High-Frequency Chest Compression: Advanced Therapy for Obstructive Lung Disease

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Abstract

First introduced nearly two decades ago, high frequency chest compression (HFCC) technology has become the preferred airway clearance therapy for patients with cystic fibrosis and a variety of other obstructive lung disorders. This paper describes the history of HFCC technology, supporting research, and the development of successive generations of HFCC machines including the inCourage System, which incorporates the most recent advances in technology and design.

History

By the early 1960s, the contribution of excess pulmonary secretions to the progression of cystic fibrosis (CF) lung disease was well understood. Treatment protocols began to include aggressive daily secretion clearance therapy with the only available method, chest physiotherapy (CPT). By 1980, after more than a decade of routine CPT, dramatic improvements in patient health and survival established CPT as the cornerstone of CF care.[1] However, despite its clear benefits, CPT may not be the ideal therapy. An array of challenges may compromise its therapeutic benefits. Caregiver limitations including poor technique, inadequate physical strength and inconsistent availability and patient factors such as treatment contraindications, inability to tolerate required positioning and unwillingness to cooperate may contribute to suboptimal CPT effectiveness.[2,3,4] Recognition of the need for a more practical and consistent form of therapy led to the development of novel techniques and technologies including high frequency chest compression (HFCC).[5]

The earliest known clinical application of HFCC was described in 1966 by Dr Gustav Beck, a chest specialist and chief of the pulmonary laboratory at St. Clair's Hospital, New York City. Beck sought to develop a physio-mechanical intervention consistent with principles of pulmonary physiology to clear mucus from severely obstructed lungs. In a geriatrics journal, he described equipment that delivered an air stream with a positive pressure of 30 cm H_2O from a compressor passed over a vibrator operating at 30 Hz.[6] Therapy was applied to the upper abdomen and lower thorax with a thoracoabdominal belt. Ten of thirteen treated patients showed significant mucus expectoration, marked reduction of dyspnea and temporary or sustained benefit. The method attracted no particular interest and was not pursued further for nearly two decades.

In the early 1980s a group of Canadian scientists, led by Dr Malcolm King, undertook a series of in vitro and animal studies to investigate the potential of HFCC to enhance pulmonary mucus clearance. Their research demonstrated significant increases in both the rate of tracheal mucus clearance and in movement of secretions from peripheral lung regions.[7,8] Additional studies elucidated some of the mucokinetic and mucolytic actions of HFCC.[9-12] Observations include a reduction in the viscoelastic and cohesive properties of mucus, thus promoting clearability by the air-liquid interactions associated with cephalad airflow velocity bias,[9-10] and that HFCC frequencies in the range of 13-15 Hz may reinforce the mucus interaction with cilia and/or the natural harmonics of the chest wall.[11] Studies also found a correlation between HFCC action and improved ventilation.[13]

In 1985, the father of a cystic fibrosis patient offered funding to Dr Warren J Warwick, Professor of Pediatrics and Director of the University of Minnesota Cystic Fibrosis Center, to find a way to simplify her regimen of four daily CPT sessions. Inspired by King's work showing enhanced tracheal mucus clearance in dogs, Warwick and Leland Hansen, a University of Minnesota senior scientist, worked to develop a system for clinical use based upon those principles and technologies. Their first creation, a sine waveform device, was a complicated system composed of a motor, piston, an air spring rubber diaphragm and a rubber vest with a tailored plastic cover. This system worked so well that the young lady was able to administer her airway clearance therapy herself. Her treatment time was reduced from four hours to two hours daily.[14]

Warwick and Hansen experimented further to develop a

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waveform that would maintain a constant pressure during both the inspiration and expiration phases of HFCC therapy. The prototype, a square waveform machine, was so successful that fifteen other families raised money to have Hansen build machines for their children with CF. Observations on these additional patients showed HFCC to be more practical and more effective than standard chest physiotherapy (CPT). Follow-up results showed an unprecedented stabilization or improvement of pulmonary function in a disease where progressive deterioration and early death had been the rule.[15] Subsequently, long-term and short-term studies have demonstrated the impact of HFCC therapy on sustaining or improving pulmonary function.[16-21]

Over the years, Warwick and Hansen performed a series of laboratory and clinical studies that helped to identify strengths and weaknesses in their HFCC machines.[22-28] They used this information to guide them in making incremental improvements. Because they could not maintain production themselves, in 1988 they licensed a medical device company to manufacture and distribute their machine.

All HFCC devices consist of similar primary components; an air delivery device with a motor-driven valve and an inflatable jacket interconnected by one or two hoses. The air delivery device creates oscillating air pressure that is delivered to the jacket via the interconnecting hose/s. The rhythmic inflation and deflation of the jacket against the user's chest produces high-frequency chest compressions that create the oscillatory effects within the airways that help mobilize bronchial secretions.

All HFCC machines have received FDA clearance to market based upon a determination of generic equivalency to predicate devices meeting the specifications approved in the original Warwick/Hansen prototype. The frequency range of commercially available HFCC machines is from 5 Hz to 30Hz. Pressures may be adjusted downward from a maximum available pressure. Some investigators believe that HFCC efficacy may be influenced by factors including differences in the pulse waveform, pulse pressure, frequencies and jacket sizing.[26, 27, 41-43]

Past and current HFCC machines utilize three different applied waveforms–square, sine and triangle. All were first developed at the University of Minnesota Cystic Fibrosis Center by Warwick and Hansen. Several papers describe that work.[13, 15, 21-27] As an outcome of that research, four generations of commercially available machines with distinct technical and performance characteristics have emerged. Individual manufacturers have added their own design features and technical modifications.

A chronology of HFCC machines

- 1988-2002: Square waveform Model 101 and Model 102, American Biosystems, aka Advanced Respiratory, St Paul, MN.
- 1992-2003: Sine waveform Model 103, Hill-Rom, dba Advanced Respiratory, Inc (aka ARI), St. Paul, MN.
- 2003-present: Sine waveform Model 104, Hill-Rom.
- 2006-present: Sine waveform Model 205, Hill-Rom
- 1994-2002: Sine waveform Med Pulse Electromed, Inc. New Prague, MN.
- 2002-present: Sine waveform SmartVest, Electromed, Inc New Prague, MN.
- 2005-present: Triangle waveform: The inCourage System, Respiratory Technologies, Inc, dba RespirTech, St Paul, MN. [2005-present].

Triangle waveform, the newest HFCC technology

In a recent peer-reviewed study comparing the differences in output characteristics between the triangle waveform and a competing sine waveform machine, data suggest that therapeutic effects may be better with triangle waveform machines than those that rely upon the older technology.[26]

In eight participating CF subjects, therapy with a triangle waveform device yielded a 20% mean increase in volumes of mucus cleared, with a range of improvement up to 41%. The shape of the waveform delivered by HFCC machines appears to be important in maximizing mucus clearance. The triangle waveform, in contrast to the sine waveform, appears to be more effective because peak airflow and maximum lung volumes occur at the same frequencies. HFCC with the triangle waveform is judged more comfortable as a result of the shorter duration of peak pressure and venting to atmospheric pressure.

In a second study, the practical advantages of triangular waveform therapy surpass those of professionally administered CPT.[27] A third unpublished study comparing airway clearance efficacy of sine and triangular waveform HFCC machines in cystic fibrosis patients was presented as a paper and poster in 2006 at the Twentieth Annual North American Cystic Fibrosis Conference.[44]

Fifteen stable CF patients were randomly allocated to receive one 30-minute treatment with each of two high frequency chest compression (HFCC) machines, The Vest airway clearance system model 104 (Hill-Rom, St. Paul MN) and the inCourage System, aka ICS (RespirTech, St. Paul MN). A two-day washout interval separated sessions; double-blinding was attempted.

Several outcomes trended in favor of the triangle waveform inCourage System machine, including greater sputum production, lower residual lung volumes (suggesting less air-trapping), increased forced expiratory volume (FEV) (suggesting greater ability to generate a mucus-clearing cough), changes in mucus viscosity and elasticity and in mucus cough transportability.

Within a decade of its introduction, HFCC gained recognition as standard of care therapy for patients with mucociliary dysfunction arising from a broad range of causes. An estimated 70% of American CF patients use HFCC as their primary airway clearance modality. However, at least 85% of patients currently using HFCC have other primary diagnoses. An estimated 50,000 patients, 9,300 physicians, 2500 hospitals and 1,100 health plans have used, prescribed or reimbursed HFCC machines. Numerous peer-reviewed clinical trials demonstrate both safety and efficacy of the device in diverse patient populations.[29-41] The therapy is recognized as standard of care in the medical literature and respiratory medicine text books.[46-47] Among modern modalities for the management of airway secretions, HFCC is by far the most thoroughly studied.[48, 49]

Summary

All currently available HFCC machines provide clinically effective therapy. Differences in design and performance characteristics may influence factors including peak efficacy,

comfort, adherence to prescribed treatments and patient preference. Recent, limited evidence suggests that waveform may be an important component of machine performance and that the triangle waveform may offer advantages. The actual significance of waveform differences in HFCC machines remains unclear. Further research, some currently in progress, should improve understanding of that aspect of the technology.

Physicians, providers and patients alike constantly seek improved therapies to maximize outcomes, improve quality of life and distribute care more equitably. HFCC technology has played a considerable role in advancing those goals. The most recent improvements, available in the inCourage System, have the potential to advance them further. HFCC is here to stay and efforts to improve the technology continue.

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