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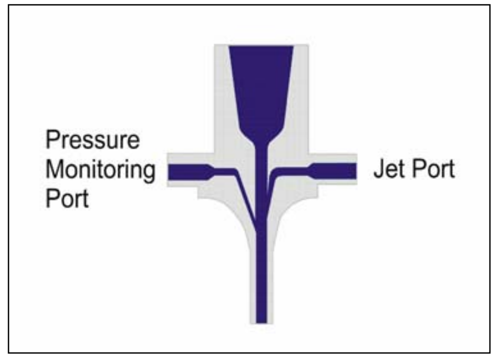
WHAT is the LifePulse
High Frequency Ventilator

Description:

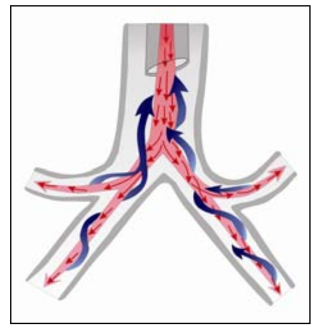
The LifePulse is pressure-limited and time cycled with adjustable PIP and rate. Inspiratory time (I-time) is kept as short as possible (0.02 sec.). Exhalation is passive.



The LifePulse delivers small tidal volumes (V_T) at rapid rates via a special ET tube adapter with built-in jet nozzle. Connecting this adapter to a patient's endotracheal or tracheotomy tube enables tandem use of CMV.

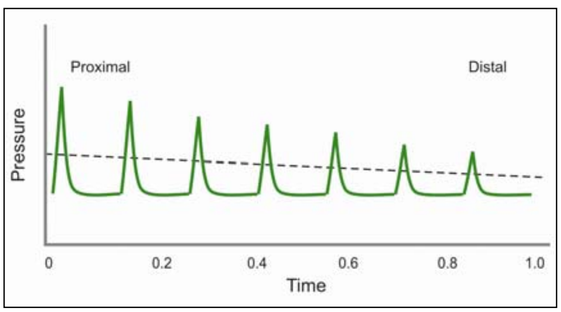
Gas flow is feedback-controlled by matching monitored PIP with set PIP. Monitored servo-controlled driving pressure (Servo Pressure) is used to detect changes in lung compliance and resistance and mishaps such as accidental extubation, pneumothorax, bronchospasm, etc.

Ventilation Controls:



Pressure amplitude (PIP-PEEP) produces V_T and controls $PaCO_2$. $V_T \approx 1$ mL/kg body mass is about half the size of anatomic dead space. The LifePulse high velocity inspirations penetrate through the dead space instead of pushing the resident deadspace gas ahead of fresh gas as we do when we breathe normally. Exhaled gas cycles out in a counter-current helical flow pattern around the gas jetting in, which facilitates mucociliary clearance in the airways.

PIP may be set as high as that used during CMV. However, because inspirations are so fast and brief, PIP falls quickly as HFV breaths penetrate down the airways, and peak alveolar pressure is much lower than peak airway pressure.



The LifePulse uses passive exhalation. Thus, airway pressure at end-exhalation, PEEP, is constant throughout the lungs, as long as rate is set slow enough to avoid gas trapping.

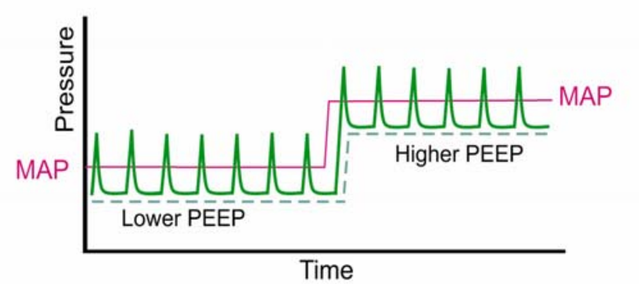
Rate is usually set 10 times faster than CMV rates, in proportion to patient size and lung time constants (lung compliance x airway resistance). Keeping I-time constant at its shortest value (0.02 sec.) allows exhalation time (E-time) to be proportionally longer at lower LifePulse rates, which aids in the treatment of larger patients and infants with restricted or obstructed airways.

At 240 bpm (4 Hz) for example, I:E = 1:12. Smaller patients may be treated at rates up to 660 bpm (11 Hz) where I:E = 1:3.5. Lowering rate may require raising PIP to maintain $PaCO_2$, because LifePulse V_T is independent of rate. But, LifePulse V_Ts are still ~10 times smaller than CMV V_Ts because of the 0.02 sec. I-time.

Oxygenation Controls:

CMV settings control oxygenation. CMV at 2-5 bpm facilitates alveolar recruitment with its larger V_Ts. PEEP is the primary determinant of mean airway pressure (MAP) and lung volume.

Optimal PEEP may be found using CMV breaths and pulse oximetry. MAP on CMV prior to starting the LifePulse is reproduced at start-up by raising PEEP 1-2 cm H_2O initially. Patients are then stabilized with CMV = 5 bpm and F_IO_2 adjusted to produce appropriate SaO_2. CMV is then switched to CPAP mode, and PEEP is increased until SaO_2 is restabilized. Thus, CMV breaths are only used intermittently.



PEEP is the primary control for MAP and oxygenation

This approach produces an HFV version of "lung protective ventilation", where alveoli are opened, kept open with appropriate PEEP (usually in the range of 8 - 10 cm H_2O), and ventilated as gently as possible. Gas for the patient's spontaneous breathing is provided by the CMV in CPAP mode.

Gas Trapping Considerations:

Gas trapping occurs when tidal volumes have insufficient time to exit the lungs. Thus, larger CMV tidal volumes represent a greater threat of gas trapping compared to much smaller HFV breaths. CMV rate should therefore be reduced before HFV rate whenever there are indications of gas trapping, such as hyperinflation on chest xray or when the LifePulse monitored PEEP exceeds CMV set PEEP. If hyperinflation persists once the CMV is in CPAP mode, decrease the LifePulse rate in 60 bpm increments to improve the I:E ratio and lengthen the exhalation time.

Tidal volumes necessary to produce adequate ventilation at high rates are very small, and lung compliance is often poor in very low birth weight infants, so gas trapping is unlikely to occur with the LifePulse. However, the maximum rate of 660 bpm is rarely used even in preemies weighing less than 1000 grams. Most LifePulse users limit rate to 540 bpm (9 Hz) where I:E = 1:4.5. The minimum I-time of 0.02 sec. usually works best for all patients at all rates.

Applications:

While some clinicians use the LifePulse for premature infants with uncomplicated RDS, it is most often used to rescue infants and children with lung injury. PIE is the most common indication for the LifePulse, because it automatically improves ventilation/perfusion matching and facilitates healing by reducing mechanical ventilation of the most affected areas of the injured lungs.

PIE is characterized by inflamed airways with high airway resistance that creates gas trapping, pulmonary overdistension, and alveolar disruption when other forms of mechanical ventilation are used. Since high airway resistance deters high velocity inspirations, resolution of PIE is much more likely using the LifePulse.

Other airleaks, meconium aspiration and other pneumonias (especially those accompanied by excessive secretions), congenital diaphragmatic hernia, and PPHN are other common applications of the LifePulse in NICUs, while trauma and severe pneumonia are typical applications in PICUs. Some institutions also use the LifePulse during and after pediatric cardiac surgery (e.g., Fontan procedure), especially when complicated by respiratory failure.

A pilot study using the LifePulse was recently initiated for "evolving" chronic lung disease in prematurely born infants at 1 to 3 weeks of age. Strategy for these patients is low LifePulse rate (240 bpm), no CMV breaths, and moderate PEEP (~8 cm H_2O). [Note: PEEP is needed to keep airways as well as alveoli open. Reducing PEEP to lessen gas trapping may make matters worse by allowing small airways to collapse during exhalation.] Previous randomized controlled trials support use of the LifePulse for uncomplicated RDS, RDS complicated by PIE, and PPHN.

Complications:

Hyperventilation with the LifePulse is associated with increased incidence of cystic periventricular leukomalacia in premature infants with RDS. A single center study revealed such increased adverse effects when the LifePulse was used with low PEEP (5 cm H_2O) where hyperventilation and inadequate oxygenation occurred during the first 24 hours of life. (Inadequate PEEP leads to using higher PIP to generate more MAP, which causes hyperventilation.)

Servo Pressure:

Servo Pressure auto-regulates gas *flow* to the patient to keep monitored PIP = set PIP. The following examples are typical of what automatically set upper and lower Servo Pressure alarms indicate.

<u>Servo Pressure Increases with:</u>

- Improving lung compliance or airway resistance, which can lead to hyperventilation
- Leaks in ventilator circuit leading up to the patient

<u>Servo Pressure Decreases with:</u>

- Worsening lung compliance or airway resistance (e.g., bronchospasm), which can lead to hypoxemia
- Obstructed ET tube (e.g., from a mucus plug)
- Accumulating secretions at the end of the ET tube (i.e., patient needs suctioning)
- Tension pneumothorax
- Right mainstem intubation

Monitoring Servo Pressure helps you determine if the patient is getting better or worse after you administer surfactant, make a change in ventilator management strategy or reposition the patient.

For more information, visit www.bunl.com or call us at 800-800-4358.

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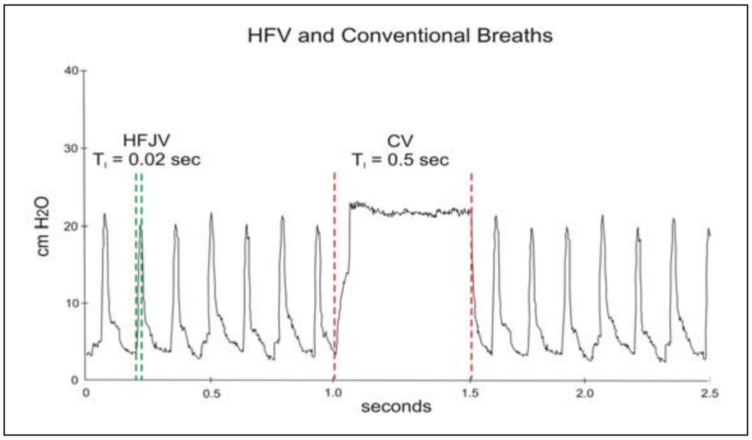
WHY the LifePulse HFV Works

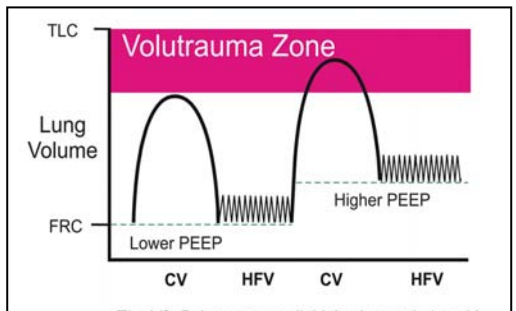
Having a clear understanding of how the LifePulse works is essential to maximize its benefits. The keys to understanding the LifePulse are an appreciation of inspiratory time (I-time), the jet nozzle, and passive exhalation.

Inspiratory Time:



The 0.02 sec. I-time used with the LifePulse is 25 times shorter than a 0.5 sec I-time used during conventional ventilation. As a result, tidal volumes delivered with the LifePulse are approximately 10 times smaller than those delivered during CMV. These very small tidal volumes allow higher levels of PEEP to be used safely, keeping the lungs open with sufficient mean airway pressure (MAP) to oxygenate.

Short I-times provide two of the most important benefits of HFV: small tidal volumes and low alveolar pressures. Small tidal volumes, when delivered with short I-times, make it impossible for the peak pressure used during HFV to be transmitted to alveoli.

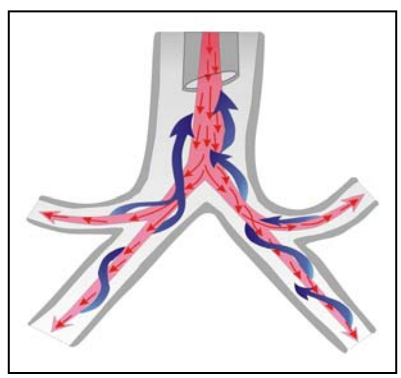


The Life Pulse uses small tidal volumes that avoid the "Volutrauma Zone" at almost any level of PEEP.

The LifePulse has a set I-time, unlike HFOV where the I-time is set as a percentage of the respiratory cycle. Therefore, as the LifePulse rate is adjusted, the only thing that changes is exhalation time (E-time). The LifePulse I:E ratio varies from 1:3.5 at 660 bpm to 1:12 at 240 bpm. Giving patients more E-time is critical for patients with hyperinflation or excessive secretions. Trapped gas and secretions have a much better chance of moving up and out of the lungs with longer E-times achieved by lower rates.

Jet Nozzle:

A second key to understanding the LifePulse is the jet nozzle built into the LifePort ET tube adapter. Squirting gas into the ET tube at high velocity allows gas to penetrate deeper into the lungs with each breath, penetrating through dead space gas instead of pushing it ahead of the fresh gas. Delivering fresh gas in this way minimizes the size of each breath and the pressure needed to deliver it to the alveoli.



With fresh gas shooting down the center of the airways, slower moving passively exhaled gas moves out along the airway walls. This countercurrent pattern facilitates airway clearance as shown in the illustration.

Passive Exhalation:

The final key to understanding LifePulse effectiveness is passive exhalation. In addition to enhancing airway clearance, passive exhalation allows the LifePulse to run at a lower MAP compared to those used during high-frequency oscillatory ventilation, which uses active exhalation.

MAP must be kept at a high enough level during HFOV to keep the negative pressure, generated during active exhalation, from causing airways collapse. This is never an issue with passive exhalation. Therefore, the LifePulse can usually provide adequate oxygenation at a lower MAP compared to HFOV.

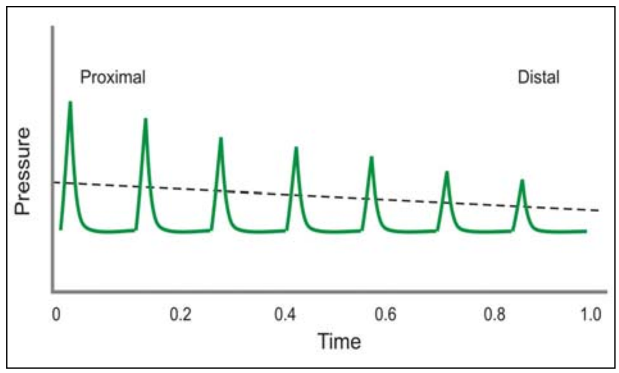
Patient Management Implications:

It is essential to stay focused on the primary control variables: MAP for oxygenation and pressure amplitude (PIP-PEEP) for ventilation. Once appropriate PEEP is set, the LifePulse PIP controls pressure amplitude and ventilation.

The MAP required for adequate oxygenation determines PEEP. There should be no pre-conceived maximum level of PEEP based on patient size. Likewise, the pressure amplitude required for adequate ventilation determines the LifePulse PIP, and there should be no pre-conceived maximum PIP based on patient size.

PEEP controls mean airway pressure with the LifePulse, and MAP determines mean lung volume. Optimal PEEP/MAP facilitates oxygenation without the use of continual CMV breaths. This strategy relegates CMV breaths to intermittent use for alveolar recruitment.

CMV breaths should be delivered using the minimum PIP necessary to provide an effective "sigh" (watch chest wall movement). In most cases this PIP will be lower than the LifePulse PIP, which will not interrupt the delivery of HFV breaths. (The LifePulse is most effective when it is uninterrupted.) When used, sigh breaths rates should be 2-5 bpm with I-times appropriate for the lung pathophysiology.



If LifePulse rate is set low enough to avoid gas trapping and inadvertent PEEP, PEEP will be constant all the way out to the alveoli. However, HFV PIP drops dramatically as the tiny tidal volumes approach the alveoli. So, there is little chance that HFV breaths will over-expand alveoli.

The best approach for an infant with hyperinflated lungs is to eliminate delivery of all the bigger CMV tidal volumes and extend the time for exhalation of the smaller HFV tidal volumes by lowering LifePulse rate. If problems are encountered using higher PEEP on hemodynamically challenged patients, go back to using the LifePulse with lower PEEP and intermittent CMV sigh breaths to keep the lungs open and improve cardiac function.

A solid understanding of how the LifePulse works will help you discover the keys to superior patient management. Remember:

- The very short I-time results in tidal volumes that are ~10 times smaller than those used during conventional ventilation, so higher PEEP levels can be used safely.
- I-time is set rather than being a percentage, so tidal volume does not change with changes in frequency.
- Adjusting LifePulse rate with its fixed I-time lets you control E-time and I:E ratio to address hyperinflation.
- Finally, longer E-times and passive exhalation enhance clearance of airway secretions.

Keeping these concepts in mind as you use the LifePulse will guide you to patient management strategies that deliver the most effective and gentle ventilation possible.

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HOW to use the LifePulse HFV
Seven Steps to Success

LifePulse HFV clinical strategies have evolved from the accumulated experience of treating tens of thousands of infants as well as from randomized controlled studies. The following seven steps are a culmination of what Bunnell has learned over the past two decades of clinical use.

1. **Start HFV ASAP**
   Many clinicians wait until an infant sustains significant lung injury before implementing HFV. Unfortunately, a failing respiratory system leads to failure of other organ systems, and once the patient reaches that point, chances for recovery are slim. The only significant difference between survivors and non-survivors in one LifePulse study was the time they spent on CMV prior to starting HFV (4 days vs. 10 days respectively). The sooner HFV is started, the better the patient's chance of recovery.

2. **Select Start-Up LifePulse Settings Based upon Patient Size and Pathophysiology**
   Monitor and record current CMV or HFOV settings using the LifePort ET tube adapter with the LifePulse in Standby mode.

   On-Time: The default On-Time (I-time) setting of 0.02 sec. works best in most situations, so leave it set there most of the time.

   Rate: Using 420 bpm usually works fine, for patients 2000 grams or less. Larger preemies, term infants, and infants with pulmonary hyperinflation, severe PIE, and other lung conditions where exhalation is compromised by airway inflammation or obstruction do better on lower rates. With I-time set at 0.02 sec., lower rates create longer exhalation times.

   The lowest LifePulse rate (240 bpm), where I:E = 1:12, is the best choice for pulmonary hyperinflation and severe PIE. Longer exhalation times facilitate diffusion of gas out of interstitial space, and allow hyperinflation to resolve. Minimizing the number and size of CMV breaths is critical in these patients.

   PIP: Start the LifePulse with PIP set 1-2 cm H_2O < the CMV or HFOV PIP monitored by the LifePulse. Press ENTER, verify the chest is vibrating, and adjust PIP as necessary to get appropriate $PaCO_2$.

3. **Maintain Pre-LifePulse MAP for Better Oxygenation at Start-Up**
   Focusing on MAP instead of PEEP reminds us what's most important for oxygenation. In general, you will use higher PEEP with the LifePulse to support MAP, which is safe because the LifePulse uses small tidal volumes and a very short I-time (0.02 sec.).

   Once you have started the LifePulse, reduce CMV support to 5 bpm and increase PEEP as needed to match the monitored pre-LifePulse MAP. [If you are switching from HFOV to HFJV, you can sometimes use less MAP (-1 to -2 cm H_2O).] We will optimize PEEP in step 5.

4. **Fine-tune PIP to Manage $PaCO_2$**
   Use transcutaneous CO_2 monitoring and get a blood gas sample within 20 minutes of starting the LifePulse to see if PIP is adequate. Sometimes clinicians are surprised to see how much PIP it takes to ventilate premature infants. Remember: it is volume – not pressure – that creates lung injury, and the LifePulse uses extremely small tidal volumes (~ 1 mL/kg). HFV pressure amplitude decreases quickly as the tiny breaths approach the alveoli. So, raising PIP is the gentlest way to lower $PaCO_2$. A LifePulse V_T delivered with a PIP of 50 cm H_2O is still much smaller than a CMV V_T delivered with a PIP of 20 cm H_2O, due to the difference in I-times.

5. **Use CMV "Sigh" Breaths to Find Optimal PEEP**
   Sigh breaths are ***contraindicated*** in the presence of severe lung injury, and we can use the removal of the last 5 CMV bpm from step 3 to find optimal PEEP.

   Adjust F_IO_2 to achieve the desired SaO_2 with the patient stabilized on the LifePulse with CMV at 5 bpm. Then switch CMV to CPAP mode and watch the pulse oximeter. If SaO_2 drops, increase PEEP 1-2 cm H_2O, re-institute the 5 bpm, and repeat the sequence. Once SaO_2 is stable with your CMV in CPAP mode, leave it in CPAP mode most of the time. However, some patients like a sigh breath rate of 2-5 bpm.

Switch CMV back to 5 bpm as needed to re-recruit collapsed alveoli after suctioning, repositioning, etc., and whenever you want to test for adequate PEEP as just described. Moving CMV back to CPAP mode once oxygenation improves (after 15 minutes or so) will minimize the size and number of larger V_T s delivered to the patient and help avoid "volutrauma."

If cardiac output suffers with higher PEEP, back off a little. Here you can use a few CMV sigh breaths per minute to compensate for inadequate MAP in the hope of improving venous return of blood to the heart. [Remember: it is O_2 delivery to the tissues that determines optimal PEEP.]

Some of the newest generation ventilators make it difficult to keep the CMV in CPAP mode with the LifePulse due to their apnea detection systems. With these ventilators, use the lowest IMV settings possible by minimizing rate, PIP, and I-time. Then turn up each setting as necessary when you want to provide effective sigh breaths.

6. **Be patient and use Servo Pressure, pulse oximetry, and transcutaneous CO_2 monitoring to stay on track**
Recognize that weaning will only be possible when the patient's medical condition is improving. There is a time for initial stabilization of the patient, and a time for weaning. In between those times, focus on maintaining good blood gases and let HFV "lung protective ventilation" facilitate healing and lung growth.

Servo Pressure responds to changes in the patient's lung mechanics. Rising Servo Pressure is generally a good sign. Falling Servo Pressure may indicate deterioration and should be addressed quickly. Any time you get a Servo Pressure alarm you should investigate. Is the ET tube poorly positioned or plugged? Is the patient's compliance getting worse? Or, is it just time to suction the airway?

If monitored PEEP on the LifePulse is higher than set PEEP on the CMV, you have inadvertent PEEP, which will force Servo Pressure down and allow $PaCO_2$ to rise. Turn the LifePulse rate down in increments of ~60 bpm until the inadvertent PEEP goes away. Then manage $PaCO_2$ by adjusting HFV PIP as needed.

If hyperinflation is not present, you can increase LifePulse rate to lower $PaCO_2$ as you would with CMV. V_T is independent of rate with the LifePulse, so increasing rate increases minute ventilation and lowers $PaCO_2$.

Fight PEEPaphobia! PEEP is the primary determinant of mean airway pressure and oxygenation (PaO_2). It also helps splint airways open in older babies who get hyperinflated, which should decrease expiratory resistance and hyperinflation.

When in doubt or whenever you need assistance with patient management strategies and troubleshooting, call the Bunnell Hotline (800-800-4358) for help. We are there for you 24 hours a day, 7 days a week.

7. **Wean Directly to Nasal CPAP**
Once the patient has cleared his maintenance phase, weaning can begin. Our natural instinct is to wean patients from HFV back to CMV at the first signs of improvement. At best, this approach may prolong your patient's time on mechanical ventilation. At worse, whatever condition caused you to go the HFV in the first place may reappear. Focus on maintaining lung protective ventilation all the way to CPAP.

Wean PIP in response to improved $PaCO_2$. When PIP is below 20 cm H_2O, you can lower LifePulse rate to minimize interference with spontaneous breathing. At 240 bpm, I:E = 1:12; therefore, the patient is spending most of his time on CPAP already!

Once the LifePulse PIP ≤ 16 cm H_2O, MAP < 8 cm H_2O, F_IO_2 < 30%, and the baby is breathing regularly, you should consider transitioning to CPAP. A short trial of ET CPAP on the CMV will give you a good indication of how the patient will tolerate NCPAP.

Don't worry about weaning PEEP too much. When you pull the ET tube, match your NCPAP to the final LifePulse MAP. You can implement NCPAP at 8 cm H_2O if that is how much is needed, and your baby will breathe a lot easier without an ET tube.

Try these 7 steps to success on your next patient and let us know how they work for you. We are constantly seeking to improve our patient management strategies!