to use Back up rate)	<p>To minimize volutrauma</p> <p>To decrease hemodynamic compromise</p>
PEEP	<p>Range 6-15 (Adjust to achieve oxygenation).</p> <p>If not already on CV or HFOV, start at 8 – 10 cm H2O</p>	To improve oxygenation and decrease PCO2	To decrease hemodynamic compromise To decrease PCO2, if not needed for oxygenation.
FIO2	Variable to obtain acceptable oxygenation	Increase as needed after optimizing PEEP	Decrease as needed to maintain acceptable oxygenation

HFJV adjustment by clinical scenarios (Table 3)

HFJV adjustment by clinical scenarios		OXYGENATION		
		Inadequate (Increase FiO ₂)	Adequate	Excessive (Wean FiO ₂)
VENTILATION	Overventilated CO ₂ is too Low	Increase PEEP while keeping PIP constant. <i>This increases MAP while decreasing ΔP to prevent hypocarbia.</i>	Decrease ΔP by decreasing PIP and consider increasing PEEP if needed to keep the MAP constant to prevent atelectasis. If over inflated decrease PIP to decrease TV	Decrease PIP until CO ₂ is acceptable. If still over inflated decrease PIP and PEEP by the same amount at a time
	Appropriate Ventilation CO ₂ is Adequate	Increase both PIP and PEEP by the same amount to maintain 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.
	Underventilated CO ₂ is too High (when PIP approaches 40 then consider increasing Insp Time-while weaning Jet rate at the same time)	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.

Glossary

Neonate: For the purpose of this CPG, a neonate is defined as an infant needing respiratory support for condition that arises during admission in the NICU.

HFJV: High frequency jet ventilator/ventilation

HFV: High frequency ventilator/ventilation of any kind

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Clinical Pathways Team Information

Clinical Pathway Team

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Johns Hopkins All Children's Hospital

Owner(s): Drifa Freysdottir, MD

Review Panel: (alphabetical order)

Sandra Brooks, MD, MPH, Chair NICU Clinical Pathway Council

Julia Krzyzewski, MAS, RRT-NPS, RT Clinical Supervisor, NICU

Joanna Machry, MD

Linda Van Marter, MD, MPH, Director, MFNI and Chief, Newborn Medicine

Clinical Pathway Management Team: Joseph Perno, MD; Courtney Titus, PA-C

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