CLINICAL PRACTICE GUIDELINE
Guideline coverage includes NICU KEMH, NICU PCH and NETS WA

Ventilation: High Frequency Jet Ventilation (HFJV)

This document should be read in conjunction with the Disclaimer

The Life Pulse High Frequency Jet Ventilator (HFVJ) is a microprocessor-controlled infant ventilator capable of delivering and monitoring between 240 and 660 breaths/min; hence, HFJV delivers very small tidal volumes at supra-physiological frequencies.

Advantages of HFJV

The key advantage of appropriate HFJV is minimised lung trauma through ultra-low tidal volume ventilation at optimal lung volume, minimising also the level of required supplemental oxygen. An additional advantage is that spontaneous breathing is more easily achieved in parallel with HFJV than with HFOV, and may be more comfortable for the infant as end-expiratory pressure is lower than during HFOV. This also potentially allows better lung perfusion than during HFOV due to lower pulmonary vascular resistance.

During HFJV, the clinician recruits the lung (as required) and identifies an optimal PEEP for alveolar stabilisation. Collapsed lung units are recruited predominantly using PEEP ("ramping" up and down, similar to recruitment with mean airway pressure during HFOV), with the addition of low rate (0-5 breaths/min) background gentle sigh breaths via superimposed conventional ventilation (CV) if required for short intervals. The high velocity low tidal volume jet "pulses" minimise the effective dead space, thereby increasing ventilation efficiency whilst also protecting the alveolar spaces from cyclic volutrauma. Any injured areas of the lungs can rest and heal. In addition, the asymmetric flow profile associated with the rapid inspiration and slow expiration enhances mucociliary clearance.

Use of HFJV from birth may limit the severity of lung disease by minimising volutrauma. HFJV may provide benefit in established non-homogeneous lung disease (e.g. pulmonary interstitial emphysema, pneumonia, meconium aspiration syndrome and evolving BPD), by resolution of air trapping and over distension. Additionally, injured areas with high-resistance airways are "rested" in inhomogeneous lung disease as the high inspiratory gas flows preferentially ventilate the healthier areas of the lung and bypass the high-resistance airways. PEEP splints the airways open, allowing gas to escape over the longer expiratory phase of each cycle. It is important to remember that whilst HFJV inspiratory pulses occur 4-11 times a second, the tidal volume is delivered in a very short time (ranging from 0.20 to 0.34 s). Hence, the inspiratory flows are more similar to the inspiratory flows of very high-frequency

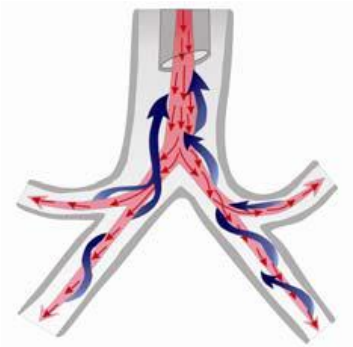


Figure 1: Gas Flows in HFJV. Fresh inspiratory gas is directed down the centre of the airways whilst the slower moving, passively exchanged gas moves outwards along the airway walls. This counter current pattern facilitates airway clearance.

HFOV: at an HFJV inspiratory time of 20 ms, the equivalent inspiratory flows in HFOV would be achieved at frequencies of 16.7 Hz (1:2) or 25 Hz (1:1).

Complications associated with HFJV

- ETT Obstruction (same as CV).
- Tracheal Injury (same as CV).
- Hypercarbia due to inadequate tidal volume consequent to:
    - inadequate HFJV amplitude,
    - insufficient inspiratory time,
    - inadequate HFJV rate.
- Hypocarbia resulting from excessive tidal volume consequent to
    - excessive HFJV amplitude,
    - excessive inspiratory time,
    - excessively high HFJV rate.

  The highest risk of hypocarbia is during initiation of HFJV (due to unrecognised increased efficiency of gas exchange) or during periods of rapid improvement/lung recruitment when delivered tidal volume may increase unless the HFJV pulse amplitude is decreased. Hypocarbia within the first few days of life is associated with the subsequent development of periventricular leukomalacia (PVL) in preterm infants [(2)].
- Hyperinflation and/or Inadvertent PEEP (air trapping) and potential development of airleak syndrome (pneumothorax, pneumomediastinum, pulmonary interstitial emphysema) consequent to:
    - Inappropriately high ventilator rate
    - Excessive PEEP (hyper-inflation without gas trapping)
- Atelectasis with risk of hypoventilation and lung injury consequent to:
    - Inadequate PEEP.

Parent Education - Consent and Parent Information Sheet

- Explain the purpose and function of the HFJV to the parents, stressing that the neonate will appear to have rapid vibrations of the chest wall, but will also be able to breathe spontaneously.
- Promote parental involvement in care as much as possible.
- Refer parents to Bunnell Parent Information Page.

Selection Criteria/Indications for Initiating HFJV

HFJV may be started at the discretion of the Consultant, for lung diseases including but not limited to:

- Air leak syndrome including PIE or unresolved pneumothorax noted on CXR.
- Infants with lung disease who have failed CV and/or HFOV - particularly if they have non-homogeneous lung disease.

Commencing HFJV from Conventional Ventilation (CV)

- Place a transcutaneous CO_2 monitor ($TcpCO_2$) on the infant and continue pulse oximetry monitoring.
- Plug the HFJV into the “Uninterrupted Power Supply”.
- Install circuit into the HFJV (refer to Setting up the HFJV Circuit).
- Attach water and place below level of HFJV humidifier.

- Attach a clean 2.5, 3.0 or 3.5 mm (as appropriate) HFJV LifePort adaptor to a clean test lung. Attach the pressure monitoring tube to the patient box.
- Connect this testing set to the installed circuit.
- Turn the **ON** switch on.
- Press **SILENCE**.

Figure 2. HFJV LifePort adaptor

- Run the SYSTEM test by pressing the **TEST** button - the numbers will change in sequence from 0 through to 9.
- Press the alarm **SILENCE** to silence at the end of the test.
- Run the FUNCTIONAL test by pressing the **ENTER** button to start default settings (PIP 20 cmH_2O, Rate 420 breaths/min, On-Time 0.02 s).
- Verify that READY condition can be met (approx. 1½ min.), monitored pressures stable and PEEP is 0.0.
- Press **STANDBY**.
- Connect the appropriate sized LifePort adaptor onto the infant's tracheal tube whilst still running conventional ventilation (HFJV remains in STANDBY) remembering to keep pressure port plugged until HFJV circuit is connected.
- Connect the circuit to the infant's LifePort adaptor whilst in Standby mode. Connect pressure adjust the SIMV PIP to achieve a tidal volume of ~ 5 mL/kg.
- Note baseline monitoring on the HFJV ventilator monitoring display whilst on SIMV (esp, PIP, and mean airway pressure).
- Set the $HFJV_{rate}$ (see "Strategies").
- Set $HFJV_{PIP}$ (in the 'Controls' section) guided by the average displayed $SIMV_{PIP}$ shown on the conventional ventilator monitoring and monitored on the HFJV (PIP on the HFJV should initially be set at approximately the average PIP used during CV when mandatory (non-triggered) breaths are being delivered).
- Check that FiO_2 is the same on both ventilators.
- Then in quick succession:
    - Reduce CV rate to 0-2 breaths/min (see "Strategies").
    - Turn CV_{PEEP} up by 1-2 cmH_2O initially.
    - Press **ENTER** on the HFJV ventilator.
    - Increase PEEP to meet the mean airway pressure noted on CV prior to switch to HFJV.
    - Turn minute volume low alarm down to '0 L/min' then high alarm '> 2 L/min'.
    - Turn apnoea alarm delay to 'off' on the conventional ventilator.

Adjust HFJV to target desired $PaCO_2$

- Observe chest movement and increase $HFJV_{PIP}$ as required to achieve appropriate level of chest "wiggle" and appropriate control of $PaCO_2$ using $TcpCO_2$.
- Ventilatory adjustments that increase CO_2 removal include:
    - ↑ $HFJV_{PIP}$
    - ↑ $HFJV_{IT}$
    - ↑ $HFJV_{Rate}$ (least preferred unless acute RDS in extreme preterm infant)
- Initial adjustments to increase CO_2 removal should be made by increasing $HFJV_{PIP}$

    - If $HFJV_{PIP}$ increases above 30 cmH_2O, subsequent HFJV adjustments to achieve adequate ventilation and CO_2 removal should alternate stepwise increases in $HFJV_{PIP}$ with stepwise increases in inspiratory time, up to a maximum inspiratory time of 0.034 s and a maximum $HFJV_{PIP}$ of 40 cmH_2O.
    - Subsequent adjustment of ventilation should consider alternating 2-3 cmH_2O increases in $HFJV_{PIP}$ with increase in $HFJV_{rate}$ 30-60 breaths/min.
- Monitor $TcpCO_2$ and observe any trends.
- Obtain a confirmatory blood gas within 20 minutes of commencing to check accuracy of $TcpCO_2$. Blood Gas as indicated thereafter (utilise trending on the $TcpCO_2$) until the $PaCO_2$ is within target range i.e. 45-65 mmHg.
- Aim to have the infant breathing gently, hence avoid overventilation with HFJV.

Optimise oxygenation and lung volume recruitment

- If SpO_2 is unstable/not maintaining previous levels, or only maintaining acceptable levels by significant increase in FiO_2, increase PEEP by 1-2 cmH_2O. Repeat as required until SpO_2 stabilises.
- Review recent chest Xray for evidence of atelectasis or hyperinflation/airleak.
- Consider formal lung volume recruitment manoeuvre, using stepwise incremental/decremental PEEP over 15 min, until FiO_2 decreases below 0.30.
    - Always adjust FiO_2 on HFJV blender and conventional ventilator simultaneously.
    - If infant has an airleak syndrome, any increase in PEEP or recruitment manoeuvre needs to be discussed with consultant first.
    - Consider using a higher CV_{PIP} to achieve recruitment breaths of 7-8 mL/kg in the setting of significant atelectasis.
    - **Do not increase CV rate > 5 breaths/min** to avoid inadvertent PEEP and risk of gas trapping. Once lung is recruited, wean CV_{rate} to 0 breaths/min if commenced at a higher rate. A stable SpO_2 (90-95 %) with a CV_{rate} of 0 breaths/min, and $FiO_2 < 0.25$ indicates appropriately recruited lung.
    - Review $TcpCO_2$ and servo pressure during lung volume recruitment, as change in compliance associated with lung volume recruitment may alter CO_2 removal.
    - Consider formal lung volume recruitment manoeuvre, using stepwise incremental/decremental PEEP over 15 min, until FiO_2 decreases below 0.30.
    - Always adjust FiO_2 on HFJV blender and conventional ventilator simultaneously.
- Adjustment in CV_{PEEP} is the primary mode of adjusting MAP. Other ventilator variables that influence MAP when adjusted include:
    - $HFJV_{PIP}$
    - $HFJV_{IT}$
    - $HFJV_{rate}$ (do not use to adjust MAP, but be aware that any adjustments in rate undertaken to influence $TcpCO_2$ may influence MAP).

Before leaving the infant's cot side

- Check automatic alarm settings when ready light is showing (MAP +/- 1.5 cmH_2O, servo pressure +/- 0.3-0.5 cmH_2O).
- Make sure the monitored pressures are stable and the Ready light is on.
- Be prepared to suction frequently within a short interval after commencing HFJV if the servo pressure decreases, or if the chest movement decreases. The READY light must be ON prior to suctioning.

Note: The **Enter button and Reset button should only be pressed** as necessary to enter new control settings or to intentionally recalculate the alarm parameters, respectively.

Inadvertent PEEP:

Always monitor $HFJV_{PEEP}$ and CV_{PEEP}. An $HFJV_{PEEP}$ reading which is higher than the CV_{PEEP} is known as "Inadvertent PEEP". Inadvertent PEEP indicates air trapping. Gas trapping occurs when tidal volumes have insufficient time to exit the lungs.

Maintain optimal lung volumes as both over-inflation and under-inflation are injurious to the newborn lung. In the case of grossly overexpanded lungs, you will need to deflate considerably before any improvements in oxygenation will result.

- To minimise overexpanded lungs: ↓ CV_{rate} to 0 then ↓ $HFJV_{rate}$ to lengthen exhalation time. $HFJV_{I\text{-}time}$ may be increased in compensation to ensure that CO_2 does not increase. Increases in $HFJV_{I\text{-}time}$ have minimal impact on the absolute expiratory time, which is a key determinant of the amount of air that can be exhaled during the expiratory phase.
- In most cases **do not** decrease PEEP as hyperinflated lungs are usually a result of air trapping due to airway collapse, not excessive PEEP.

Management

Homogeneous Lung Disease. e.g. Respiratory Distress Syndrome, Pneumonia (esp. Group B Streptococcal) and Pulmonary Haemorrhage:

- Choose an initial CV Rate of 0-5 breaths/min depending on the severity of the disease process and the degree of under inflation. Maintain alveolar inflation using a PEEP of 6-12 cmH_2O depending on the severity of the disease. $HFJV_{PIP}$ is started at ≈ CV_{PIP} (see above).
- For patients with a very poor compliance, it may take a higher background CV_{PIP} level to recruit atelectatic alveoli (e.g. 26-34 cmH_2O), but once recruited, optimal PEEP can be used to prevent loss of lung recruitment. The CV_{PIP} and CV_{Rate} can then be weaned appropriately.

As compliance improves, FiO_2 should be decreased before weaning PEEP. CV_{PIP} and CV_{rate} should be kept as low as possible. Clinically, improved compliance can be recognised by an increase in Servo Pressure (refer to Understanding Servo Pressure).

Air leak:

- Choose an initial CV Rate of 0 breaths/min (i.e. CPAP mode), or up to 2 breaths/min if coexistent atelectasis is a concern and there is no gross airleak (no pneumothorax).
- Maintain alveolar inflation using a PEEP of 6-8 cmH_2O depending upon the severity of the disease.

- Start $HFJV_{PIP}$ below the CV PIP and increase $HFJV_{PIP}$ as required to achieve slight wiggle. This strategy is appropriate for most infants with PIE or pneumothorax.
- Preference increase in $HFJV_{I\text{-}time}$ rather than increase in $HFJV_{rate}$ to improve CO_2 removal once adequate chest wiggle is achieved.

Non-Homogeneous Lung Disease. e.g. Meconium Aspiration Syndrome and focal Pneumonia:

- Use lower $HFJV_{rate}$ (240-360 breaths/min) to avoid gas trapping.
- Use higher PEEP (8-12 cmH_2O) to splint airways and allow meconium/secretions to evacuate in the swirling HFJV expiratory flow.

Understanding Servo Pressure

Servo Pressure auto-regulates gas **flow** to the infant to keep monitored PIP=set PIP. Servo pressure changes as lung volume or mechanics change. (Note: Servo Pressure increase is usually good but it may indicate an airleak or circuit leak).

Servo Pressure increases with:

- Improving compliance or resistance.
- Leak around ETT.
- Tubing leak.

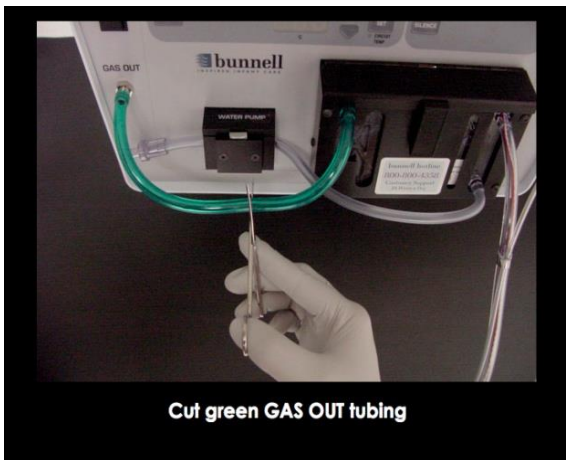
Servo Pressure decreases with:

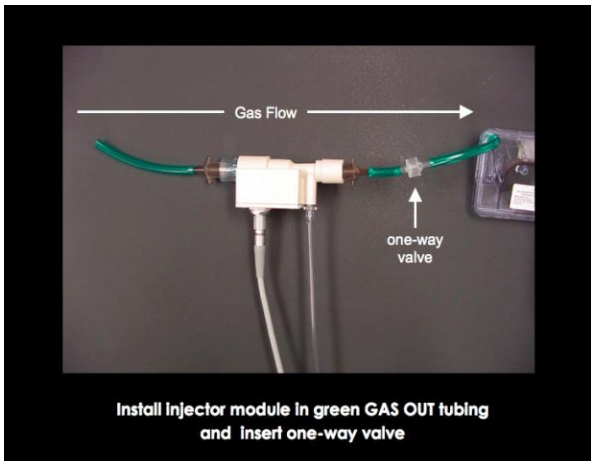
- Worsening compliance or resistance.
- Obstructed ETT.
- Bronchospasm.
- Tension pneumothorax.
- Right mainstem intubation.
- Infant needs ETT suctioning.
- Infant activity.

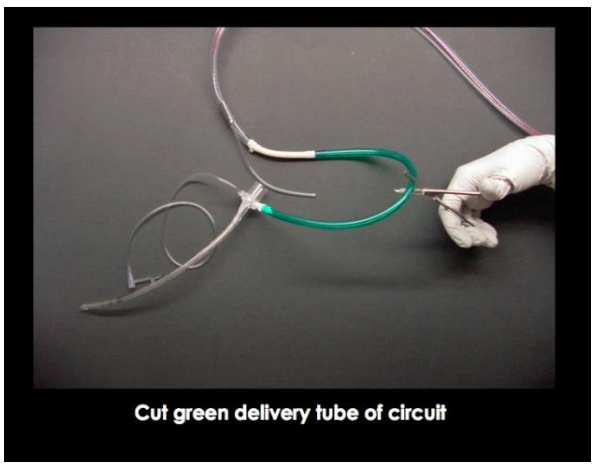
ETT Suctioning on the HFJV

- Make appropriate preparations to suction.
- Check that the HFJV **Ready light is ON**.
- **Place the Jet into the Standby mode**.
- **Immediately suction** the infant using the Ballard's closed suction system with the in-built "elbow" **then recommence HFJV by pressing ENTER**.
- Repeat the above 2 steps as often as required to achieve effective clearance of the secretions. Suctioning may need to be performed more frequently in the first 4-6 hours after commencing HFJV. Suctioning frequency may then subside.
- Make sure the monitored pressures are stable and the Ready light is on before leaving the infant's cot side.

Nitric Oxide and HFJV







General approach to weaning:

- Wean ventilation in the reverse order to the approach used to control $PaCO_2$ during initiation of ventilation:
    - Turn CV to CPAP mode (CV_{rate} 0 breaths/min).
    - Wean sedation, if any is being administered.
    - Initially prioritise decrease in HFJV rate, followed by PIP.
    - Note: PEEP may need to be ↑ slightly to support MAP and oxygenation.
    - Once $HFJV_{rate}$ is decrease to 240 breaths/min, decrease $HFJV_{I\text{-}Time}$ alternating with further decreases in $HFJV_{PIP}$ until $HFJV_{I\text{-}Time}$ decreases to 0.02 s.
    - Lower FiO_2 throughout as appropriate
    - Continue to decrease $HFJV_{PIP}$ until infant is either
        - **extubated** ($HFJV_{PIP}$ 15-25 cmH_2O, infant breathing regularly and maintaining acceptable $PaCO_2$). Extubate to nCPAP device set at a level matching the final HFJV MAP, usually 6-8 cmH_2O. Note: There is no need to change from HFJV to a CV mode before extubation.
        OR
        - **transferred** back to SIMV+VG without HFJV.

Cleaning and Storage

When High Frequency Jet Ventilation (HFJV) has been ceased, leave the Jet Ventilator by the bedside until completely satisfied the infant will not require the ventilator. A satisfactory blood gas sample, good $TcpCO_2$ readings and oxygen saturations will confirm the decision to cease HFJV.

- The HFJV with its accompanying conventional ventilator can now be cleaned and set up ready for use.
- **HFJV circuit** - The whole patient circuit is disposable including the humidifier cartridge and green oxygen tubing. The Jet adaptor is also disposable.
- **Non-disposable parts** - Wipe over the patient whisper box, HFJV, Conventional Ventilator and its humidifier together with temperature probe and adaptor with hospital grade disinfectant.
- Set up as per Setting up HFJV Circuit procedure.
- Always check the conventional ventilator settings and function prior to moving for storage.

Setting-Up the HFJV Circuit

- Open new circuit which comes as one complete piece with all connections secured.
- Open humidifier door to slide cartridge in and lock.
- Firmly attach the green tubing to “Gas Out” on the front left of the ventilator.
- Attach the thin clear purge tubing to “Purge” on the front right of the ventilator and to the Whisper Jet Patient Box (patient box) on the ventilator side.
- Place a red IV cap on the end of the circuit (water pump tube) and then attach the Pinch tubing to the other side of the red cap to keep the circuit clean.
- Place the circuit into a plastic drawstring bag for protection until used.

Note: Leave the jet set up at this point when placing the jet into storage. The pinch tube will become damaged if stored loaded into the pinch valve. It is important to **only** proceed with the next steps just prior to the HFJV being used.

- Open water pump and insert the clear water inlet tube from the bottom right of the humidifier cartridge. Mind fingers when snapping the pump door closed.
- Press the “push to load” button on the top of the patient box and gently stretch the pinch tube into the pinch valve under the plexiglass cover on the patient box.
- Connect the water inlet tube to the short giving set and connect the water transfer tubing to the 1 L water for irrigation bag and unclamp the transfer tubing. (Keep bag below ventilator to avoid gravity filling the humidifier cartridge).

References

1. Bunnell. Life Pulse High Frequency Ventilator In-Service Manual, pages 1-88; Salt Lake City http://www.bunl.com/index.html
2. Giannakopoulou C, Korakaki E, Manoura A, Bikouvarakis S, Papageorgiou M, Gougiosis D, Hatzidaki E: **Significance of hypocarbia in the development of periventricular leukomalacia in preterm infants. Pediatr Int 2004 Jun; 46(3):268-73**
3. Klein, J. Neonatology Handbook: Pulmonary: Management Strategies with High Frequency Jet Ventilation.
4. Bunnell. Technology & Clinical Bulletin, August 27, 2010.

Recourses

Consent and Parent Information Sheet

Bunnell Parent Information

Bunnell Life Pulse HFJV Controls

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