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Comparison of Active Cycle of Breathing and High-Frequency Oscillation Jacket in Children With Cystic Fibrosis

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Summary. High-frequency chest compressions (HFCC) have been suggested as an alternative to conventional chest physiotherapy to aid sputum clearance in patients with cystic fibrosis (CF). We aimed to compare the active cycle of breathing techniques (ACBT) with the Hayek Oscillator Cuirass, performing HFCC on secretion clearance in children with CF during an exacerbation. Ten children (7 males; median age, 14 years; range, 9–16) received either two supervised sessions using HFCC or two self-treatment ACBT sessions in random order on successive days. Baseline pulmonary function was similar prior to treatments. Sputum weight increased significantly with ACBT compared with HFCC during treatment (5.2 g vs. 1.1 g, $P < 0.005$, morning; 4.1 g vs. 0.7 g, $P < 0.01$, afternoon). Pulmonary function improved significantly after morning ACBT (forced vital capacity (FVC): 2.67 l to 2.76 l, $P < 0.03$; forced expiratory volume in 1 sec (FEV_1): 1.59 l to 1.62 l, $P < 0.03$). Following afternoon ACBT, there was a significant increase in FVC (2.64 to 2.79, $P < 0.02$), but no significant change in FEV_1. Pulmonary function did not change at any time following HFCC. Compared with ACBT, HFCC by Hayek Cuirass is not an effective airway clearance treatment modality for children with CF during an infective exacerbation. **Pediatr Pulmonol. 2004; 37:71–75.**

Key words: physiotherapy; cystic fibrosis; infective exacerbation; high-frequency chest wall oscillation.

INTRODUCTION

Much of the morbidity and mortality in cystic fibrosis (CF) is due to lung complications, of which the production of thick, tenacious sputum is a major feature. Chest physiotherapy to enhance airway clearance is important in CF, and available techniques include: ACBT; autogenic drainage; positive expiratory pressure mask (PEP); and the Flutter VRP1. Recently, high-frequency external chest compression (HFCC) was also suggested as an additional useful modality.[1–3]

There are a few studies looking at the role of HFCC in CF produced using a variable air pulse delivery system, the ThAIRpy Bronchial Drainage System (American Biosystems, Inc., Stillwater, MN). Arens et al.[2] and Braggion et al.[3] examined adult patients with CF during an acute exacerbation and compared ''conventional physiotherapy practice'' (CPT) with HFCC. Both studies found HFCC by ThAIRpy as effective as CPT. Grece[4] and Tecklin et al.,[5] in retrospective 3-year and 1-year studies, found HFCC and CPT comparable in effect for airway clearance. Warwick and Hanson also looked at the long-term effects of HFCC in CF management, and found an improvement in pulmonary function compared with CPT.[6] However, they acknowledged that subjects were more compliant with HFCC than with CPT, and that their results did not distinguish between the effects of adhering to treatment and that of a new technique, which is also likely to have a considerable placebo effect. Scherer et al. studied 14 pediatric outpatients with stable CF and compared CPT with two different forms of HFCC and two forms of oral high-frequency oscillation administered via a mouthpiece.[7] They found no differences in amounts of sputum cleared or in pulmonary function between the different techniques.

Another device which can deliver HFCC is the Hayek External High-Frequency Oscillator. This is a device for administering negative pressure ventilation across the chest wall, which has been shown to be an advantageous mode of ventilatory support during anesthesia,[8] acute

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respiratory failure in adults on intensive care,[9] and in severe chronic obstructive pulmonary disease.[10] An increase in pulmonary blood flow, coronary blood flow, and cardiac output were also reported.[11,12] There are no published studies specifically investigating HFCC by Hayek Cuirass, and none comparing HFCC with our proven clinical practice of secretion clearance by ACBT. This study was therefore undertaken to evaluate the Hayek Cuirass for HFCC as a mode of airway clearance in children with CF during an infective exacerbation.

MATERIALS AND METHODS

Study Subjects

We studied 10 children with known CF (7 males; median age, 14 years) diagnosed by either or both methods of sweat chloride >60 mmol or positive genotype,[13] who were admitted to the Paediatric Respiratory Unit of the Royal Brompton Hospital with an acute respiratory exacerbation as defined by conventional criteria.[14] All subjects were proficient in self-treatment of ACBT,[15] and were able to perform reproducible spirometry and expectorate sputum. No child had a history of recent hemoptysis, pneumothorax, or chest trauma, or had any disturbance of vision, hearing, or balance. The Ethics Committee of the Royal Brompton Hospital approved the study, and fully informed written consent was obtained. Subjects were familiarized with the functioning of the Hayek Oscillator and the HFCC.

Hayek Oscillator 1000

The Hayek Oscillator 1000 Cuirass TM (Flexico Medical Instruments AG, Zürich, Switzerland) is a flexible, lightweight, clear plastic shell, which covers the anterior chest wall and upper abdomen. Velcro straps around the body secure it, and a foam skirt at the edges of the cuirass create an airtight seal. From the front of the cuirass, wide-bore flexible tubing connects to a mobile, microprocessor-controlled power unit. A diaphragmatic pump inside the unit operates over a wide range of frequencies to generate an oscillating pressure, which is transmitted to the chamber between the chest wall and shell, enabling ventilation. Both the inspiratory and expiratory phases are active, with set modes and operator-set with automatic adjustments. The chest is oscillated around a mean negative-pressure baseline. One of the preset modes is called ''secretion mode,'' which delivers a period of high-frequency/low-amplitude chest wall oscillation (T1), followed by a period of high-span oscillation at low-frequency with a shortened expiratory ratio (T2). T1 lasts for 3 min, inspiratory:expiratory ratio (I:E) 1:1, operating 600 cycles per minute (CPM), with inspiratory values of -12 cm H_2O to expiratory values of $+6$ cm H_2O. T2, with I:E 5:1, has a frequency of 60 CPM ranging inspiratory pressures of -24 cm H_2O to expiratory pressure of $+12$ cm H_2O. T2 is set at 3 min; however, in piloting the secretion mode, 3 min was not tolerated, and we reduced this phase to 2 min. The study investigator had been instructed in its use by technical support staff from Breasy Medical Equipment, Ltd., the UK distributors of the Hayek Oscillator.

Methods

The study commenced during the second 24 hr of admission. Randomization occurred by sealed envelope. On the first day of the study, subjects received either treatment A or treatment B, and crossed over the following day (five in each group). Treatment A consisted of supervised use of the Hayek Oscillator 1000 on secretion mode: the two-phase cycle consisted of four two-phase cycles, 600 oscillations per minute for 3 min, followed by 60 oscillations per minute for 2 min. Treatment B consisted of supervision of self-treatment ACBT incorporating relaxed breathing control, 3–4 thoracic expansion exercises, and the forced expiration technique. Each regimen was performed twice a day, at the same times of day and for 20 min each session. In the morning, whichever treatment had been determined by randomization was performed in supine position. In the afternoon, HFCC was performed with the subject sitting in a chair, as recommended by the manufacturers, and ACBT was carried out in a gravity-assisted position as indicated by individual assessment. On both days, clinical status of all subjects was evaluated, and an additional evening treatment to clear secretions was carried out if necessary by standard ACBT.

Measurements

An independent, blinded observer measured the weight of wet sputum produced during each treatment, including 15 min immediately following treatment, and sputum produced over a 24-hr period, excluding treatment times. Recordings of forced vital capacity (FVC) and forced expiratory volume in 1 sec (FEV_1) were taken immediately before, immediately following, and at 10 min after the end of treatment (MicroLoop II Spirometer, Micro Medical Ltd., UK). The spirometer was calibrated with a 1-liter syringe before each study, and measurements were made in accordance with American Thoracic Society standards.[16] During all treatment sessions, arterial oxygen saturation and heart rate were continuously recorded (Nellcor Oximeter). Blood pressure measurements were taken immediately before, every 10 min during, and immediately following treatments (Dynamap). All subjects completed a five-point, five-item questionnaire for each treatment mode. They were asked to rate the treatment mode for 1) ease of technique; 2) comfort; 3) secretion clearance; 4) breathlessness; and 5) recommendation to a friend.

Statistical Analysis

A Wilcoxon signed-rank test was used for statistical analysis, $P < 0.05$ being judged significant.

RESULTS

Patient Characteristics

We studied 10 patients (7 male), median age 14 years (range, 9–16) (Table 1).

Sputum

There was a significant increase in the amount of sputum produced during ACBT treatment compared to HFCC, both in the morning treatment (5.2 g vs. 1.1 g, $P < 0.005$) and following the afternoon treatment (4.1 g vs. 0.7 g, $P < 0.01$; Fig. 1). There was no significant difference in 24-hr sputum weights.

Pulmonary Function

Figure 2 illustrates the percent changes in FVC, and Figure 3 the percent change in FEV_1 for each treatment of ACBT and HFCC.

There was significant improvement in pulmonary function immediately following ACBT morning treatment (FVC 2.67 l to 2.76 l, $P = 0.02$; FEV_1 1.59 l to 1.62 l, $P = 0.02$) (Table 2). At 10 min following ACBT treatment, there was a sustained significant increase in FVC ($P = 0.03$) and FEV_1 ($P = 0.03$). There were no differences in baseline measurements before either treatment regimen.

The improvement in FVC following afternoon ACBT was also significant immediately and after 10 min ($P = 0.01$ and $P = 0.01$, respectively).

There was no significant change in pulmonary function at any time following HFCC (Table 2).

No differences in heart rate, arterial oxygen saturation, or blood pressure were found at any time with any patient.

Patient Preference

All subjects found treatment by ACBT comfortable to perform. Sixty percent found the Hayek Cuirass HFCC uncomfortable. Eighty percent of subjects felt it difficult trying to clear secretions by HFCC; however, ACBT made it easier to clear secretions.

DISCUSSION

This study showed that children at the start of treatment for a pulmonary exacerbation in CF were able acutely to clear more sputum with ACBT than with HFCC by Hayek Cuirass. On each study day, baseline measurements of pulmonary function were comparable. Following chest physiotherapy using ACBT, a significant improvement in pulmonary function was seen, whereas there was no change in pulmonary function following HFCC treatment by Hayek Cuirass. Furthermore, the weight of expectorated sputum was greater with sessions of ACBT than with HFCC. It is unsurprising that 24-hr sputum weights were similar on both days because those children, in whom it was clinically indicated, underwent an additional evening ACBT treatment session on HFCC treatment days.

We studied only one preset Hayek mode, and it is possible that a different oscillation frequency and amplitude may have changed the results of our study. Jones et al.[17] studied isotope mucociliary clearance rates in CF subjects and in normal controls. In control subjects, they found that the highest oscillated flow producing the most effective clearance occurred between frequencies of 10–15 Hz. The second phase of the Hayek ''secretion mode'' is at 1 Hz and is said to encourage coughing. The first phase of each 5-min cycle is 3 min at 10 Hz. However, Jones et al. found that the oscillated flows produced in the chest by HFCC were actually much lower in CF subjects than those produced in normal subjects at the same frequencies.[17] They found that oscillated flow was positively correlated with FEV_1, and in particular, with higher airway resistance, oscillated flow was less. In our subjects with a mean

TABLE 1— Patient Characteristics Prior to First Treatment[1]

Gender	Age (years)	FVC (liters)	FVC % (predicted)	FEV_1 (liters)	FEV_1 % (predicted)
M	14	2.04	65	1.22	42
M	12	1.53	65	0.71	33
M	16	2.34	69	0.85	27
M	16	4.04	114	2.83	86
F	15	3.04	111	2.23	86
M	9	1.97	94	1.45	76
M	13	2.71	91	1.45	53
F	12	2.62	89	2.08	74
F	14	2.85	89	1.72	56
M	16	1.65	49	0.87	28
Median	14	2.48	89	1.58	55
Range	9–16	1.53–4.04	49–114	0.85–2.83	27–86

[1]FVC, forced vital capacity; FEV_1, forced expiratory volume in 1 sec.

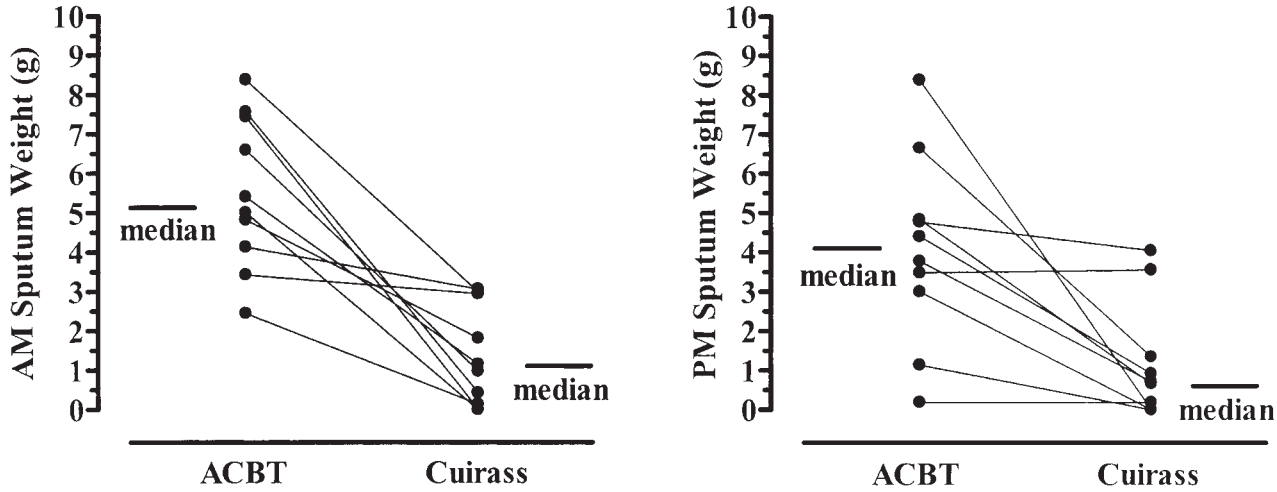

Fig. 1. Comparison of morning (left) and afternoon (right) sputum weights following ACBT and HFCC.

FEV_1 of 61% predicted, it is possible that 10 Hz may not have been sufficient to enhance airway clearance. Arens et al.[2] found HFCC more beneficial in their mildly affected CF group than in their moderate and severely affected group. In addition, several authors addressed the concern of a reduction in functional residual capacity (FRC) which can be seen with HFCC, which might further increase airway resistance. Petros et al. suggest that with the Hayek Cuirass, this undesirable effect may be minimized through the Hayek operating around a negative pressure baseline.[18] Although our subjects showed no deterioration in arterial oxygen saturation during HFCC, any reduction in FRC may have increased airway resistance and affected airway oscillatory flow. Unfortunately, we were not able to measure FRC during "secretion mode" oscillation frequencies in own study. Perry et al. found that the addition of positive expiratory end pressure (PEEP) during HFCC increased lung volume and oscillated airflow in subjects with chronic obstructive airways disease.[19] They used the ThAIRpy Vest, and speculated that the addition of PEEP could enhance the effectiveness of HFCC in clearing bronchial secretions. We did not apply PEEP, so we cannot rule out a similar effect in CF patients using the Hayek Oscillator for HFCC. This may be worthy of further study.

Although we have speculated on why sputum may be cleared less efficiently with the Hayek for HFCC in CF subjects, whatever the true mechanism, it is clear that the Hayek is not as effective a method of acute secretion clearance as ACBT in children with CF during an infective exacerbation. Our study findings conflict with previous reports comparing HFCC and secretion clearance,[1–3] but direct comparisons are difficult to make, as the ThAIRpy Vest and Hayek are different machines with different operating modes. Futhermore, previous studies compared HFCC with other physiotherapy techniques, e.g., postural drainage and percussion.[4–7] ACBT, which incorporates breathing exercises and the forced expiration technique, was shown to be more effective than postural drainage and percussion alone.[15]

The main weakness of our study is that it is short-term, and this does not address whether HFCC might actually confer benefits in the long term. We cannot comment on whether there might be better adherence in the long or short term to either treatment regimen. Short-term patient preference does not encourage the belief that long-term adherence to HFCC is likely. Both expectorated sputum weight and change in pulmonary function were inferior using HFCC by Hayek Oscillator. We recognize that the

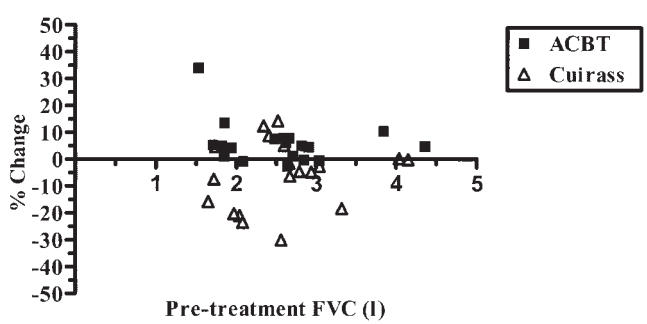

Fig. 2. Percent change in FVC following treatment.

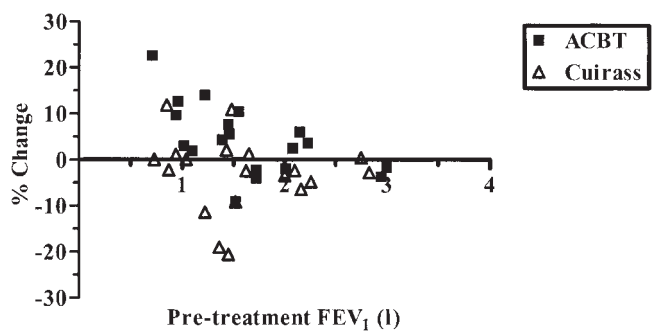

Fig. 3. Percent change in FEV_1 following treatment.

TABLE 2— Summary of Lung Function (Separate AM and PM Values)

	FVC (liters)			FEV_1 (liters)		
	Pretreatment	Posttreatment	*P* value	Pretreatment	Posttreatment	*P* value
ACBT (AM)	2.62 (1.82–4.36)	2.74 (1.87–4.57)	0.02	1.462 (0.94–3.00)	1.56 (1.03–2.95)	0.02
ACBT (PM)	2.62 (1.53–3.85)	2.68 (1.80–4.25)	0.01	1.54 (0.71–3.95)	1.55 (0.87–2.84)	0.58
Hayek (AM)	2.41 (1.65–4.04)	2.62 (1.39–4.05)	0.37	1.45 (0.85–2.83)	1.46 (0.85–2.75)	0.37
Hayek (PM)	2.63 (1.72–4.15)	2.64 (1.59–4.14)	0.09	1.57 (0.73–2.75)	1.48 (0.73–2.76)	0.09

measurement of sputum as an outcome measure has limitations; however, the improvement in lung function, together with increased expectoration of sputum, both support the conclusion that ACBT is superior. We cannot exclude the possibility of a better outcome if HFCC had been used throughout the exacerbation, or during home physiotherapy between exacerbations. Testing these hypotheses would require a large patient group, and in the case of domiciliary treatment, a long study period. Finally, our study involved supervised treatment sessions, and therefore adherence was not measured. However, the subjective reports from children were that ACBT is the preferred method of airway clearance compared with HFCC by Hayek Cuirass. We acknowledge the small number of subjects in this study, and we cannot exclude the possibility of benefit being demonstrated in other age groups, or those with different severity of disease; however, there is no reason to suppose this could be so.

In conclusion, in children with CF during an infective exacerbation, HFCC by Hayek Cuirass is not effective for clearing bronchial secretions. The Cuirass is expensive, and more children prefer ACBT. The Hayek Oscillator for HFCC is not routinely indicated for secretion clearance in children with an infective exacerbation of CF.

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