Optimization of Secretion Clearance with the HFCC Triangle Waveform

High-frequency chest compression therapy, also known as high-frequency chest wall oscillation, has become a standard airway clearance treatment for patients with CF, bronchiectasis, and more.

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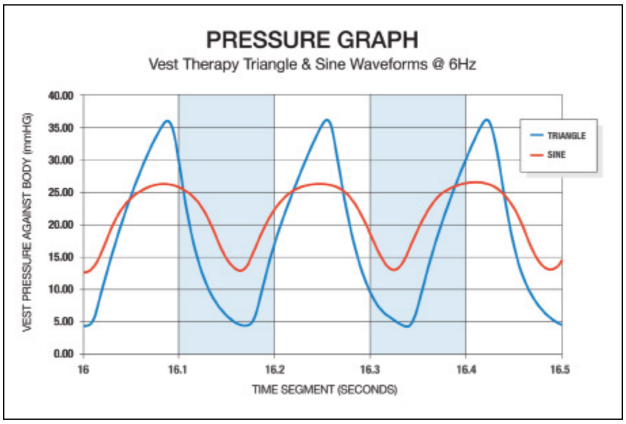

Figure 1. Vests applied to stationary mannequins using each system's own vest, hoses and waveform generator. Pressure oscillations measured inside the vests (a proxy for pressure against the body) with waveform devices set to maximum output and oscillating at 6 beats per second. Plots begin at point of steady-state pressure operation, approximately 16 seconds from startup. 6Hz frequency allows the waveform shape differences to be clearly depicted.

Airway clearance therapy (ACT) has long been considered a key tool in managing the obstructed airways of people with cystic fibrosis (CF) and more recently, bronchiectasis and other chronic lung diseases. ACT clears secretions from the airways and helps reduce infection and inflammation[1] that can further damage lung tissue.

Of the several modalities that exist to deliver ACT, high-frequency chest compression (HFCC) therapy—also known as high-frequency chest wall oscillation (HFCWO)—has become a widely used standard treatment.[2] HFCC creates "oscillatory airflow bias" that allows greater outflow from the lungs than is achieved through normal breathing.[3] The airflow patterns created by HFCC help dislodge mucus that adheres to bronchial walls.[3] HFCC also changes the physical nature of the mucus, breaking it down and ultimately allowing it to be moved to the central airways where it is coughed out or swallowed.[3] (Mucus has been shown to shear and thin after being subjected to high shear forces.[4])

HFCC augments both central and peripheral airway clearance.[5] HFCC was developed in the late 1980s by pediatric pulmonologist Warren J. Warwick, MD, and Leland G. Hansen, MPH, as they and their colleagues at the University of Minnesota sought to improve airway clearance options for children with CF. HFCC systems consist of an air pulse generator that attaches via tubes to an adjustable, inflatable vest that patients wear. Though HFCC devices share the same fundamental components, there are differences in the percussive waveforms they generate. The varying frequency and pressure combinations they deliver can affect therapeutic efficacy and patient comfort.

Editor's Note
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Factors That Influence HFCC Effectiveness

The extent of mucus clearance by HFCC depends on many factors. Patient variables include lung health, treatment adherence,[3] age, and patient preference[1] regarding therapy options. The therapeutic results of HFCC devices are also influenced by vest fit (size and snugness), and the frequency, pressure and waveform of the air pulse generated by the system.

Physicians and other health professionals such as respiratory therapists determine if a patient would benefit from an HFCC system. They also recommend the therapeutic pressure and frequency settings intended to meet individual needs. The two primary types of HFCC systems available today, however, differ from one another in terms of how they function; therefore, their operating and performance characteristics, as well as patient comfort, should be considered when prescribing therapy.

Sine Waveform and Triangle Waveform: Different Approaches with Distinct Results

Current HFCC machines can be distinguished by their pressure waveforms, which are defined by amplitude and frequency.[3] HFCC frequency is measured in cycles (number of peak waves) per second or Hertz (Hz). The original HFCC waveform—the so-called "square" waveform—was developed in the late 1980s. This technology was optimized by attaching a vest to a square waveform air pulse unit with active venting capabilities, which creates a "triangle" waveform. Triangle waveform systems have been available for a decade and function quite differently from sine technology, which was introduced in 1995.[6]

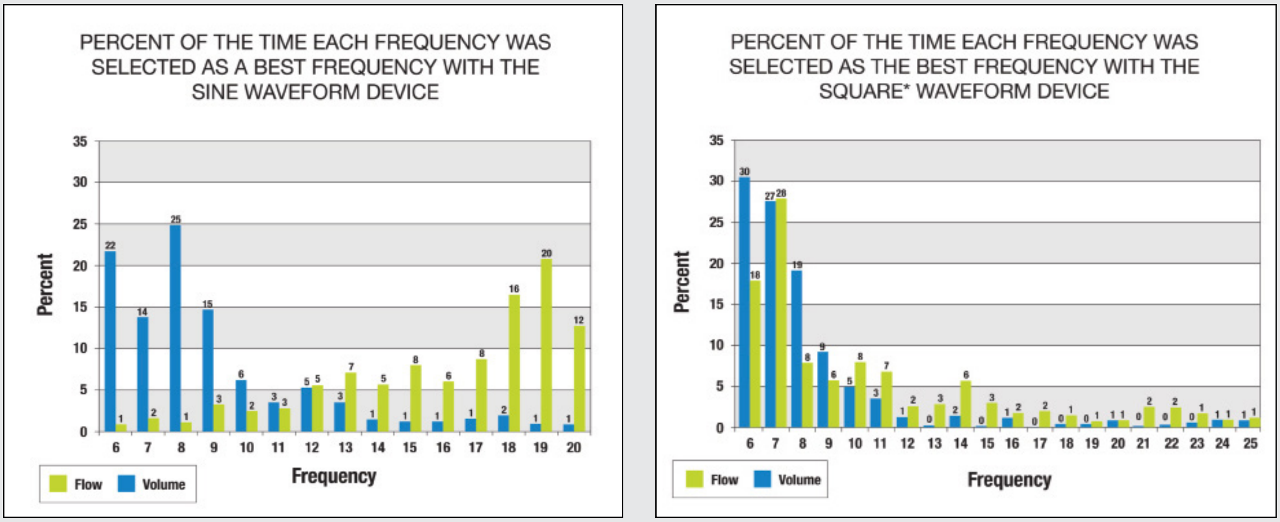
Data suggest that shape of the waveform affects mucus clearing via HFCC in the following ways:

1) A common approach for gauging HFCC efficacy is to measure airflow at the mouth.[3,6] Triangle waveforms have been shown to produce more airflow at the mouth with less applied energy to the chest.[6] In theory, the most efficient HFCC system generates the best airflow at the mouth with the least energy required.[3]

2) The triangle waveform creates peak air pulse pressure for a shorter duration than sine waves. This shorter application of peak pressure and lower trough pressure allows the user to take less restricted, deeper breaths, bringing more air into the lungs, which the vest can then force out[6] **(See Figure 2 online at *RTmagazine.com*).** This sharper peak produces a rapid "thump" to the chest—an effect similar to manual CPT, but in a manner that is more consistent, repeatable and numerous (typically 6 to 15 cycles per second).[7] In the course of a typical 30-minute HFCC therapy session with a triangle waveform system, a patient will receive more than 18,000 "thumps."[7]

3) HFCC oscillatory airflow in the lungs is considered a major factor in moving mucus.[3] Triangle waveform has been shown to be more effective than sine waveform in mucus clearing,[6] delivering a

Figure 3. (Reprinted with permission from *BI & T* (Biomed Instrum Technol). 2006;40:319-324.)



Percentage of the time each frequency resulted in the highest airflow (green bars) and volume (blue bars) with the sine waveform. The operational range of the sine waveform is 5 to 20 Hz.

Percentage of the time each frequency resulted in the highest airflow (green bars and volume (blue bars) with the square waveform (which becomes a triangle waveform when a vest is attached to the air pulse generator). The operational range of the square waveform is 5 to 25 Hz.

20% increase in sputum production.[6] This improvement is thought to be due to both the highest airflows and largest air volumes occurring over the same frequency range (5-11 Hz), which may produce greater mucus-shearing force.[6] In contrast, sine waveforms produce the largest volumes at one end of the frequency range (5-11 Hz), and the largest airflows at the other end of the range (15-20 Hz).[2] **(See Figure 3, above.)**

The best frequencies for patient therapy are those that produce the highest airflows and largest volumes.[6] Another possibility for the difference in mucus clearing performance is that the triangle waveform has greater pulse pressure as a result of higher peak and lower trough pressures.[6] The "thump" of a sharp pressure increase and immediate release creates an airflow bias, which can act to dislodge mucus. Larger airflow bias is created through larger pressure differences, and larger airflow bias contributes to higher air velocity than occurs with normal breathing.[3]

4) Patients can tolerate the higher peak pressures produced by triangle waveforms because that maximum level of pressure is applied very briefly. Patients perceive sine waveforms at an equivalent peak pressure as uncomfortable (or as one paper put it: "crushing and intolerable")[6] because the maximum pressure occurs for a longer duration with the sine wave's rounded peak.

Active Venting for Deeper Inhalations, More Air Movement

When a breath is taken, the chest wall expands. This action pushes the chest against the interior of the pressurized HFCC vest. In an open, triangle-wave producing system, air in the vest is released into the atmosphere both in response to the user's breath and through the cycling of air pulses/spikes produced by the system's patented air chopping system. Sharp peak waveforms are created through "active venting" where air inflow ceases immediately and the pressure rise experiences a sharp drop off. The triangle waveform's sharper peaks and resulting sudden impact loosen and move mucus through the lungs and airways. Also, the combination of the triangle wave system's lower base pressure and active venting allows the chest to easily expand for deeper, more comfortable breaths during therapy.[6]

In a closed, sine wave-producing system, a mechanical diaphragm squeezes the air back and forth within the system like a bellows mechanism to create surges in airflow rather than the abrupt air pulses created in a triangle wave system. Compressions and decompressions create the pressure increases and decreases and produce a natural sine wave. These rounded waveforms do not yield the kind of percussive "thump" that a triangle wave system does.

Sine wave systems also start with a higher base pressure in the vest than triangle waveform devices. **(See Figure 1, page 25.)** A closed, sine wave system vest acts somewhat like a blood pressure cuff around the chest. As the chest expands, the space between the chest and the vest decreases. Because the air cannot escape the system, pressure on the patient is increased, which can result in a feeling of constriction for the user.

Triangle Waveform for Patient Comfort, Therapy Adherence, Secretion Clearance

Though both sine wave and triangle wave devices apply oscillations to the chest wall, prescribers should consider the differences in how those oscillations are delivered.

Patient comfort is a key factor in therapy adherence. In a comparison, vest users reported easier breathing during therapy with a triangle waveform system than with a sine wave system.[2-3] It stands to reason that the more comfortable the therapy is, the higher the likelihood of adhering to a prescribed regimen. Active venting is designed to enhance patient comfort as well as contribute to triangle waveform development that produces mucus shearing, breakdown and movement.

Individual therapy needs determine the types of interventions best suited for desired outcomes. Prescribers who fully appreciate the differences in currently available HFCC systems can ensure patients receive the most effective therapy for their needs. **RT**

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