Acute respiratory infection in patients with cystic fibrosis with mild pulmonary impairment: Comparison of two physiotherapy regimens

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Chest physiotherapy is an essential part of the management of cystic fibrosis, yet comparatively few studies have investigated the commonly used forms of chest physiotherapy during acute respiratory exacerbations. Fifteen subjects with cystic fibrosis and predominantly mild pulmonary impairment completed a randomised cross-over trial with 24 hours between treatments. The active cycle of breathing techniques (ACBT) assisted by a physiotherapist was compared with the ACBT performed independently by the patient. Measurement outcomes included pulmonary function tests, indirect calorimetry and oximetry parameters. Energy expenditure was not significantly different between the two treatment regimens, though significant improvements in pulmonary function were apparent 24 hours following the therapist-assisted ACBT. In this group of subjects, neither form of treatment proved superior in terms of energy consumption, but a reduction in airways obstruction was observed as a carry-over effect following the therapist-assisted ACBT. **[Williams MT, Parsons DW, Frick RA, Ellis ER, Martin AJ, Giles SE and Grant ER (2001): Acute respiratory infection in patients with cystic fibrosis with mild pulmonary impairment: Comparison of two physiotherapy regimens. *Australian Journal of Physiotherapy* 47: 227-236]**

Key words: Cystic Fibrosis; Energy Metabolism; Oxygen Consumption; Respiratory Therapy

Introduction

During acute respiratory infections in cystic fibrosis, resting energy expenditure is increased due to fever, inflammatory responses and nutritional requirements. This results in reduced pulmonary function and indirect increases in the work of breathing (Gozal et al 1992, Steinkamp et al 1993). Resting energy expenditure has been reported to be reduced significantly by the completion of a hospital admission for intensive medical management of an acute respiratory exacerbation for subjects with cystic fibrosis (Naon et al 1993, Steinkamp et al 1993).

Despite the substantial research into the physiotherapy management of cystic fibrosis, there are insufficient studies which investigate the efficacy of physiotherapy or compare different physiotherapy regimens during admission to hospital for management of acute pulmonary exacerbation. Of these studies, few have been conducted during the early stages of an admission (Oberwalder et al 1991, Pryor et al 1990, Regelmann et al 1990). Patients requiring hospitalisation due to worsening pulmonary function are likely to be most compromised clinically and metabolically during the initial days of an admission. This study measured the energy expended during, and pulmonary function changes following, therapist-assisted treatment compared with independent physiotherapy treatment of subjects with cystic fibrosis during acute respiratory exacerbations of their disease.

Methods

Subjects were current patients of the specialist Cystic Fibrosis Clinic of the Women's and Children's Hospital, Adelaide, admitted to hospital for management of an acute exacerbation of their respiratory disease. Ethical approval for this study was granted by the relevant committees of the Women's and Children's Hospital, and the University of South Australia. All subjects with cystic fibrosis admitted to hospital for management of an an acute respiratory infection were invited to participate in this study. Subjects were required to be 12 years of age or older and able to fast prior to testing (preferably overnight). The criteria for determining an acute respiratory infection was based on the definition provided by Gold et al (1987), that is, subjects were required to fulfil at least three of the following criteria: 1) acute respiratory exacerbation characterised by increased cough, volume and purulence of sputum, fatigue, tachypnoea and dyspnea; 2) decreased exercise tolerance; 3) anorexia and weight loss, alone or in combination; and 4) sufficiently severe condition, judged by a physician of the Cystic Fibrosis Clinic, to require hospitalisation.

Plan and design The research design was of the within-subject, repeated measures 2 x 2 (AB/BA) cross-over style with a 24 hour washout period. Subjects acted as their own control and undertook both treatments. The subjects were randomly assigned to undergo either the therapist-assisted treatment followed 24 hours later by the independent treatment (AB protocol), or the independent treatment

followed 24 hours later by the therapist-assisted treatment (BA protocol). Patients were admitted on Day Zero and underwent required medical management procedures. Thereafter, research testing occurred on Day 1 and Day 2 of the admission as well as the morning of the day of discharge, Day X. All testing was carried out during the morning and at the same time each day. If subjects were unable to complete the trial for any reason, they were withdrawn from the study. Subjects continued with their preferred physiotherapy programs and prescribed medications throughout the study. Sympathomimetic agents can increase resting energy expenditure (Vaisman et al 1987) however these drugs could not be withheld from subjects requiring these agents as part of their medical management. Their usage continued but the timing and dosage were kept the same between days of the study.

Treatments The most common physiotherapy regimen throughout Australia for the management of patients with cystic fibrosis admitted to hospital is the ACBT incorporating manual techniques and gravity-assisted positioning (Bartlett et al 1993). The ACBT was performed according to guidelines developed by Partridge et al (1989) and Pryor (1991).

During pilot work for this project, the duration of standard physiotherapy treatments and frequency of ACBT cycles within daily treatment were recorded and monitored. On average, the duration of each treatment session was approximately 20 minutes, each standardised ACBT cycle was around two minutes, with variations due to spontaneous coughing and recovery time using breathing control. During the study the total number of ACBT cycles performed during the treatment phase was individualised and not set, however the standardised ACBT study regimen was controlled.

The standardised ACBT study regimen was used in both the therapist-assisted and independent regimens. The standardised ACBT consisted of breathing control, four thoracic expansion exercises, breathing control, three thoracic expansion exercises, breathing control, two forced expirations (huffs and breathing control) (Pryor 1991).

Therapist-assisted ACBT: the physiotherapist provided manual (tactile) facilitation during the thoracic expansion exercises and huffing. Percussion was applied at approximately 133 bpm during the first set of thoracic expansion exercises and vibration during the second set of thoracic expansion exercises

Independent ACBT: the patient performed the ACBT under the supervision and with the verbal guidance of the physiotherapist.

Treatment position: The treatment was conducted in the same gravity-assisted position on both treatment days, determined by auscultation during the baseline measures on the first day of testing. Only one gravity-assisted position was maintained throughout the 20min treatment period as Webber (1988) recommends that a minimum of 10 minutes in one position is required for gravity to influence secretion movement and a position change midway throughout treatment would confound the energy expenditure measurements. All subjects were familiar with both treatment regimens and the same physiotherapist was in attendance for all subjects.

Equipment Energy expenditure was measured by indirect calorimetry. A low deadspace exercise mask (Hans Rudolph Exercise Series 7910) maintained a leak-free contact with the subject's face. This mask has two inspiratory ports and one expiratory port, each complete with one-way valves. Minute ventilation (L/min) was measured with a pneumotachometer (Fleisch Size 3, unheated) inserted into one inspiratory port, and was connected to a Validyne MP-45 differential pressure transducer which relayed signals to a Hewlett Packard amplifier (Model 77028). The inspiratory flow signal was integrated digitally and converted to expiratory volume via the standard nitrogen correction (Ruppel 1991). The second inspiratory port was fitted with a gas-tight secretion removal system consisting of a suction cannula and specimen trap, a control valve attached to a water displacement system and wall suction (negative 150 mmHg; Parsons and Williams 1996). While sputum was expectorated during treatment, the volume was not measured, nor considered during analysis, as there is no convincing evidence that volume of sputum equates with pulmonary function, and it is likely to underestimate airways secretion clearance (Williams et al 2000).

The expiratory port was connected via smooth bore tubing to a 4L mixing box. Concentrations of oxygen (per cent) and carbon dioxide (per cent) were determined by Ametek S-3A/1 (oxygen) and Bio Precision B1050-0001 (carbon dioxide) analysers. Analogue output signals were converted via an A-D board (Metrabyte DAS-8) to digital signals at 30Hz for real-time display, analysis and storage. Values for minute ventilation, mean expired oxygen and carbon dioxide were continuously monitored and stored using computer software (Labtech Notebook). Mean mixed-expired gas values were corrected for both ambient conditions (STPD) and time delays due to gas transport through the collection system. Oxygen consumption (VO_2), carbon dioxide production (VCO_2) and respiratory exchange ratio (RER) were calculated via standard equations and expressed as mean values per minute corrected for body weight (ie VO_2 ml/kg/min, VCO_2 ml/kg/min, VCO_2/VO_2, Ruppel 1991). The ventilatory equivalent for oxygen (Ve/VO_2) was calculated during the analysis phase (Ruppel 1991). Resting oxygen saturation (% SpO_2) and heart rate (bpm) were recorded throughout the testing procedure using a Nelcor 200E Pulse Oximeter (taped finger interface).

The indirect calorimetry system was calibrated against a rotameter (CEC-Elliot) for flow and a 120L Tissot spirometer for volume. Alpha-standard gas mixtures of oxygen, carbon dioxide and nitrogen were used to calibrate the gas analysers. Measures for flow and volume were accurate to 3%, which is within the widely accepted

American Thoracic Society standards (1991). Gas analysis for carbon dioxide and oxygen was accurate to 0.02%. Reliability of resting indirect calorimetry measures for the test procedure was confirmed in a previous study, with VO_2 (r = 0.72), VCO_2 (r = 0.72), and Ve (r = 0.89) producing acceptable correlations between days of testing (Williams et al 1994). Inspiratory flow, volume and gas sensors were calibrated prior to each subject's test.

Baseline measurements: The subject's age and gender were recorded, and height and weight were measured with a wall stadiometer (Holtain Limited) and calibrated scales, respectively. Dynamic pulmonary function was assessed by flow/volume curves and whole body plethysmography using a Jaegar MasterLab system. Predicted values were derived from the equations of Zapletel et al (1969) and Crapo et al (1981) for subjects between four and 18 years of age. Pulmonary function studies were performed by the principal investigator with the subjects standing for flow/volume manoeuvres and seated within the body box for plethysmography.

After the calorimetry and oximetry equipment was connected, the subject rested quietly in the sitting position (sitting with trunk at 45 degrees above horizontal on an Evans postural drainage bed) for 15 minutes while calibration procedures for the gas-analysis equipment were carried out. This time allowed for stabilisation of metabolic rate and for saturation of the gas mixing box with expired moist air; baseline energy expenditure was then measured for 20 minutes. The subject was then positioned for treatment and 20 minutes of either the assisted ACBT or independent ACBT commenced. Cough and huff frequency were recorded throughout the test procedure. Coughing was defined as a spontaneous, uncontrolled manouvre, whereas huffing refers to a specific component of the treatment phase as instructed by the physiotherapist. The computer screen and equipment displays were not visible to the physiotherapist or subjects. No measurements were made during repositioning procedures.

On completion of the 20min treatment period, the subject rested in the sitting position for a further 40 minutes; measurements were continued throughout this time and were recorded as two 20min periods, designated Recovery 1 and Recovery 2. Once the indirect calorimetry and oximetry equipment were removed, pulmonary function tests were again performed. The same procedure, but with the alternate treatment, was carried out 24 hours later. Throughout the measurement periods (baseline, treatment, recovery), inspired and expired gas volumes, expired concentrations of oxygen and carbon dioxide, oxygen saturation and heart rate were continuously recorded and the frequency of spontaneous coughing was recorded.

On the day of discharge from hospital, pulmonary function tests were repeated (flow/volume loops and body plethysmography). Resting energy expenditure and oximetry were monitored for 20 minutes following 15 minutes of stabilising time. Weight was measured to establish weight loss or gain during admission and resting energy expenditure on discharge was calculated using the weight at discharge.

Analysis Day-to-day variability in oxygen consumption has not previously been reported for acutely unwell patients with cystic fibrosis. Therefore a preliminary test based on the resting oxygen consumption values for both days of testing for the first 10 subjects enrolled in this study was used to estimate daily variability in the primary outcome measure, oxygen consumption. Results of this test gave a standard deviation of 0.53 ml/kg/min where 10% of the mean is approximately 0.5 ml/kg/min. A sample size of 12 was required to ensure sufficient discriminating power (Type I error probability of 0.05, Type II error probability of 0.20, statistical power of 80%, between treatment regimens for oxygen consumption. Statistical analysis was calculated using the Minitab software package (Minitab Inc, Version 7.2). Results are presented as means and standard deviations unless otherwise indicated.

A two-way ANOVA (group and treatment) was used to determine whether physiotherapy resulted in differences between baseline and treatment. This was followed by cross-over two-sample *t*-tests to determine differences between regimens for responses to treatment for indirect calorimetry and pulmonary function parameters with $p < 0.05$ regarded as significant (Jones and Kenward 1989). The influence of carry-over, period, and interaction effects were also analysed. Carry-over effects refer to the effects of the initial treatment resulting in changes to the baseline of the second treatment. The effect of the test day, rather than the specific treatment, is the period effect. Significant relationships between treatments and days are termed interaction effects.

Results

Data were collected over a 14 month period (May 1995 to July 1996). Nineteen subjects consented to undertake the study. Four subjects failed to complete the procedure: one 12-year-old female was unable to cough effectively while wearing the Hans Rudolph Exercise mask during treatment stage; two stopped the test during the baseline data collection stage due to nausea (12-year-old male and 16-year-old male); and one subject failed to attend on the second day of testing (12-year-old male). Fifteen subjects, six female and nine male, completed the experimental procedure (Assisted/Independent protocol = 7; Independent/Assisted protocol = 8). Descriptive details for this group are contained in Table 1. Twelve subjects had mild pulmonary impairment (FEV_1 > 60% predicted; American Thoracic Society 1991) and three had moderate pulmonary impairment (FEV_1 40-60% predicted). No subjects were regarded as having severe pulmonary impairment (FEV_1 < 40% predicted). There was no statistical difference in pulmonary function between the two treatment groups (AB or BA) prior to the initial treatment on Day 1 as calculated by two-sample *t*-tests (*p* values ranged from 0.15 - 0.97).

Table 1. Descriptive details for the sample of 15 acute cystic fibrosis subjects on admission and discharge from hospital.

Parameter	Admission Day 1 n = 15 mean	(SD)	Discharge n = 15 mean	(SD)
Age (years)	15.4	(1.4)		
Gender	6 F, 9 M			
Weight (kg)	56.65	(8.6)	57.9	(10.5)
Weight (% predicted)	88.8	(9.1)	90.4	(9.0)
Height (cm)	164.15	(10.2)		
Length of admission (days)			15.6	(3.6)
Pulmonary function (% predicted)				
FVC	97.3	(17.6)	103.1	(13.2)
FEV_1	88.1	(21.6)	96.0	(15.5)
FEV_1/FVC	93.8	(12.5)	97.2	(9.4)
PEF	94.6	(27.7)	107.1	(23.3)
FEF_{25}	97.0	(37.2)	111.2	(34.9)
FEF_{50}	86.8	(37.5)	103.8	(35.9)
FEF_{75}	68.9	(32.3)	74.6	(29.3)
$FEF_{25/75}$	75.5	(27.9)	85.7	(29.3)
TLC	102.4	(11.4)	104.6	(11.6)
ITGV	107.5	(14.2)	110.4	(20.6)
RV	134.2	(22.7)	124.8	(26.4)
RV%TLC	138.7	(22.0)	123.4	(22.4)

Key:

FVC = forced vital capacity, FEV_1 = forced expiratory volume in one second, FEV_1/FVC = ratio of forced expiratory volume to forced vital capacity, PEF = peak expiratory flow, FEF_{25} = forced expiratory flow at 25% of vital capacity, FEF_{50} = forced expiratory flow at 50% of vital capacity, FEF_{75} = forced expiratory flow at 75% of vital capacity, $FEF_{25/75}$ = forced expiratory flow between 25% and 75% of vital capacity, TLC = total lung capacity, ITGV = intrathoracic gas volume, RV = residual volume, RV%TLC = residual volume as a percentage of total lung capacity

Indirect calorimetry parameters No significant differences were observed when mean resting values for indirect calorimetry parameters were compared between the AB and the BA group for Day 1. Mean and standard deviation (SD) values for all parameters are presented in Table 2. Good to excellent correlations were demonstrated for all parameters when baseline values were compared between the two days of testing (r ranging from 0.67 to 0.93), with the exception of cough frequency (r = 0.40). The coefficient of variation for resting VO_2 between days was 11%. When comparing baseline values with values during physiotherapy treatment, there were significant increases in VO_2 ml/kg/min (STPD) (p = 0.008; 10.7%), VCO_2 ml/kg/min (STPD) (p < 0.001; 19.4%) and the RER (p = 0.005; 7.2%). In addition, there was a small increase in Ve (p = 0.32; 4.8%) and SpO_2 (p = 0.34; 0.4%) and a small decrease in Ve/VO_2 (p = 0.21; 5.2%) and heart rate (p = 0.83; 0.5%); however these latter changes were not significant. The frequency of coughing during treatment was found to be greater than during baseline (p < 0.001).

Using two-sample cross-over t-tests, when the therapist-assisted ACBT and independent ACBT regimens were compared during the first two days of the admission, no significant differences were found for Ve (p = 0.76), VO_2ml/kg/min (STPD) (p = 0.32), VCO_2 ml/kg/min (STPD) (p = 0.79), RER (p = 0.59), Ve/VO_2 (p = 0.49), SpO_2 (p = 0.28), heart rate (p = 0.22) or cough/huff frequency (p = 0.43).

No carry-over or treatment by period interactions were demonstrated for any parameter. However there were significant period effects for Ve (p = 0.046), VO_2 ml/kg/min (STPD) (p = 0.02) and VCO_2 ml/kg/min (STPD) (p = 0.01); that is, the difference between baseline and treatment was smaller on the second day of treatment.

Table 2. Mean and standard deviation for indirect calorimetry parameters throughout the experimental procedure for the acute cystic fibrosis subjects "Assisted ACBT" is the therapist-assisted ACBT.

Parameter	Regimen	Baseline	Treatment	Recovery 1	Recovery 2	Discharge
Ve L/min	Assisted ACBT	8.11 (1.58)	8.53 (1.37)	7.88 (1.82)	7.92 (1.87)	8.27 (1.31)
	Independent ACBT	8.08 (1.44)	8.45 (1.77)	7.45 (1.41)	7.36 (1.08)	
VO_2 ml/kg/min	Assisted ACBT	5.08 (0.61)	5.68 (0.85)	5.23 (0.65)	5.23 (0.56)	5.39 (0.82)
	Independent ACBT	5.10 (0.64)	5.58 (0.95)	5.12 (0.70)	5.06 (0.61)	
Ve/VO_2	Assisted ACBT	1.61 (0.32)	1.51 (0.21)	1.52 (0.40)	1.52 (0.36)	1.48 (0.50)
	Independent ACBT	1.59 (0.25)	1.52 (0.22)	1.46 (0.31)	1.45 (0.16)	
VCO_2 ml/kg/min	Assisted ACBT	4.97 (0.69)	5.94 (0.65)	4.73 (0.62)	4.91 (0.55)	5.49 (0.81)
	Independent ACBT	4.98 (0.76)	5.94 (0.88)	4.62 (0.80)	4.72 (0.72)	
RER	Assisted ACBT	0.95 (0.07)	1.02 (0.10)	0.87 (0.10)	0.91 (0.10)	1.06 (0.10)
	Independent ACBT	0.95 (0.07)	1.01 (0.10)	0.89 (0.11)	0.93 (0.07)	
Heart Rate bpm	Assisted ACBT	85.83 (8.90)	86.29 (8.19)	84.55 (9.72)	83.65 (9.30)	82.71 (10.65)
	Independent ACBT	85.42 (10.7)	83.91 (10.63)	82.16 (12.14)	79.45 (7.99)	
Oxygen Saturation%	Assisted ACBT	96.07 (1.61)	96.56 (1.99)	96.38 (1.53)	96.97 (1.53)	96.32 (0.92)
	Independent ACBT	96.13 (1.66)	96.53 (1.93)	95.90 (1.55)	96.45 (1.49)	
Cough Frequency	Assisted ACBT	1.8 (2.07)	13.53 (9.07)	1.73 (2.46)	1.33 (1.63)	1.26 (2.84)
	Independent ACBT	2.6 (3.06)	13.26 (5.86)	1.40 (2.06)	1.26 (1.70)	
Forced expiratory manoeuvres (cough+huff)	Assisted ACBT		26.00 (7.70)			
	Independent ACBT		26.66 (5.16)			

When baseline values for indirect calorimetry parameters were compared between the first day of testing and discharge using two-sample cross-over *t*-tests, significant increases were found for VCO_2 ($p = 0.02$, 10.5%) and RER ($p = 0.002$, 11.2%) (Table 2). Although there were increases in other parameters, these were not statistically significant.

Pulmonary function Cross-over two-sample *t*-tests were calculated for each pulmonary function variable between pre- and post-treatment measurements on both days of testing. No significant differences were found for any pulmonary function variable between the initial two days of testing. Additionally, no significant improvement or deterioration in pulmonary function was demonstrated immediately following physiotherapy treatment for either treatment regimen.

A significant carry-over effect was demonstrated for the FEV_1/FVC ratio ($p = 0.047$) where the therapist-assisted ACBT resulted in a 7.9% increase in pre-treatment values on day two, whereas the independent treatment resulted in 0.5% increase (Table 3 and Figure 2). There were also carry-over effects for FEV_1 ($p = 0.07$), FEF_{50} ($p = 0.08$), FEF_{75} ($p = 0.08$) AND $MMEF_{25/75}$ ($p = 0.06$), but these failed to reach statistical significance. That is, when the therapist-assisted ACBT was conducted on Day 1, there were improvements in baseline values for these parameters on Day 2.

Pulmonary function values were compared using paired *t*-tests between the pre-treatment Day 1 of testing and the

Table 3. Raw data for the carry-over effect demonstrated for FEV_1/FVC.

	Assisted/Independent regimen (AB) n = 7			Independent/Assisted regimen (BA) n = 8		
	Day 1 pre	Day 2 pre	Diff	Day 1 pre	Day 2 pre	Diff
	65.7	70.2	4.5	83.6	86.1	2.5
	77.3	99.4	22.1	82.7	86.5	3.8
	93.8	102.0	8.2	103	103	0.0
	105.0	107.0	2	88.1	87	-1.1
	105.0	110.0	5	93.4	96.6	3.2
	104.0	113.0	9	104.0	102.0	-2.0
	99.6	100.0	0.4	111.0	110.0	-1.0
				90.3	88.9	-1.4
mean	92.9	100.2	7.3	94.5	95.0	0.5
	$p = 0.81$*				$p = 0.40$**	

* Two-sample *t*-test AB Day 1 pre vs BA Day 1 pre

** Two-sample *t*-test AB Day 2 pre vs BA Day 2 pre

day of discharge. Significant changes were observed for RV ($p = 0.049$, mean decrease of 7%) and RV%TLC ($p = 0.02$, mean decrease 9.5%) and statistically non-significant changes were demonstrated for FVC ($p = 0.06$, mean increase of 5.9%), FEV_1, ($p = 0.07$, mean increase of 9%) and FEF_{50} ($p = 0.05$, mean increase of 19.5%).

Discussion

In this group of patients with cystic fibrosis and predominantly mild pulmonary impairment, energy expenditure during chest physiotherapy treatment exceeded energy requirements at rest. The physiotherapy regimens consisted of sequential but repetitive cycles of respiratory muscle work resulting in differences in the breathing pattern, ventilatory volumes, velocity of airflow and cough frequency when compared with the resting period. For these reasons alone, physiotherapy could be expected to result in increased energy requirements. While position changes between baseline, treatment and recovery may have influenced energy expenditure measurements, no data were recorded during these postural changes and data collection was recommenced only when the subjects indicated they were comfortable and relaxed.

Resting VO_2 values for these acutely unwell subjects with cystic fibrosis (5.08 (0.61) ml/min/kg) are comparable with previous studies. Cropp and Rosenberg (1981) found that in a group of 16 clinically stable cystic fibrosis subjects (age of 19.5 (2.38)), resting oxygen consumption was 4.92 (0.31) ml/min/kg in subjects with cystic fibrosis and 3.16 (0.20) ml/min/kg in normal control subjects. Hirsch et al (1989) compared a group of nine normal subjects (age range 13 to 28 years) and 13 cystic fibrosis subjects with moderate to severe pulmonary impairment (age range 11 to 31 years, FEV_1 47 (22.9), FVC 67 (25.4)) and found an average resting oxygen consumption of 3.2 ml/min/kg in normal subjects and 5.3 ml/min/kg in subjects with cystic fibrosis.

While the resting values for cystic fibrosis subjects reported in this current study are higher than normal control values, it appears that the energy cost of physiotherapy was modest compared with published reports of maximal oxygen consumption in cystic fibrosis subjects. Shah et al (1998) reported the maximal oxygen consumption of 17 cystic fibrosis subjects (age 25 (10), FEV_1 62 (21)) as VO_2 max 24.6 (6.0) ml/min/kg. This suggests that while physiotherapy requires approximately a 10% increase in energy expenditure, this is neglible compared with the maximal capacity of oxygen consumption.

No significant difference was found between indirect calorimetry parameters of independent and therapist-assisted treatment in this group of cystic fibrosis patients. Furthermore, no significant difference was found in the frequency of forced expiratory manoeuvres, heart rate or oxygen saturation between the two forms of treatment. Physiotherapy treatment of either kind resulted in smaller differences between baseline to treatment on the second day of treatment for minute ventilation, VO_2 ml/kg/min (STPD) and VCO_2 ml/kg/min (STPD). This suggests that subjects, in general, expended less energy during treatment on the second day of treatment. The initial physiotherapy treatment may have had a role in reducing the expenditure of energy during treatment on the second day, possibly by facilitating secretion clearance and improving the distribution of ventilation. However, the subjects were also receiving intravenous antibiotics, supplemental vitamins, bronchodilating medication and nutritional support. The

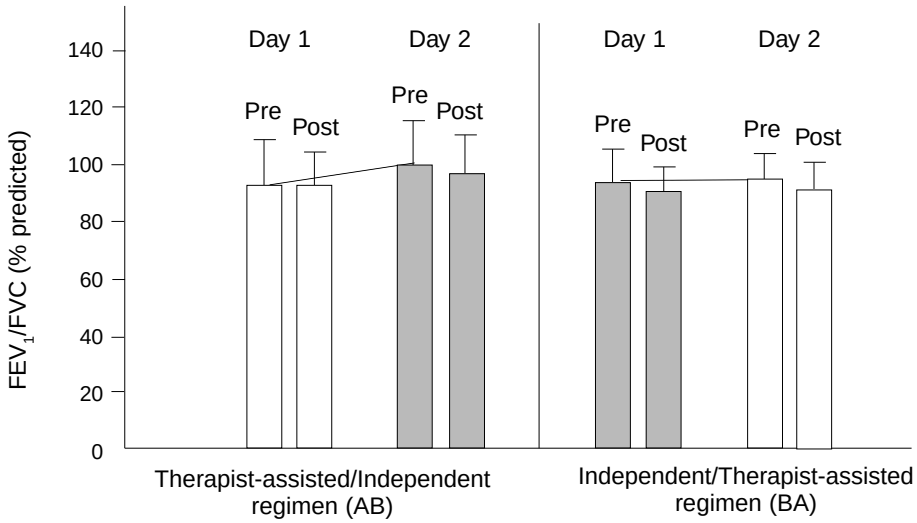

Figure 1. Carry-over effect for FEV_1/FVC for the therapist-assisted regimen. Shaded bars indicate independent regimen, unshaded bars indicate therapist-assisted regimen.

consistent reduction in differences between baseline and treatment values on the second morning of testing suggests that the overall constitution of the subjects had improved, resulting in less effort expended during physiotherapy.

Immediately following physiotherapy treatment, there was no significant change in any pulmonary function variable. However, with the therapist-assisted form of chest physiotherapy the FEV_1/FVC ratio exhibited a significant positive carry-over effect, while FEV_1, FEF_{50}, FEF_{75}, $MMEF_{25/75}$ demonstrated carry-over effects which failed to reach the required level of significance. Given that at least 23 subjects would have been required for sufficient statistical power to confidently determine pulmonary function differences between physiotherapy regimens, the results of the 15 subjects who were able to be recruited may well have reached statistical significance with an increased sample size. The carry-over effects for pulmonary function parameters were associated with the AB protocol. That is, when the therapist-assisted ACBT was conducted on Day 1, there was a significant improvement in baseline values on Day 2.

One explanation for these improvements in pulmonary function for the AB regimen is the potentially confounding effects of cough frequency and any additional physiotherapy treatments during the washout period. It is possible that the increased cough frequency during treatment may have been responsible in part for augmenting secretion clearance rather than the manual techniques of percussion and vibration. However, the frequency of forced expiratory manoeuvres (cough and huff) between the two regimens was similar and, if forced expiratory manoeuvres were the predominant reason for improvements in pulmonary function, these improvements should have occurred for both regimens rather than just the therapist-assisted form.

Subjects were required to continue their normal physiotherapy management during the intervening time between test mornings. The use of the cross-over *t*-tests to analyse carry-over effects effectively negates confounding effects of further treatments if only one group shows significant improvement. That is, for the AB group to show significant improvements in pulmonary function on Day 2, only these subjects would have had to perform additional chest physiotherapy which resulted in improved pulmonary function, while the BA group would have to either not perform chest physiotherapy or perform chest physiotherapy which did not alter or improve pulmonary function.

When the medical management and physiotherapy treatments during the 24 hour washout period were compared, no differences could be found which might contribute to the carry-over effect for the AB group. Fourteen of the 15 subjects had two further physiotherapy treatments between the first and second day of the study (one subject had one further physiotherapy treatment; BA group). Each treatment was of 15-20min duration and consisted predominantly of positive pressure mask therapy in the sitting position. No formal exercise and physical activity was scheduled and all subjects were restricted to activities of daily living. All subjects had nebulised bronchodilators prior to each physiotherapy treatment and were receiving an antibiotic regimen of Tobramycin and Ceftazidime titrated to weight.

Management of acute respiratory infection includes intravenous administration of antimicrobial drugs, intensive physiotherapy and nutritional support. With such regimens it has been demonstrated that pulmonary function

parameters, particularly those indicative of airway obstruction (FEV_1, FVC) distribution (RV, TLC), and intrathoracic gas volume significantly improve following 10 to 14 days of treatment, though significant measurable improvements have not been reported to occur before four to seven days of treatment (Gozal et al 1993, Redding et al 1982, Regelmann et al 1990, Rosenberg and Schramm 1993). Based on these previous studies, and given the events of the intervening 24 hours between the two test sessions, particularly combined with the type of physiotherapy treatment undertaken by subjects during this time (no manual techniques, ACBT or gravity-assisted positioning) it seems unlikely that the carry-over effect noted with the pulmonary function tests could be ascribed to the medical management or random occurrences in the AB group subjects.

While statistically significant, the clinical relevance of these improvements in pulmonary function following therapist-assisted treatment is unclear. These rapid improvements suggest that the inclusion of manual techniques has an effect on relieving airway obstruction, possibly by facilitating mucociliary clearance. It may be that the therapist-assisted treatment "kick-starts" airway clearance mechanisms leading to prolonged but effective improvements in regional or widespread airway secretion movement. The longer term results of such improvements remains speculative, however augmented secretion clearance may well reduce the proteolytic burden of the lung, resulting in slower progression of pulmonary impairment over time (Reisman et al 1988).

Subjects with moderate pulmonary impairment (n = 3) were observed to have higher oxygen consumption during physiotherapy treatment when compared with subjects with mild pulmonary impairment, but the small sample size prohibited statistical analysis. Other authors have reported that subjects with more severe pulmonary impairment had greater energy requirements at rest (Bronstein et al 1995, Fried et al 1991, Pencharz 1992) and hence may respond differently to physiotherapy treatment which includes manual techniques. For example, percussion combined with thoracic expansion exercises has been reported to result in significant increases in both inspiratory volume and VO_2 in normal subjects (Dallimore et al 1998), raising the concern that, in the absence of adequate time allowed for relaxation (breathing control), deconditioned patients with severe respiratory impairment may be unable to meet the increased demand for oxygen. Elsewhere, anecdotal reports of physiotherapy-related relaxation and reduced work of breathing have often been attributed to the massage effect of percussion rather than simply the secretion facilitation. Furthermore, while the ACBT as investigated in this study was consistently carried out using the same frequency of repetitions of each of its component techniques, in clinical practice this regimen is tailored to suit the individual patient. At present it is unclear which of the techniques (such as the ACBT) included in conventional management practices are responsible for such findings.

Published comparisons of therapist-assisted versus independent regimens have shown no clear differences in outcome measures in subjects with cystic fibrosis admitted to hospital for a respiratory exacerbation. While some studies have reported small but significant improvements in pulmonary function with independent physiotherapy management (Bain et al 1988, Pryor et al 1979, Pryor et al 1981), the majority can demonstrate no significant differences in pulmonary function parameters between treatment techniques (Arens et al 1994, Bauer et al 1994, Cerny 1989, Hofmeyr et al 1986, Murphy et al 1983, Reidler et al 1996, Webber et al 1985). It is important to note that a number of these studies (Murphy et al 1983, Reidler et al 1996, Webber et al 1985) lacked sufficient sample sizes to allow confident discrimination between treatments, and increased pulmonary function variability during recovery from exacerbations may have further reduced the likelihood of revealing significant improvements.

The volume of expectorated sputum was not recorded during this study and few subjects expectorated any sputum at all throughout the testing procedure. Few, if any, studies can demonstrate a relationship between expectorated sputum volume and changes in pulmonary function. Oberwalder et al (1991) investigated the physiotherapy management of cystic fibrosis patients admitted to hospital for an acute respiratory exacerbation and noted that pulmonary function increased significantly following physiotherapy treatments towards the end of the admission, even though the volume of sputum expectorated was progressively smaller. Such findings suggest that the volume of sputum expectorated does not primarily explain or correlate with improvements in pulmonary function. While easily measured, sputum volume is neither a reliable nor valid measure of chest physiotherapy as it is unlikely to reflect secretion movement within the bronchial tree in the absence of expectorate (Hasani et al 1994).

Previous studies have reported significant reductions in resting energy expenditure when admission results are compared with the day of discharge (Naon et al 1993, Steinkamp et al 1993). In this study, five of 15 subjects had reduced oxygen consumption at discharge compared with admission (mean decrease 8.5%), nine subjects demonstrated an increase (mean increase 13.4%) and one subject did not have oxygen consumption measured at discharge. The increases found upon discharge in this study were unexpected and, in the absence of any other signs of clinical deterioration, we speculate that these findings are primarily the result of retesting the subjects immediately prior to leaving the hospital.

Conclusion

Energy expenditure was significantly greater during physiotherapy treatment than at rest in this group of 15 subjects with cystic fibrosis admitted to hospital for management of an acute respiratory exacerbation. The modest increases in energy expenditure during

physiotherapy treatment may be due to the substantial increase in the frequency of coughing, altered breathing patterns and changes in respiratory muscle work. No evidence of fatigue, oxygen desaturation or worsening airflow obstruction was found during the initial two days of this admission, nor during or following physiotherapy treatment. In these subjects with mild and moderate pulmonary impairment, neither the therapist-assisted nor independent forms of the ACBT were found to be superior in conserving energy required during treatment. When the therapist-assisted ACBT was conducted on Day 1, improvements were observed for a number of pulmonary function parameters on the second day of testing. Although various forms of chest physiotherapy are widely used in ongoing management for cystic fibrosis, a clear understanding of the mechanisms by which individual techniques effect change is lacking. Future directions for studies into energy expenditure and physiotherapy may include the effect of other airways clearance techniques (positive expiratory pressure mask, autogenic drainage), specific positioning regimens, the influence of excessive airway secretions, severity of pulmonary impairment and the exploration of carry-over effects.

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