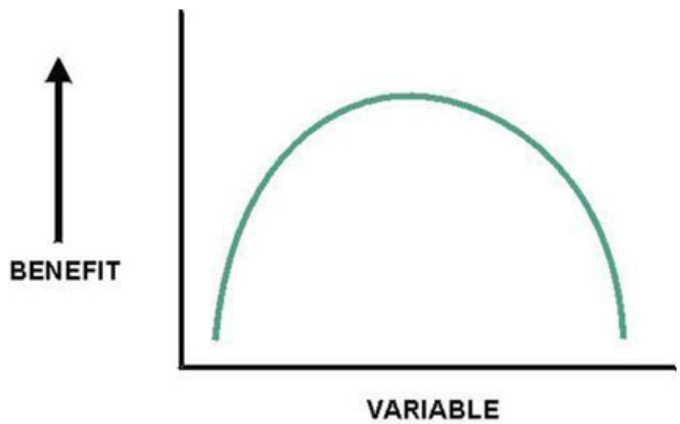
Fundamentals of Patient Management During HFJV

by Evan D. Richards, BS & Bert Bunnell, ScD

There are at least two golden rules of mechanical ventilation: Know Thy Ventilator and Know Thy Patient. These rules apply to the Life Pulse™ High-Frequency Jet Ventilator just as readily as they apply to conventional ventilators. A healthy understanding of fundamental mechanical and physiological principles will result in a healthier practical application of high-frequency jet ventilation (HFJV) on infants.The Life Pulse uses various physical processes, some complex and some simple, to achieve better blood gases using less pressure. It is important to return to a few fundamentals in order to understand how these processes affect patient management during jet ventilation.

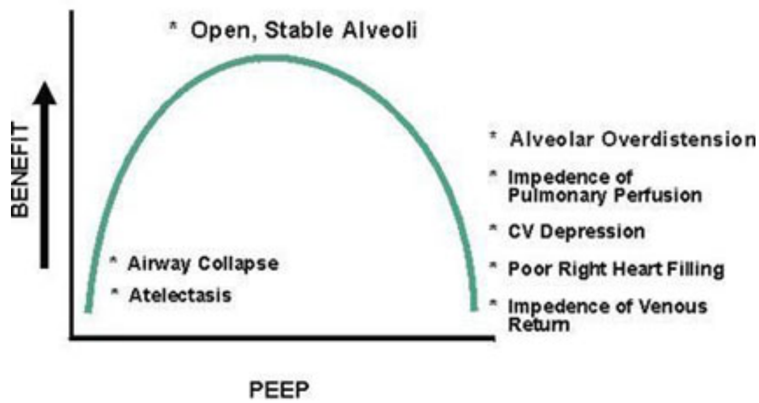
THE BENEFIT CURVE



Imagine something in your life that carries a benefit to you. Maybe work is your passion. You love what you do **so** much that you can't seem to work enough. You can control this benefit by asking for more work, picking up extra shifts, taking call, etc. Eventually, the rest of your life begins to suffer. The benefits of your work begin to diminish as you work more and more.

Somewhere in the middle of not enough and too much work is a perfect balance that gives you the maximum benefit.
Many things are this way: magazine subscriptions, pets, medication, children, some say even money. The key with all things that benefit, jet ventilation included, is moderation . . . not too little, not too much. And benefits come from variables you can control.

DETERMINING OPTIMAL PEEP

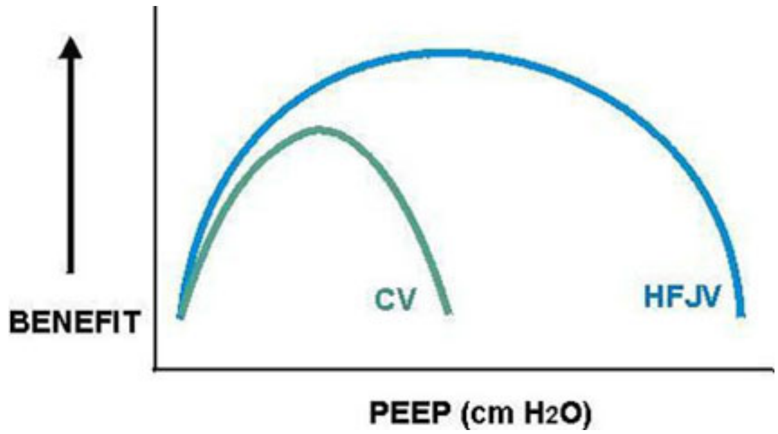


Positive End Expiratory Pressure (PEEP) is an operator-controlled variable during mechanical ventilation that can be beneficial or detrimental depending on how it is used. Too little PEEP may result in airway and alveolar collapse. Too much PEEP and MAP may cause alveolar overdistension and create numerous hemodynamic problems.1

An important ventilator strategy is to find and use *optimal PEEP*. Optimal PEEP is the PEEP level that will provide the best blood gases with the least detrimental impact on cardiopulmonary function.

An xray can reveal much about PEEP levels. You may be able to determine inadequate PEEP by the appearance of atelectasis or poor expansion. Excessive PEEP can manifest its iatrogenic consequences as overdistension on xray or decreased cardiac output. Determining optimal PEEP is crucial and will change from patient to patient, from pathophysiology to pathophysiology, and depending upon the stage and severity of the disease.

PEEP BENEFITS DURING CV AND HFJV

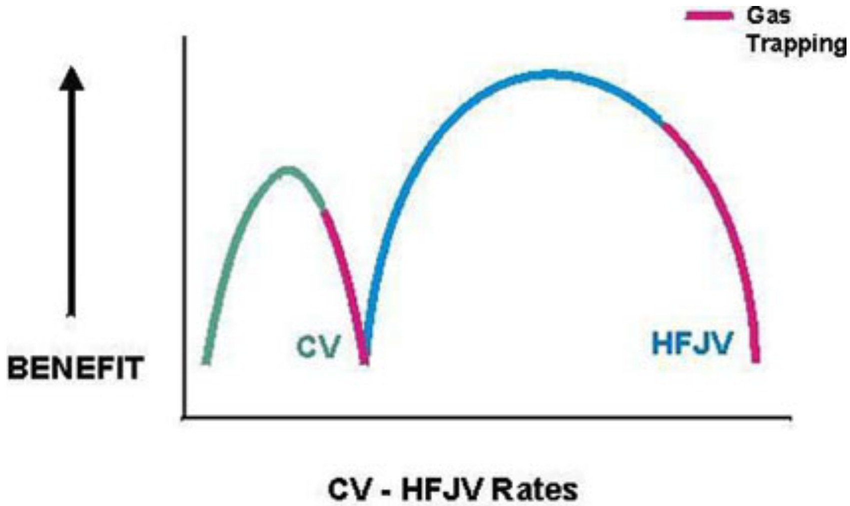


The range of optimal PEEP (and its benefits) may be higher during HFJV than conventional ventilation (CV).[2] The Life Pulse uses significantly less tidal volume and mean airway pressure (MAP) than other forms of mechanical ventilation.[3,4,5] Therefore, during HFJV, higher PEEP may be used without elevating MAP to levels that are potentially harmful.

Remember the two golden rules of ventilation when determining optimal PEEP during HFJV. **Know your ventilators.** Understand that the PEEP displayed on the Life Pulse is measured distally, inside the trachea, while the PEEP displayed on the conventional ventilator is a proximal value. A discrepancy between the two displays may be your first alert that the baby's pathophysiology is changing. For example, as lung compliance improves, the Life Pulse delivers larger tidal volumes to meet the set PIP. The greater the volume of gas going *into* the lungs, the longer it takes to get the gas *out of* the lungs. The displayed PEEP on the Life Pulse may begin to rise while the displayed CV PEEP remains unchanged. This discrepancy allows you to detect inadvertent PEEP and may be an early indication that the Life Pulse rate needs to be lowered to allow more expiratory time.

Know your patient. The PEEP and MAP should be higher if atelectasis is a primary concern and lower if air leaks or impaired hemodynamics [6] are primary concerns. Make logical decisions about a baby's appropriate PEEP levels. Be able to determine when the baby is getting too little or too much PEEP.

RATE BENEFITS DURING CV AND HFJV

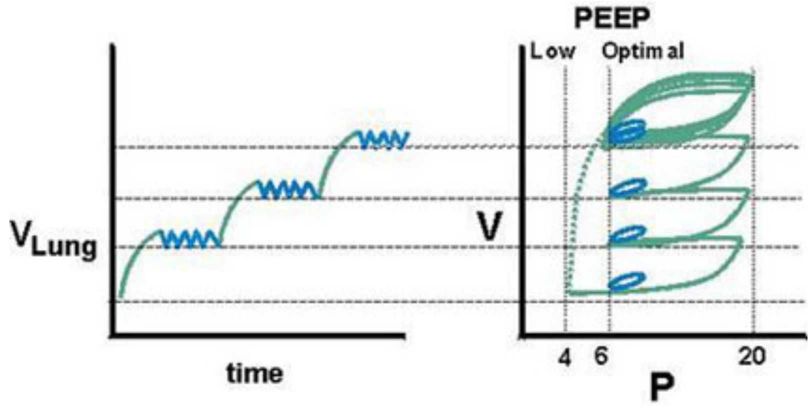


As with PEEP, the optimal rate of HFJV is important. Too low a rate may result in elevated $PaCO_2$. An excessive rate might cause gas trapping.[7] The Life Pulse should operate near the lungs' *natural* or *resonant frequency,* where minimum energy is required to affect gas movement into and out of the lungs.[8] As the name implies, it is the frequency at which the lungs most easily expand and contract and the amount of pressure required to ventilate the patient is minimized...naturally.

The natural frequency range is broad, and as long as the Life Pulse is operating within a baby's range of resonance, he will benefit from improved ventilation.

Again, the golden rules of ventilation apply. Know that resonant frequency is higher for smaller patients than it is for larger patients. Know that the Life Pulse is effective over its entire range of 240 to 660 bpm and most infants are well ventilated at an HFJV rate of 420 bpm. Know that small changes in the rate may have little impact on $PaCO_2$ due to the broad range of resonant frequency. And know that larger patients [9] and patients prone to gas trapping may benefit from lower HFJV rates (240-360 bpm).

RECRUITING AND MAINTAINING LUNG VOLUME



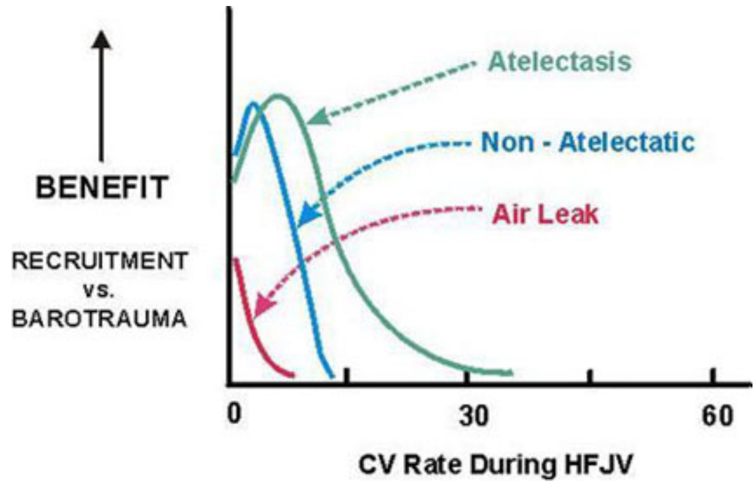
Dr. Allison Froese discussed ventilator strategy at the 1990 Snowbird Conference on High Frequency Ventilation of Infants.[10] Dr. Froese created an animal model of RDS by lavaging the lungs of adult rabbits. She attached the rabbits to the Life Pulse and a CV and placed them in a plethysmograph. She was then able to use a strip chart recorder to track changes in lung volume resulting from a particular ventilator strategy. Dr. Froese offered compelling evidence of the importance of recruiting and maintaining lung volume in non-compliant lungs.

If a Lung Volume/Time curve and a Pressure/Volume curve are compared side-by-side, the importance of the critical opening and closing pressures, and of recruiting and maintaining lung volume, can be demonstrated. What little increase in lung volume the Life Pulse produces upon inspiration is quickly lost during expiration. The Life Pulse tidal volume is small enough and the I-time short enough to achieve better blood gases with less pressure, but not big and long enough to effectively overcome atelectasis. Each bigger, longer CV breath is able to recruit a certain amount of lung volume and improve FRC. Over time, resting lung volume is "stair stepped" upward IF ADEQUATE PEEP IS PROVIDED!

If the PEEP is too low, or is reduced after lung volume has been recruited (e.g., by turning down PEEP, disconnecting the CV circuit, suctioning the patient, etc.), lung volume will be lost and the recruitment process must begin again from scratch.

Getting atelectatic alveoli open and keeping them open are two crucial requirements for effective patient management. And, by knowing your patient and knowing your ventilators, CV and HFJV may be used in tandem to recruit and maintain lung volume using the lowest possible pressures and tidal volumes.

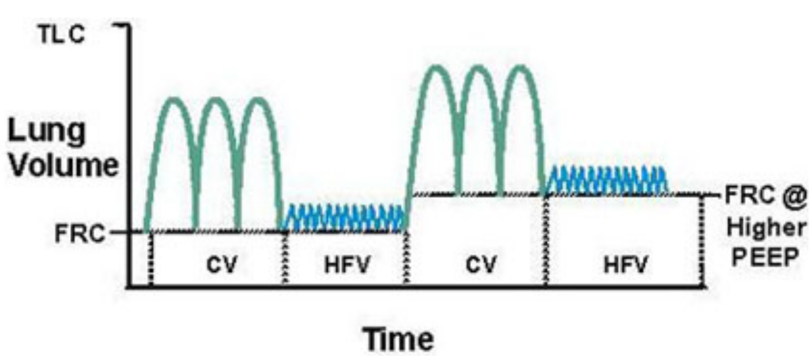
ALVEOLAR RECRUITMENT WITH BACKGROUND VENTILATION



The CV is used in tandem with the Life Pulse to deliver periodic background "sigh" breaths of longer inspiratory times and larger tidal volumes sufficient to open collapsed alveoli. Alveoli have a critical opening pressure above which they will inflate. The CV is used to reach this pressure and is, therefore, responsible for the bulk of alveolar recruitment and oxygenation. Too few CV breaths, especially at low PEEP levels, may result in atelectasis. Too many CV breaths will increase the risk of barotrauma.

The benefits of increasing background CV breaths during HFJV decrease quickly at rates higher than 10 bpm. Again, the background rate will vary from patient to patient, from pathophysiology to pathophysiology, and through various stages of the disease process. Lower CV rates are indicated when barotrauma is a primary concern. Higher CV rates are indicated when atelectasis and poor compliance are primary concerns. CV rates greater than 10 bpm are typically used for short time periods of an hour or less.

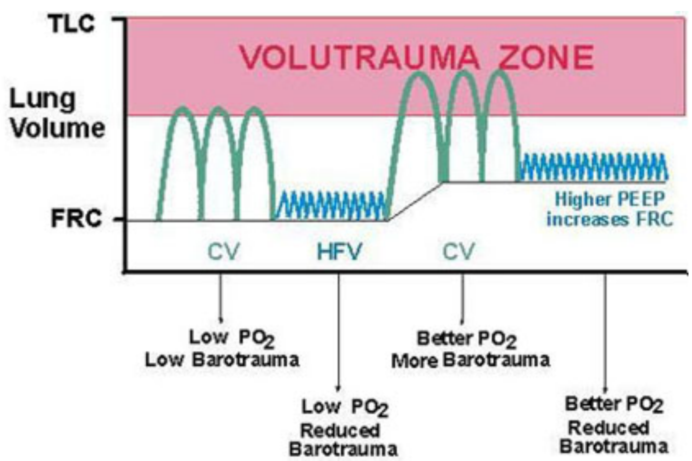
TIDAL VOLUME AND PEEP



Besides a critical opening pressure, alveoli have a critical *closing* pressure below which they will collapse. Opening the alveoli will be of little benefit if adjustments are not made to keep them open. The CV plays a pivotal role in maintaining alveolar recruitment (i.e., avoiding derecruitment) by providing optimal PEEP to preserve alveolar stability and enhance alveolar interdependence.

Using the Life Pulse, MAP can be lowered substantially by reducing the number of large tidal volume breaths delivered by the CV. Higher PEEPs may then be used without dramatically increasing MAP. Oximetry, Life Pulse servo pressure, and xrays will help you find optimal PEEP. But the most important variables when attempting to keep PEEP above the critical closing pressure, as always, are knowing your patient and knowing your ventilators.

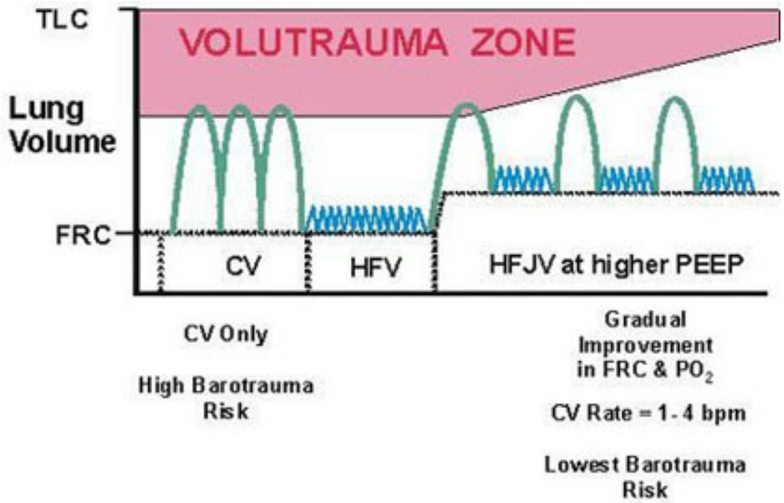
TIDAL VOLUME IN NON-COMPLIANT LUNGS



Alveoli in lungs with poor compliance are difficult to recruit. The critical opening pressure is high and each time this pressure is reached, the risk of creating or aggravating barotrauma increases due to the relatively large tidal volumes delivered by the CV (7-20 ml/kg) and by a disproportionate amount of the tidal volume going to alveoli that are already open. Thus, we prefer to call this risk "volutrauma."

The Life Pulse delivers remarkably low tidal volumes (1-3 ml/kg). The threat of barotrauma can be decreased in babies with non-compliant lungs if alveolar stability is maintained with an optimal, usually higher PEEP. The CV breaths required to open the alveoli can be reduced during HFJV and optimal PEEP can support adequate oxygenation and alveolar stability while the Life Pulse maintains efficient ventilation.

MINIMIZING THE BAROTRAUMA ZONE



The risk of volutrauma is increased when volumes are delivered that encroach into the Volutrauma Zone. (The Volutrauma Zone may be defined as the point where a volume of gas exceeds the lungs' capacity to accommodate it.)

The more frequently large volumes are delivered, the greater the risk of volutrauma. Lung volume and FRC increase as alveoli are recruited, and, ideally, this recruitment can be accomplished without encroaching on the volutrauma zone. Conventional ventilation alone may not be enough to simultaneously recruit alveoli and avoid volutrauma.

During HFJV, the number of CV breaths can be reduced to 0-5 bpm. FRC and PaO_2 may improve gradually over time as long as alveolar recruitment is maintained with optimal PEEP. It is unnecessary to continue to expose the lungs to high-volume, high-pressure CV breaths once alveolar expansion has been achieved. The CV PIP may be lowered, or the CV rate may be reduced even further, reducing the risk of barotrauma.

So...what is the moral of this story? There are probably several morals. We found at least four: 1) Know thy patient; 2) Know thy ventilator; 3) Appreciate optimal PEEP, and; 4) All things in moderation. You can probably find even more.

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