3100A High Frequency Oscillatory Ventilator (HFOV)
Outline

• 3100A Equipment Set-up
• High Frequency Ventilation (HFV) Theory
• Technical Aspects of the 3100A
• Acute Lung Injury
• 3100A Description, Operation and Management
• Disease Specific Clinical Application Strategy
• Research
• Troubleshooting
• FAQ
Disclaimer

• Do not use this presentation as a substitute for:
  ◦ Reading and understanding the operator’s manual
  ◦ As a substitute for being properly trained
  ◦ As a substitute for competency using the 3100A or 3100B High Frequency Oscillatory Ventilator.

• This presentation is intended to aid in the training staff on the rationale, setup and use of the 3100A High Frequency Oscillatory Ventilator. Management of a patient on the 3100A HFOV must be altered based on the patient’s individual clinical needs. This presentation is not intended to be used as a substitute for clinical experience or medical guidance.
3100A High Frequency Oscillatory Ventilator (HFOV)

Equipment Set-up
Prior to use

- Assemble bellows, circuit, caps/diaphragms, pressure lines
- Perform
  - Patient Circuit Calibration
  - Ventilator Performance Check
Pre-patient Checks

Patient Circuit Calibration

Performance Check

VENTILATOR PERFORMANCE CHECKS

ON-PATIENT or OFF-PATIENT
These graphs illustrate the typical performance to be expected from the Model 3100A:

1. Insert stopper in Patient Circuit “Y” and turn on both gas sources.
2. Set BIAS FLOW for 20 LPM, and rotate mean Pressure LIMIT to “Max.”
3. Pressure system, and adjust for a Mean Pressure of 19–21 cm H2O.
4. Set FREQUENCY to 15, %I TIME to 33, and START the oscillator.
5. Set POWER to 5.0 and “center the piston.”
6. Observe the following parameters, at the altitude range of your facility, and verify they fall within the ranges specified:

<table>
<thead>
<tr>
<th>ALTITUDE (ft)</th>
<th>MEAN (cm H2O)</th>
<th>ΔP (cm H2O)</th>
</tr>
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<tbody>
<tr>
<td>0–2000</td>
<td>15–23</td>
<td>56–75</td>
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<td>52–70</td>
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<td>15–23</td>
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</tr>
<tr>
<td>8000–10,000</td>
<td>15–23</td>
<td>41–56</td>
</tr>
</tbody>
</table>
Pre-patient Checks

- Performed between each patient use
- Circuit calibration failures are usually due to leaks in the system
- In the case of test failure, of either of these pre-use procedures, do not use
- Check with CareFusion tech support or an authorized biomedical service technician
3100A High Frequency Oscillatory Ventilator (HFOV)

Theory of High Frequency Ventilation (HFV)
Theory of HFV

• Defined by FDA
  ◦ A ventilator that delivers more than 150 breaths per minute
  ◦ Delivers a small tidal volume, usually less than or equal to anatomical dead space volume
  ◦ While HFV’s are frequently described by their delivery method, they are usually classified by their exhalation mechanism
    • Active or passive
    • Usually named by their delivery method
Theory of HFV

• **1915**
  Dr. Henderson published the first paper on adequate ventilation with small tidal volume and rapid rate.

• **1950 - 1970’s**
  Dr. Jack Emerson, Dr. Forrest Bird, Dr. Burt Bunnell, etc. designed and tested different styles of high frequency ventilation.

• **1980 - 1990’s**
  Approval of (4) different styles of high frequency ventilators for patient application.

• **2001**
  Approval of 3100B for Adult High Frequency Oscillatory Ventilation.
Theory of HFOV

- Chang theorized that convective processes were more predominant with an increase in Vt and lower frequencies. A diffusive mechanism may be more predominant where there is a decrease in Vt and higher frequencies are used.

Mechanisms of Gas Exchange in HFOV

1. Direct bulk flow
2. Taylor dispersion
3. Pendeluft
4. Asymmetric velocity profiles
5. Cardiogenic mixing
6. Molecular diffusion

Mechanisms of Gas Exchange in HFOV

Convection (Bulk Flow) Ventilation

• Even with small tidal volumes, direct alveolar ventilation occurs to short path length units that branch off of the primary airways.
Augmented (Taylor) dispersion

- Complicated interplay between convective forces and molecular diffusion
- Addition of convective flow to a diffusive process significantly increased dispersion of molecules
At high frequencies, distribution becomes strongly influenced by time constant inequalities. Gas from fast units (short time constants) will empty into the slow (long time constants) units.

Cardiogenic Mixing

• As the heart beats, it adds to the peripheral gas mixing.
Molecular Diffusion

- Is felt to be one of the major mechanisms for gas exchange in the alveolar regions.
- It is responsible for the gas exchange across the AC membrane and also contributes to the transport of $\text{O}_2$ and $\text{CO}_2$ in the gas phase near the membrane.
- This may be due to the increased turbulence of molecules.


Principles of Ventilation

• Ventilation is primarily controlled by the pump/piston mechanism

• Alveolar ventilation during CMV is defined as: 
  \[ f \times V_t \]

• Alveolar Ventilation during HFV is defined as: 
  \[ f \times V_t^2 \]

• Therefore, changes in volume delivery (as a function of Amplitude, Frequency or % Inspiratory Time) have the most significant effect on CO\textsubscript{2} elimination

• Delivers a pulse of gas into the ETT via a special adapter and pinch valve mechanism
• Exhalation is **Passive**
• Frequency of 4 - 11 Hz
• Peak Airway Pressure of 8- 50 cmH\(_2\)O
• Used in tandem with a conventional ventilator
• Mean Airway Pressure limited to conventional ventilator capabilities
Percussionaire®
Volumetric Diffusive Ventilation®

- A pneumatic cartridge (Phasitron®) interrupts the pressurized gas source
- **Passive** Exhalation
- Frequency of 1.6 - 21.6 Hz
- Paw is not directly adjusted
- May deliver HFV on top of a conventional breath
• Electrically powered, electronically controlled piston-diaphragm oscillator
• **Active** Exhalation
• Produces an active exhalation, and does not depend on passive recoil of the chest for CO₂ removal
• Stand Alone Ventilator
• Does not require nor deliver a conventional breath through the system
• Does not require a special ET tube

• Approved in 1991, the 3100A HFOV is indicated for ventilatory support and treatment of respiratory failure in neonates.

• Approved in 1995 for Pediatric Application, with no upper “weight limit”. This is to treat pediatric patients failing conventional ventilation.
Theory of HFOV
Oxygenation and Ventilation

Oxygenation is controlled by:
• FiO₂
• mPAW

Ventilation is controlled by:
• Power/Amplitude
• % Inspiratory Time
• Frequency
Suggested Reading


3100A High Frequency Oscillatory Ventilator (HFOV)
Technical Aspects of the 3100A
3100A Operational Characteristics

LED Indicators

- Source Gas Low LED
- Battery Low LED
- Oscillator Overheat LED
- Oscillator Stopped LED
- Oscillator Start/Stop LED

3100A Operational Characteristics

LED Indicators

• Caution alarms activate a yellow LED only (no audible alarms). Caution alarms are:
  ◦ Battery Low
  ◦ Source Gas Low
  ◦ Oscillator Overheated
3100A Operational Characteristics

LED Indicators – Low Gas Source

• Input pressure is less than 30 psi, either from blended gas or cooling air. Check both gas supplies
• Check input filter
• Be sure there are no restrictions in the gas systems (high pressure hoses, valves, gas inlets)
3100A Operational Characteristics

LED Indicators – Battery Low

• 9 volt battery to power only alarms

• “Battery Low” LED on:
  ◦ Replace Battery

• It is normal for this light to be on when pressing the “Reset Power Fail” button
3100A Operational Characteristics
Power Fail Alarm

- Red LED
- Modulated tone alarm
- Can be reset, regardless of whether or not alarm condition is corrected
- Oscillator will need to be restarted when condition is corrected (Start/Stop switch)

- The 45 second silence alarm will silence this alarm and be lit for the duration of the alarm silence.
3100A Operational Characteristics
LED Indicators – Oscillator Stopped

• Oscillator Stopped Alarm
  ◦ Will occur when Amplitude is less than 7 cmH₂O
  ◦ A red LED and audible indication occurs
  ◦ No action is taken by device
  ◦ Alarm resets automatically when the alarm condition is corrected

• The 45 second silence alarm will silence this alarm and be lit for the duration of the alarm silence.
3100A Operational Characteristics

LED Indicators – Alarms

• Warning alarms automatically reset after correction of the alarm condition. They are indicated by:
  ◦ Red LED
  ◦ Audible Alarm

• Low Mean $P_{aw}$ (mPAW) Alarm (Warning Alarm)
  ◦ Adjustable from 3-49 cmH$_2$O
  ◦ Common causes of activation:
    • Disconnection
    • Leak in system
    • Patient spontaneously breathing

• High Mean $P_{aw}$ (mPAW) Alarm
  ◦ Circuit obstruction (water in circuit, occluded expiratory limb)
  ◦ Patient activity (coughing, breathing)
3100A Operational Characteristics

LED Indicators – Alarms

- \( P_{aw} > 50 \text{ cmH}_2\text{O} \): This alarm condition will activate the dump valve, which opens the patient circuit to ambient pressure as a safety measure.
  - Press and hold “Reset Power Fail” to restart

- \( P_{aw} < 20\% \text{ of Set Max } P_{aw} \): This alarm condition will also activate the dump valve, which opens the patient circuit to ambient pressure. The correction for this is to adjust the high mPAW alarm to an appropriate setting.
  - Press and hold “Reset Power Fail” to restart
Radio Frequency Interference

• This equipment generates, uses and can radiate radio frequency energy

• Operation of radio transmitters (cell phones, walkie-talkies) within 20 feet of this instrument may cause:
  ◦ False alarms
  ◦ Erroneous pressure readings

• Avoid the use of radio transmitters/cell phones within 20 feet of the 3100A.
3100A Operational Characteristics

Settings

- Mean Airway Pressure Measurement
- Piston position indicator
- Amplitude (Δ P) Measurement
- Power Setting (adjusts amplitude)
- Mean Pressure Limit
- Bias Flow Setting
- Frequency (Hz)
- Mean Airway Pressure Adjust
- % Inspiratory Time

Set Max $P_{aw}$ Alarm Setting
Set Min $P_{aw}$ Alarm Setting

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3100A Operational Characteristics

Settings

- Mean Airway Pressure (mPAW)
  - Ranges 3-45 cmH₂O

- Bias Flow
  - Ranges 0-40 L/min

- Amplitude (Delta P)
  - Ranges 8-110 cmH₂O

- Frequency
  - Ranges 3-15 Hz

- % Inspiratory Time
  - 30%-50%
Balloon Deflation (valve opening)

- Main power failure
- \( mPAW > 50 \text{ cmH}_2\text{O} \)
- \( mPAW < 20\% \) of “Set Max Paw”
Acute Lung Injury

Pathophysiology of ALI, ARDS and VILI
Acute Lung Injury in Neonates

• Occurs most commonly in very low birth weight (VLBW) and extremely low birth weight (ELBW) infants

• Regarded as:
  ◦ Lack of Surfactant
  ◦ Overinflation during or after resuscitation
  ◦ Increased edema formation
  ◦ Increases in inflammatory cytokine production
  ◦ Repetitive opening of the adequate lung alveolar units

Acute Lung Injury in Neonates

Absence of Surfactant
Atelectasis
Tidal Breathing
High Distending Pressures
Airway Stretch / Distortion
Cellular Membrane Disruption
Edema / Hyaline Membrane Formation
Higher FiO₂, Volumes, Pressures
Volutrauma, Barotrauma, Biotrauma
PIE, BPD
3100A High Frequency Oscillatory Ventilator (HFOV)

Description, Operation, and Management
Normal Alveoli

Videos courtesy of Gary F Nieman, MS
Conventional Mechanical Ventilation (CMV)

Videos courtesy of Gary F Nieman, MS

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Airway Pressure Release Ventilation (APRV)
High Frequency Oscillatory Ventilation (HFOV)

Videos courtesy of Gary F Nieman, MS
CMV - Inspiration

HFOV - Inspiration

CMV - Expiration

HFOV - Expiration

Videos courtesy of Gary F Nieman, MS
3100A Operational Characteristics

• Blended medical air and oxygen is provided to the ventilator circuit, 40-60 psig.

• Medical air is connected to the back of the ventilator to keep the piston cool, 40-60 psig

• Inspired gas is humidified, recommend to keep the inspiratory temperature at 36 – 37 degrees Celsius.

• Bias flow is used to maintain mean airway pressure within the circuit.
High Frequency Oscillatory Ventilation
A few simple facts

• Lung volume maintained by applying constant mean airway pressure

• Pressure amplitude determines oscillations in pressures around the mean airway pressure

• Inspiration and expiration are BOTH ACTIVE

• Frequency 3-15 Hz
  ◦ Frequency determines the duration of piston displacement and hence Vt
3100A Front Panel Controls

Flow meter 0-40 L/min

Cap/diaphragms
3100A Front Panel Controls

Bias Flow

Resistance
Settings
Bias Flow, Adjust and Limit Knob

Mean Airway Pressure Limit Adjust
Flow Adjust
Mean Airway Pressure Adjust

Settings

Bias Flow

• A continuous flow of fresh, humidified gas which replenishes the oxygen to and removes carbon dioxide from the patient circuit

• Typical setting:
  ◦ Premature baby 8-15 L/min
  ◦ Near-term baby 10-20 L/min
  ◦ Small child 15-25 L/min
  ◦ Large child 20-30 L/min
Settings
Bias Flow
Settings
Mean Airway Pressure

• Starting points for HFOV vary based on size and disease state

• Settings include:
  ◦ mPAW
    • Holds airways open
    • Increases lung volume
    • Improves oxygenation, and minimally effects ventilation unless underinflated or overinflated.
    • Controlled by “Adjust” knob
Settings
Mean Airway Pressure

- Mean airway pressure setting requires 3 setting adjustments:
  - Usually set in combination with bias flow
  - Adjust the control marker between the 10 o’clock and 2 o’clock position when possible
Settings
Mean Airway Pressure Limit

• It is used to as a safety measure to limit the mean airway pressure to the patient.

• To set:
  ◦ With the mPAW limit control set to “Max”
    • Set desired bias flow and mPAW adjust
    • Slowly turn mPAW limit control counter-clockwise until a drop in the mean airway pressure is observed.
    • Turn mPAW limit control clockwise 1/8 of a full turn, recheck mPAW monitor to assure proper mean airway pressure setting
      – The Limit is usually set 2-5 above the current mPAW
• Limits the total pressure that the patient can receive.

• This should not be left at a “MAX”. If so, the patient could receive up to 50 cmH\textsubscript{2}O before ‘dump valve’ is activated.

• This should be set, usually, 2-5 cmH\textsubscript{2}O above set mPAW.
3100A Front Panel Controls
Power/Amplitude Control

Power Adjust control

Oscillator

Inspiratory bias flow

Valve

Gas outflow

Valve

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3100A Front Panel Controls
Power/Amplitude Control

• Amplitude is a measurement created by:
  ◦ The force that the piston moves with based on the POWER setting, resulting in a volume displacement and a visual CHEST WIGGLE.

• Initiate Power of 2 and increase to give a “wiggle” through:
  ◦ The umbilical area for the neonate
  ◦ Waist/crest for the pediatric patient
Piston Centering
3100A Front Panel Controls
% Inspiratory Time

- Typically started at 33%
- Range is 30-50%
- Increasing % IT may also have an impact on lung recruitment by increasing delivered mPAW
- Allows more time for piston travel resulting in larger tidal volume

3100A Front Panel Controls

**Frequency**

- Secondary control for ventilation
- Frequency controls the time allowed for the piston to move forward and backward
- The lower the frequency, the greater the volume displaced

![Diagram of 3100A Front Panel Controls](image)

3100A Front Panel Controls

Frequency

• Typical initial settings (disease dependent):

  - < 1000 gms: 12-15 Hz
  - 1000-1500 gms: 10-13 Hz
  - 1-10 kg: 9-10 Hz
  - 11-20 kg: 8 Hz
  - 21-30 kg: 7 Hz
  - > 30 kg: 6 Hz
Basic patient management guidelines

• Suctioning
  ◦ Suctioning should be done prior to placing patient on HFOV
  ◦ The need to suction during HFOV use should be determined based on institution policy and clinical signs, just as with Conventional Ventilation (CV). The Multi-Center Studies found no difference in the frequency of suctioning between the HFOV and CV patients. However, some have observed that more frequent suctioning becomes indicated during the treatment of the sickest infants, especially after they have stabilized.
  ◦ A closed in-line suction system or a suction adapter may be used if it does not interfere with the function of the mean airway pressure alarm.
  ◦ Suction only PRN
Basic patient management guidelines

• Repositioning
  ◦ Any patient position is possible while on HFOV
    • Protect the endotracheal tube when turning the patients head
    • After any position change observe chest wiggle and endotracheal tube position

• Auscultation
  ◦ In order to assess heart sounds or bowel sounds you must stop the piston
    • Remember: stopping the piston stops ventilation, so your patient may not tolerate this well
  ◦ Lung sounds may be heard if the patient is breathing spontaneous
Example of where the 3100A circuit may enter the bed of a neonate
Basic patient management guidelines

• Sedation
  ◦ Depends on underlying disease process
  ◦ Per hospital policy
Potential Complications

• Over distension
  ◦ Recognizable by increased PCO$_2$ and/or decreased saturation and possible decrease in blood pressure
  • If left untreated may lead to a pneumothorax

• Partial Endotracheal Tube obstruction
  ◦ Recognizable by a decreased chest wiggle and/or decreased saturation
Arterial Blood Gases

• **Hyperoxia - High PaO\textsubscript{2} or SaO\textsubscript{2}**
  - Decrease FiO\textsubscript{2} per unit guidelines to maintain saturation parameters
  - Once FiO\textsubscript{2} is weaned to acceptable range, begin to wean mPAW

• **Hypoxia – Low PaO\textsubscript{2}**
  - Increase FiO\textsubscript{2}
  - Increase mPAW (if hypo-expansion or de-recruitment is expected)
  - Monitor mean arterial pressure
Arterial Blood Gases

• Hypercarbia - High PaCO$_2$
  • Increase amplitude to increase chest wiggle, increase power setting by no more than 0.5 power setting or no more than 5 cmH$_2$O
  • In most cases, the amplitude should not be more than 3 times mPAW. Consider:
    – Check chest x-ray
    – mPAW may need adjusting to maintain FRC
    – Consider decreasing Frequency

TRANSCUTANEOUS CO$_2$ MONITORING RECOMMENDED
Arterial Blood Gases

• Hypocarbia - Low \( \text{PaCO}_2 \)
  • Increase frequency by 1
  • Decrease amplitude pressure by no more than 2-5 cmH\(_2\)O pressure, decrease power setting to decrease amplitude pressure.

TRANSCUTANEOUS CO\(_2\) MONITORING RECOMMENDED
General HFOV Strategy

• Be aggressive in finding the optimal settings especially when lung volume is low on the pressure volume curve
• Make changes slowly on stable patients when higher on the pressure volume curve
• Allow 30-60 minutes for desired effect
• Wean FiO$_2$ to $<30\%$ and then start to wean mPAW
• Adjust Power/Frequency for acceptable CO$_2$/pH
3100A High Frequency Oscillatory Ventilator (HFOV)

Disease Specific Clinical Application Strategy

Published by Dr. Donald Null
Primary Children’s
Salt Lake City
Remember

- The 3100A requires use of disease specific strategies
- Application for diseases other than those indicated and application of an inappropriate strategy, will not result in positive outcomes.
- CWF stands for Chest Wiggle Factor, which may be described as a visible vibration of the chest wall from the shoulders to the umbilicus
- % Inspiratory Time is set to 33% for all strategies. Increasing the % I-Time may increase gas trapping.
RDS (Diffuse Alveolar Disease)

- **Preterm RDS (< 1 kg)**
  - Paw – Set 1-2 cmH\(_2\)O above CMV Paw or initiate at 10 cmH\(_2\)O
  - Frequency – Set to 15 Hz
  - Power – Start at 2.0 and then adjust for adequate CWF

- **Term or Near Term RDS**
  - Paw – Set 2-4 cmH\(_2\)O greater than CMV’s Paw
  - Frequency – Set to 10 Hz
  - Power – Start at 2.0 and then adjust for adequate CWF

**DO NOT CHASE AMPLITUDE**
Air leaks in the Premature Infant

- **Pulmonary Interstitial Emphysema (PIE)**
  - Paw – Set equal to or 1 cmH$_2$O less than CMV Paw
  - Frequency – Set 15 Hz
  - Power – Start at 2.0 and then adjust for minimal CWF

- **Gross Air leak**
  - Paw - Set equal to or 1 cmH$_2$O greater than CMV Paw
  - Frequency – Set 15 Hz
  - Power – Start at 2.0 and adjust for adequate CWF

***MORE oxygen -> LESS pressure***
Focal (Non-Homogeneous) Pneumonia

- **mPAW** – Set equal to or 1 cmH\textsubscript{2}O greater than the CMV Paw
- **Frequency** – Start at 10 Hz and adjust down to 8 Hz
- **Power** – Start at 2.5 and then adjust for a good CWF

- Infants that present with patchy or lobar pneumonia on CXR may not respond as well as those infants with diffuse lung involvement.
- Infants that present with hyperinflation may be at risk for air leak.
Meconium Aspiration
Diffuse Haze

- mPAW – Set 2-4 cmH$_2$O greater than CMV Paw or 12-14 cmH$_2$O
- Frequency – Start at 10 and adjust down to 6 Hz if needed for air trapping
- Power – Start at 2.5 and then adjust for good CWF
- Use HFOV to stent airways open.
- The meconium liquid produces a chemical pneumonitis/RDS scenario.
- Monitor CXR regularly for over distension or gross air leak.
Meconium Aspiration
Air Trapping

- mPAW – Set **equal** to CMV Paw or 12 cmH$_2$O

- **Frequency** – Start at 8 and decrease if needed

- Power – Start at 2.5 and then adjust for good CWF

- Use HFOV to stent airways open.
General guidelines for initial settings
Meconium Aspiration-Clinical Tips

- Due to the presence of air trapping, overly-aggressive use of the Paw can further aggravate air trapping which may result in PIE or Pneumothoraces.

- PPHN may also complicate this picture.

- Monitor chest x-ray frequently to assess patient for over distension or gross air leak.

- Monitor for any signs of PPHN (Persistent Pulmonary Hypertension of the Newborn)
Congenital Diaphragmatic Hernia

- mPAW – Set equal to or 1-2 cmH\textsubscript{2}O greater than CMV mPAW
  - mPAW is dependent on the inflation of the lung on the non-herniated side.
- Frequency – Set to 10 Hz
- Power – Start at 2.5 and then adjust for adequate CWF
- CXR rib inflation criteria DOES NOT apply to CDH.
- As few as 6 ribs may be visible.
Pulmonary Hypoplasia (Hydrops)

- mPAW – Set equal to the CMV Paw
  Increase Paw until acceptable saturations
- Frequency – 10-15
- Power – Start 2.0 and then adjust for minimal CWF

- Inadequate lung tissue & decreased surface area available for gas exchange.
- Prior to the application of HFOV you should assess:
  - CXR for the degree of lung inflation
  - Determine if PPHN exists
  - Cardiac Status
A good indicator that the patient is ready to be extubated is when the underlying need for HFOV has resolved and the patient is stable and tolerating suctioning and procedures well.

<table>
<thead>
<tr>
<th></th>
<th>2 kg</th>
<th>1–2 kg</th>
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<tr>
<td>mPaw</td>
<td>11–13.5 cmH₂O</td>
<td>9–11 cmH₂O</td>
<td>6–10 cmH₂O</td>
</tr>
<tr>
<td>Frequency</td>
<td>6–10 Hz</td>
<td>6–10 Hz</td>
<td>7–12 Hz</td>
</tr>
<tr>
<td>Amplitude</td>
<td>15–22 cmH₂O</td>
<td>12–20 cmH₂O</td>
<td>10–16 cmH₂O</td>
</tr>
</tbody>
</table>

- Patients may be weaned off to CPAP, NIPPV or HFNC per hospital protocol.
- In general, consider CPAP or NIPPV for patients in the higher mPaw range.
CareFusion 3100A HFOV
Research
HFOV: Clinical Trials in Neonates

• First Multicenter trial conducted in 1989
  ◦ Study terminated due to concerns of increased intraventricular hemorrhage (study criticized for lung strategy methods)

• At least 2 subsequent trials (by Clark in 1992, and Gerstmann in 1996) demonstrated increased survival without chronic lung disease
  ◦ No difference in incidence of intraventricular hemorrhage
  ◦ Improved outcomes were attributed to better lung recruitment strategy. (Low vs. optimal lung volume)

HFOV: Clinical Trials in Neonates

• Early use of HFOV results in fewer days of mechanical ventilation.\(^1,2,3\)
• Neonates treated with HFOV early spent less time on oxygen.\(^1\)
• Neonates treated with HFOV early had fewer incidences of necrotizing enterocolitis.\(^1\)
• Early use of HFOV resulted fewer abnormal brainstem audio-evoked responses.\(^1\)
• Neonates treated with HFOV had lower hospital costs.\(^1,3\)
• Infants placed on HFOV earlier had less chronic lung disease.\(^1,3\)
• Infants placed on HFOV needed fewer doses of surfactant.\(^2\)
• Infants placed on HFOV required fewer days in the ICU and were discharged home sooner than infants on conventional ventilation.\(^2\)

High-Frequency Oscillatory Ventilation versus Conventional Mechanical Ventilation for Very-Low-Birth-Weight Infants

- 500 Infants enrolled, 601 to 1200 grams, less than 4 hours old.
- Randomized to CMV or HFOV, management according to protocols
- Infants assigned to HFOV extubated earlier
- Less need for supplemental O$_2$ @ 38 weeks estimated gestational age
- No increased incidence of adverse effects

Lung Recruitment Using Oxygenation during Open Lung High-Frequency Ventilation in Preterm Infants

• 103 preterm infants
• Ninety-nine infants (96%) received a first dose of exogenous surfactant

Results:
• The mean presurfactant continuous distending pressure – 20.5 +/-4.3 cmH$_2$O
• The mean postsurfactant continuous distending pressure – 14.0 +/-4.0 cmH$_2$O
• Surfactant treatment did enable a reduction in the pressure amplitude 24.4 +/- 0.6 vs. 22.2 +/- 0.6 cmH$_2$O
• Fraction of inspired oxygen of 0.24 +/- 0.04%
• Median days of HFOV was 2 (2-4) days

High-Frequency Oscillatory Ventilation with Low Oscillatory Frequency in Pulmonary Interstitial Emphysema

Pilot study using HFOV with PIE.
19 cases of PIE
• 14 Bilateral
• 5 Unilateral
• 15 infants survived, including 10 of the bilateral cases (71%), and all of the unilateral cases

Strategy of using lower frequency to treat PIE with air trapping:
1. Recruit the lung with a sufficient mPAW
2. Decrease %IT to 30%
3. Decrease frequency to 5-6
4. Place the affected side down for “compressive atelectasis”

High-Frequency Oscillatory Ventilation with Low Oscillatory Frequency in Pulmonary Interstitial Emphysema

1. Pre-transition, on continuous positive airway pressure, 7 cmH$_2$O, FiO$_2$ 0.6. Cystic PIE on right side, with compressive atelectasis of left lung.
2. Day 2 post-transition, infant in lateral position with left lung uppermost, frequency 5 Hz, mean airway pressure (PAW) 11 cmH$_2$O, FiO$_2$ 0.21.
3. Day 4 post-transition, PAW 7 cmH$_2$O, FiO$_2$ 0.4. Cystic change on right side now resolving.
4. Day 4 post-transition, PAW 7 cmH$_2$O, FiO$_2$ 0.3. Complete atelectasis of right lung. Infant now returned to neutral position.
5. Day 6, frequency now restored to 12 Hz, PAW 7 cmH$_2$O, FiO$_2$ 0.21. Right lung re-expanded without return of significant cystic disease.

High-Frequency Oscillatory Ventilation with Low Oscillatory Frequency in Pulmonary Interstitial Emphysema

In each case, the pre-transition X-ray is shown at top, and the X-ray at day 4-5 post-transition is shown at bottom.
Randomized, multicenter trial of iNO and HFOV in PPHN

- 205 neonates in a randomized, multi-center trial
- Patients were either RDS, MAS, idiopathic PPHN, pulmonary hypoplasia without congenital diaphragmatic hernia & congenital diaphragmatic hernia
- Study population: > 34 weeks gestational age, PaO$_2$ < 80 mm Hg on FiO$_2$ 1.0, echo evidence of PPHN
- Patients were randomized to iNO (20 ppm) with conventional ventilation or HFOV
- Conclusion: Patients treated with HFOV & iNO was more successful than HFOV or iNO alone in severe PPHN

Late outcomes

• 319 adolescents born before 29 weeks and oscillated
• Compared: lung function and respiratory health, health-related quality of life, and functional status
• Completed at 11 and 14 years of age

• Results: Significant differences in favor of HFOV in several other measures of respiratory function, including forced expiratory volume in 1 second, forced vital capacity, peak expiratory flow, diffusing capacity, and impulse-oscillometric findings

• Conclusion: “In a randomized trial involving children who had been born extremely prematurely, those who had undergone HFOV, as compared with those who had received conventional ventilation, had superior lung function at 11 to 14 years of age, with no evidence of poorer functional outcomes.”
3100A High Frequency Oscillatory Ventilator

Troubleshooting
Troubleshooting the 3100A High Frequency Oscillatory Ventilator should always be performed OFF PATIENT
**Alarm**

High Paw (mPAW) >50 cmH₂O

- Check the following:
  - Obstruction of the circuit expiratory limb
  - Obstruction of the pressure sense line
  - A patient breathing spontaneously at a high mPAW
  - Check bias flow: Adjust as needed
Alarm
High mPAW

• Check the following:
  ◦ Spontaneously breathing patients may activate this alarm: check and assure bias flow is adequate
  ◦ Improper setting of thumbwheel-follow institutional guidelines
  ◦ Expiratory limb obstruction: check circuit
  ◦ Pressure sensing line obstruction: check circuit
  ◦ Patient circuit temperature rise: check humidifier
Alarm
Low mPAW

• Check the following:
  ◦ Increased spontaneous breathing: check bias flow and mPAW
  ◦ Improper setting of thumbwheel: Adjust as needed
  ◦ Improper setting of mean airway pressure or flowmeter
  ◦ Patient circuit temperature drop
  ◦ Leak in circuit or humidifier
  ◦ Diaphragm cap leak: Replace as needed
Alarm
<20% of Set Max

• Check the following:
  ◦ Improper thumbwheel setting: Readjust
  ◦ Improper setting of mPAW and/or bias flow: Adjust settings accordingly
  ◦ Improper setting of mean pressure limit: Adjust as needed
  ◦ Leak in patient circuit or humidifier (be sure circuit is connected to the patient)
  ◦ Cap Diaphragm leak: Replace cap
Alarm

Oscillator Stopped

• Power setting too low
  ◦ Amplitude too low (less than 7)
  ◦ Gradually increase power setting for desired Amplitude

• Oscillator not centered
  ◦ Readjust piston centering
  ◦ Oscillator failure
    • Remove from use
    • Call Carefusion technical support
LED
Low Source Gas

• Input pressure is less than 30 psi, either from blended gas or cooling air – check both gas supplies
• Be sure there are no restrictions in the gas systems (high pressure hoses, valves, gas inlets)
• Check input filter
LED
Battery Low

• 9 volt battery to power only alarms

• “Battery Low” LED on:
  ◦ Replace Battery

• It is normal for this light to be on when pressing the “Reset Power Fail” button
LED
Oscillator Overheated

• No cooling gas flow
  ◦ Check all gas connections
  ◦ Check inlet filter for obstruction of cooling gas flow (off patient)

• Mis-centered piston at high extremely high Amplitude settings
  ◦ Center piston

• Mechanical Failure
  ◦ Remove from use
  ◦ Call Carefusion technical support
Pre-use Checks
Failure to pass Patient Circuit Calibration

• Leak in circuit or humidifier
  ◦ Common leak sites are water trap stopcocks, temperature probe insertion sites and humidifier chambers and connections
  ◦ Leak in patient circuit or humidifier - fix leak or replace the circuit/humidifier chamber (consider MR290HFV chamber)
  ◦ Improper flow setting
    • Be sure that during circuit calibration, the flowmeter ball is set at 20 L/min in the middle of the ball.
    • Internal leak
      – Call Carefusion technical support
Pre-use Checks
Failure to pass Ventilator Performance Check

• Stripped Power knob
  ◦ Make sure Power knob only adjust between 0.0-10.0

• Incorrect flow meter setting
  ◦ Check flow meter and be sure flow meter ball is set at 20 L/min in the middle of the ball

• Incorrect altitude range being used
  ◦ Verify altitude and retest

• Oscillator not centered properly
  ◦ Re-center oscillator
3100A High Frequency Oscillatory Ventilator (HFOV)

Frequently asked Questions
Can we use close-suction or swivel adaptors?

• Yes. It is best to confirm that you can adequately ventilate with those adaptors in place before inserting them in the circuit.

• Also, those adaptors add extra resistance to the circuit and may not allow the alarms to detect a disconnect. It is recommended that you have other monitors in place to detect a disconnect (pulse oximeter etc.).
Where is iNOmax™ DS placed into the 3100 circuit?

1. Sensormedics 3100A/B Ventilator
2. Ventilator Outlet
3. Injector Module
4. iNOmax® DS
5. NO/N₂ Injector Tube Connection
6. Injector Module Electrical Cable Connection
7. One-Way Valve
8. Humidifier Inlet
9. Humidifier Outlet
10. Patient Gas Sample Line Connection
11. Bias Flow Tube
Where is PrinterNOx placed into the 3100 circuit?
Why are mean airway pressures higher on HFOV?

- Mean airway pressure seem to be higher on HFOV because unlike conventional and jet ventilation, there are no conventional (tidal) breaths to recruit the lung. Optimal gas exchange occurs when the lung is at FRC. Depending on the severity of lung disease, the pressures required to recruit the lung to FRC may seem high.

- "Based on the relationships between MAP, compliance, functional residual capacity, and indexes of ventilation/perfusion matching, we conclude that increasing MAP to achieve normal FRC... is a simple method of optimizing lung volume in surfactant depleted subjects [during HFOV]."

- *Specific compliance and gas exchange during high-frequency oscillatory Ventilation. Brian Wood, MD; Padmani Karna, MD; Alicia Adams, RRT. Crit Care Med 2002; 30:1523-1527.*
I heard that the amplitude must never be greater than three times the mean airway pressure. Is that true?

• There is, and to my knowledge never was, any scientific evidence to support this claim. As far as we can determine, this was used in early training sessions as a signal to the clinician.

• However, if a relatively high amplitude (>MAP x 3) is required to maintain normocarbia, perhaps lung volume should be reassessed. In our experience, the above clinical scenario often represents under inflation, and a chest x-ray may be warranted. Underinflated lung units will require higher amplitudes to achieve adequate ventilation. If the lung volume was normalized (FRC), one would often find that lower power setting (less amplitude) would be required to achieve the same degree of ventilation.

• The converse can also present the same clinical scenario. If the lung were over inflated, higher amplitudes may be required to achieve adequate ventilation. Once again, a chest X-ray would be your best assessment tool for lung volume determination.
The vent shuts off when I turn the MAP to less than 10. Why?

• The upper alarm is set at 45 or above. The vent is designed so that if the MAP falls to 20% of what the upper alarm is set at then the unit will shut off. Adjust alarms down to at least 3 above what MAP is set at and this problem will not occur.
The vent will not start, but pressurizes, usually MAP is low, less than 12. Why?

• Usually the upper alarm is set too high for unit to start. Just as with above situation, the vent requires that a MAP of 20% of what upper alarm is set at to start unit, if MAP is low and upper alarm is set high, then not enough of a MAP is generated to start the vent. Adjust upper alarm down to at least 3 above what you have MAP set at.
Is it okay that I leave the bias flow at 20 L/min?

- After pt circuit calibration and performance check is complete we do recommend adjusting flow rate based on what type of pt is on vent. For premature infants we recommend flow rate of 10-15 L/min, for near-term 10-20 L/min, small child 15-25 L/min, and for a large child 20-30 L/min. For adults usually flow rates of 20-40 L/min should be used. All recommendations are in both the 3100A and 3100B Operator's Manuals.
On the 3100B, after making a change in vent settings, that is not the MAP, the auto-limit is triggered?

• With any change on the 3100B, the stroke volume changes and in turn changes the MAP. We recommend that with any change in vent settings to watch the MAP and adjust that if necessary.
The Amplitude is low on the Performance Check. What should I do?

- Bypass Humidifier, check power knob (0.0 to 10.0), DDI adjustment (in Operator's manual), replace Bellows/Water trap, take vent to a Factory Trained Biomed.
On the 3100B, after making a change in vent settings, that is not the mPAW, the auto-limit is triggered?

• This is normal.
If the Battery Low light is illuminated, do I have to turn off the vent to replace the battery? Will the vent stop?

• No, the battery doesn't "drive" the vent.
• The battery can be replaced while in use on a patient.
What is the upper weight limit on the 3100A?

• There really isn't any "upper weight limit" on the 3100A. However, at maximum settings, the driver will get hot and an overheat condition is a possibility. The Driver Displacement Indicator light may start to drift, but do not try to "center the piston." Chasing the indictor light may only make the piston even more off-centered and increase the risk of overheating. As long as the settings are stable, do not adjust the piston centering knob. Keep the back side of the driver clear from any drapes or other items. A fan can be directed to the back of the driver to help cool the driver also. The newer 3100A ventilators are manufactured with a 3 Ohm driver which runs "cooler" and quieter... allowing higher settings to be used for longer periods of time.

• If a patient is greater than 35kg, the 3100B is available for use.
Why is my amplitude always fluctuating?

- Amplitude increased: Airway resistance increased and/or total lung compliance decreased
- Amplitude decreased: Airway resistance decreased and/or total lung compliance increased

**Note:** Changes in amplitude are normal as the patient’s pulmonary status changes; assess the patient for chest wiggle, piston sounds, patient position etc. and take appropriate action
Thank you