Respiratory Medicine (2012) **106**, 155–172

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/rmed

REVIEW

The active cycle of breathing technique: A systematic review and meta-analysis

Lucy K. Lewis [a,*], **Marie T. Williams** [a], **Timothy S. Olds** [b]

[a] *School of Health Sciences (C7-51), University of South Australia (city east campus), GPO Box 2471, Adelaide, South Australia 5001, Australia*
[b] *Health and Use of Time (HUT) Group, Sansom Institute for Health Research, University of South Australia, GPO Box 2471, Adelaide, South Australia 5001, Australia*

Received 21 December 2010; accepted 30 October 2011
Available online 18 November 2011

KEYWORDS
Breathing exercises;
Bronchiectasis;
Cystic fibrosis;
Meta-analysis;
Physical therapy techniques;
Review systematic

Summary
Question: What is the best available research evidence (volume, quality, consistency, generalisability) for the active cycle of breathing technique (ACBT)?
Design: Systematic review with meta-analysis.
Participants: Participants with respiratory conditions characterised by chronic sputum production.
Intervention: The active cycle of breathing or forced expiratory technique.
Comparator: All comparators including control conditions.
Outcome measures: All outcomes providing continuous data.
Results: Twenty-four studies were included. Ten comparators were identified with the most common being conventional chest physiotherapy, positive expiratory pressure and a control. The outcomes most frequently assessed were sputum wet weight ($n = 17$), forced vital capacity ($n = 12$) and forced expiratory volume in 1 s ($n = 12$). Meta-analysis was completed on the primary outcome of sputum wet weight. The standardised mean difference (SMD, random effects) showed an increase in sputum wet weight during and up to 1 h post ACBT compared to conventional physiotherapy (SMD 0.32, 95%CI 0.05–0.59), external oscillatory devices (0.75, 0.48–1.02), and control (0.24, 0.02–0.46).
Conclusion: The overall body of evidence was classified as good (good volume, quality and consistency, excellent generalisability). High level, variable risk of bias research evidence favours ACBT over most alternatives for short-term improvements in secretion clearance.

* Corresponding author. Tel.: +61 8 8302 2080; fax: +61 8 8302 2550.
E-mail address: lucy.lewis@unisa.edu.au (L.K. Lewis).

0954-6111/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rmed.2011.10.014

Contents

Introduction

The active cycle of breathing technique (ACBT) and the forced expiratory technique (FET) are commonly used to promote airway clearance for individuals with chronic lung disease characterised by copious secretions. Abnormal secretion production can potentially lead to airway obstruction and sputum retention, thereby predisposing the airways to infection and inflammation. Treatment methods that aim to clear secretions may decrease the frequency of infections, therefore preventing further airway damage and deterioration of lung function, and potentially reducing the rate of progression of lung disease.[1,2] The FET consists of one or two forced expirations or huffs, followed by breathing control (relaxed breathing).[3] The FET is an integral part of the ACBT, in conjunction with thoracic expansion exercises and interspersed periods of breathing control.[4] A typical ACBT cycle therefore consists of breathing control, 3–4 thoracic expansion exercises, breathing control, and the forced expiratory technique (huffing). The number and frequency of each of the components of the ACBT can be altered, but all components of the cycle must be present, and interspersed with breathing control.

A number of mechanisms have been proposed as the means by which ACBT achieves enhanced secretion clearance (Fig. 1). The forced expiratory manoeuvres (low- and high-volume huffing) are thought to promote secretion movement through changes in thoracic pressures and airway dynamics.[5] Breathing control is reported to prevent bronchospasm and oxygen desaturation while the thoracic expansion exercises assist in the loosening and clearance of secretions, and the improvement of collateral ventilation.[3,4] It is possible that the physiological effects of ACBT may differ slightly across different patient populations, depending on the degree of sputum production, stage of disease, and whether the patient is medically stable, or in an exacerbated state. Airway clearance techniques such as the ACBT have been shown to result in favourable outcomes in people with a wide range of lung disease, including non-CF bronchiectasis,[6] cystic fibrosis,[7] and COPD.[8]

The difficulty in determining which outcomes should be considered in reviewing the literature associated with a technique such as the ACBT stems from the ambiguity between short and long term goals. While it is possible that short term goals such as improved sputum clearance may lead to improved longer term health outcomes such as improved quality of life or reduced disease progression, it remains to be seen whether this causal chain is represented in the current body of evidence underpinning the technique.

This review sought to identify the body of evidence underpinning the FET and ACBT, and therefore recorded all reported outcomes. Due to the short duration of the majority of included studies, meta-analysis was completed only on outcomes which were considered to reflect a short term, airway clearance mediated effect such as sputum weight, rather than outcomes reflecting multiple therapies (pharmacological agents, nutrition). Actual sputum production is a commonly used outcome measure for airway clearance techniques in clinical practice. Clinicians have been shown to commonly use sputum production in patient assessment, and patients commonly consider sputum production in their own assessment of the efficacy of airway clearance techniques such as the ACBT.[9,10] The outcome of sputum volume has been identified as a relevant, inexpensive, minimally invasive, easily accessible and clinically useful marker to monitor response to therapy in people with cystic fibrosis[11] and bronchiectasis.[12] In people with bronchiectasis, daily sputum volume has been identified as an important prognostic indicator, with people with higher daily sputum volume having poorer quality of life.[13] To date, few studies report improvements in pulmonary function as a result of airway clearance techniques in people with chronic lung disease during non-exacerbated states. Short and longer term changes in pulmonary function tests (PFTs) in people with chronic lung conditions generally cannot be solely attributed to the impact of airway clearance techniques. It is likely that any changes in PFTs induced by clearance techniques will be small, transient and subsumed within day to day variance of PFTs which may be as high as 15 per cent in the forced expiratory volume in 1 s (FEV_1) in people with cystic fibrosis (CF).[14] Therefore, outcomes relating to overall lung function such as forced vital capacity (FVC) and FEV_1 which reflect severity of pulmonary impairment and disease progression were not included in the meta-analysis.

This systematic review summarised all primary data from experimental studies of FET/ACBT in order to assess the body of evidence for the intervention. A modified National Health and Medical Research Council[15] body of evidence matrix used in a previous review[16] was used to assess the volume, quality, effectiveness, and consistency

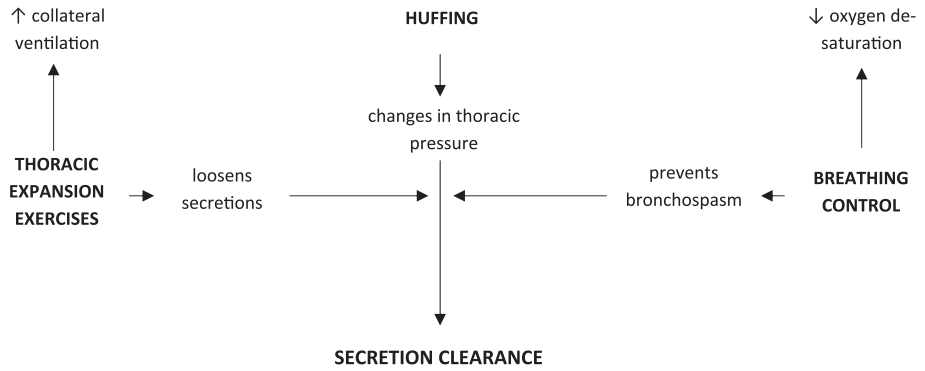

Figure 1 Proposed mechanisms by which FET/ACBT results in secretion clearance.

of the evidence. The primary question of this review was: *What is the best available research evidence (volume, quality, consistency, generalisability and effectiveness) for the therapeutic interventions of FET/ACBT?*

Method

Identification and selection of studies

The databases AMED, MEDLINE, CINAHL, Scopus, Web of Science and the Cochrane Library were searched from inception to August 2008 (Appendix). Titles and abstracts were screened to identify relevant studies. Citations were retrieved as full text for more detailed evaluation of applicability. Reference lists of all full text articles included in the short list and all systematic reviews located were screened. Researchers involved in the area were invited to review the publication short list to identify any additional studies.

Initially, citations were identified which indicated explicitly that at least one treatment group had received FET or ACBT in the title or abstract. Two reviewers independently screened the initial search results for potentially eligible studies. The reviewers resolved disagreements by consensus. All identified studies were then retrieved in full, as were any studies where the abstract was unavailable or where ambiguity existed. To be included, studies were required to use an experimental design, report primary original data pertaining to the therapeutic techniques of FET/ACBT, and be published in English. There were no publication year limits.

Assessment of characteristics of studies

Quality and volume of the evidence

Risk of methodological bias was assessed using the LOW appraisal tool.[16] The presence or absence of nine criteria was assessed by two independent reviewers with a maximum possible score of nine. Criteria were assessed using only the documentation provided in the publication. Disagreements were resolved by a third independent reviewer. Due to the focus of this review on establishing the best research evidence for the FET/ACBT and the likelihood that varying levels of evidence would be retrieved, the Lloyd-Smith hierarchy of evidence,[17] rather than the NHMRC hierarchy was used as this hierarchy accounts for the lower levels of evidence.

Generalisability of the evidence

Studies including people with respiratory conditions where chronic sputum production was likely to be a feature (CF, bronchiectasis, chronic bronchitis) were considered to represent the population where FET/ACBT is indicated. While chronic sputum production is a feature of these conditions, it is likely that there is considerable variation in sputum production both between and within populations,[18] with the range of reported daily sputum volume differing between people with chronic bronchitis (5 to >50ml),[19] and bronchiectasis (20—500ml).[20] To date, no information could be found which reported the average daily sputum volume in people with cystic fibrosis. The generalisability of the included studies (how representative the studies were to the population of interest) was assessed separately to the critical appraisal (LOW tool), using a modified NHMRC body of evidence matrix. Generalisability of the evidence was determined by calculating the percentage of studies that included participants with chronic sputum producing respiratory diseases. The generalisability was classified as excellent if greater than 90 per cent of the studies included participants with respiratory conditions with chronic sputum production, good (75—90%), fair (50—74%) and poor (<50%).[16]

Participants

There were no restrictions placed upon the age range of participants (children or adults) or symptoms (asymptomatic and participants with acute or chronic conditions). Animal studies or papers reporting mathematical models were excluded.

Intervention

Within the existing literature and in the clinical environment, variations occur in the definition and application of physiotherapy treatment modalities. The ACBT was included if it was described as containing three essential components: 1) breathing control, 2) FET and 3) thoracic expansion exercises. The technique may also include postural drainage (PD) or percussion/shaking.[21] Similarly, the technique of FET was required to contain relaxation or breathing control, and huffing, and may include PD and percussion/shaking.

Comparators

Possible comparisons were a control or another intervention. Studies which compared the intervention plus or minus an adjunct therapy such as pharmacological agents were excluded. For the purposes of this review, comparators have been grouped together according to the following descriptions.

Conventional physiotherapy (CPT): any combination of PD, percussion, shaking, vibrations, huffing and directed coughing.[21]

Devices which provided resistive inspiratory manoeuvres (RIM): adjunctive equipment which provided resistance of approximately 80 per cent of the maximal sustained inspiratory pressure.

Devices which altered airways pressure or air flow: including oscillatory devices such as flutter and acapella, positive expiratory pressure (PEP) devices and oral high frequency oscillation (OHFO).

Devices which applied intermittent pressure to the chest wall: including mechanical percussion devices such as the Equi-med percussor and high frequency chest compression devices such as the Hayek Oscillator.

Exercise: prescribed for the purpose of airway clearance.

Autogenic drainage (AD): high expiratory flow rates at varying lung volumes to increase sputum clearance and avoid closure of the airways.

Outcome measures

All outcomes were recorded. Decisions concerning meta-analysis were made upon completion of data extraction and

only outcomes that reflected a specific outcome of airway clearance were considered for meta-analysis.

Data analysis

The relevant details about the method (study design, participants, intervention, outcome measures) and results (sample size, means, standard deviations, standard errors, confidence intervals, *p* values, correlation coefficients) were extracted by two independent reviewers. Data were extracted for the outcome of sputum wet weight which used continuous scales of measurement (interval, ratio) either reported by authors or subsequently calculated from published data.

Data on the primary outcome measure of sputum wet weight were entered into the Cochrane Collaboration's Review Manager Software (RevMan 5.0) to enable calculation of pooled estimates using a random effects model.Data from cross-over trials were incorporated using the generic inverse variance method, involving expression of data in terms of the paired mean differences between interventions and their standard error.[22] These values were calculated either from individual paired participant data, or by calculation of mean differences between interventions and their standard error from means, standard deviations, reported *p* values and confidence intervals. For studies that did not report paired results, but means and standard deviations for each intervention, paired analyses were approximated by assuming a degree of correlation between the interventions, based on an average observed correlation among the other studies. Sensitivity analyses with an assumed correlation of zero were performed to assess the impact of the assumed correlation on the outcome of the meta-analysis.[22]

The overall effect of the intervention was reported using standardised mean differences (SMDs).Ninety-five per cent confidence intervals (95% CIs) were calculated for each individual study and the pooled estimates. Heterogeneity of studies was quantified using the I^2 statistic with $p < 0.05$ considered statistically significant. Where significant heterogeneity existed, studies and data were reviewed in order to identify possible sources of variation.

Results

Flow of studies through the review

Five hundred and thirty nine titles were identified by the electronic search and two publications identified through contacting experts. Of these, 107 full text publications were retrieved, of which 24 were included in the final review. Reasons for exclusion of studies are presented in Fig. 2.[23]

Characteristics of studies

Volume and risk of methodological bias of evidence

The volume of the evidence was assessed using the Lloyd-Smith evidence hierarchy.[17]No studies fulfilled the criterion for the highest level of evidence (1a, systematic reviews) and two randomised controlled trials were classified as level 1b. Eighteen of the included studies were crossover in design, with 11 of these classified as level 1b (clear randomisation procedures) and seven as level 2a (unclear randomisation procedures). The remaining four studies were classified as level 2b. Risk of methodological bias within studies ranged from two to nine points (Table 1) (note: a maximum score of nine was possible only for studies with a separate control group). The most common methodological issues were inadequate reporting of sample size justification (item 3, 19 studies) and absence of a separate control group (item 4, 22 studies). Twelve of the 22 studies without a separate control group did not report sufficient information regarding duration of the washout period or stability of baseline measures (item 6).

Generalisability of evidence

Ninety-two per cent of the included studies included participants with respiratory conditions with chronic sputum production. Of these, the majority ($n = 16$) recruited participants with CF,[3,7,24–37] four with non-CF bronchiectasis[6,38–40] and two investigated chronic bronchitis.[8,41] The remaining studies included participants with acute hypercapnic respiratory failure,[42] and chronic obstructive pulmonary disease (COPD).[43] Therefore the generalisability was classified as excellent with 92 per cent ($n = 22$) of the included studies carried out on respiratory conditions with likely chronic sputum production (Table 2).

Participants

Twelve of the 24 included studies quantified disease severity using percentage of predicted FEV_1. Using the Global Initiative for Chronic Obstructive Lung Disease (GOLD)[44] COPD severity classification system (mild $\geq$ 80, moderate 50–80, severe 30–50, very severe $<$ 30), the severity of disease in 10 of the studies was classified as moderate, and in two studies as severe. The remaining studies did not report the $FEV_{1(\%\ predicted)}$ at baseline. Nine studies were undertaken with participants experiencing an acute respiratory exacerbation.[3,7,26,28,33–36,42]

Thirteen studies were conducted exclusively on adults ($\geq$18 years).[6–8,25,26,28,33,38–43] Nine studies were conducted on a combination of adolescents (12–17 years) and adults,[3,24,27,29,30,32,34–36] and two studies included children ($<$12 years) with adolescents and adults.[31,37]

Intervention

The majority of the included studies investigated the ACBT ($n = 21$), with the remaining three studies investigating the FET. Fifteen studies involved single treatments.[6–8,25,26,29,30,32,34–38,40,41]In four studies the duration of each treatment arm was less than seven days.[3,27,28,33] One study had a variable treatment time for each participant depending on the length of stay in the intensive care unit but averaged approximately eight to nine days.[42] In the remaining four studies the duration of each treatment arm ranged from three weeks to six months.[24,31,39,43]

Comparator/control

Ten of the included studies compared the intervention with an oral device (*n*: 5 PEP, *n*: 3 flutter, *n*: 1 acapella, *n*: 1

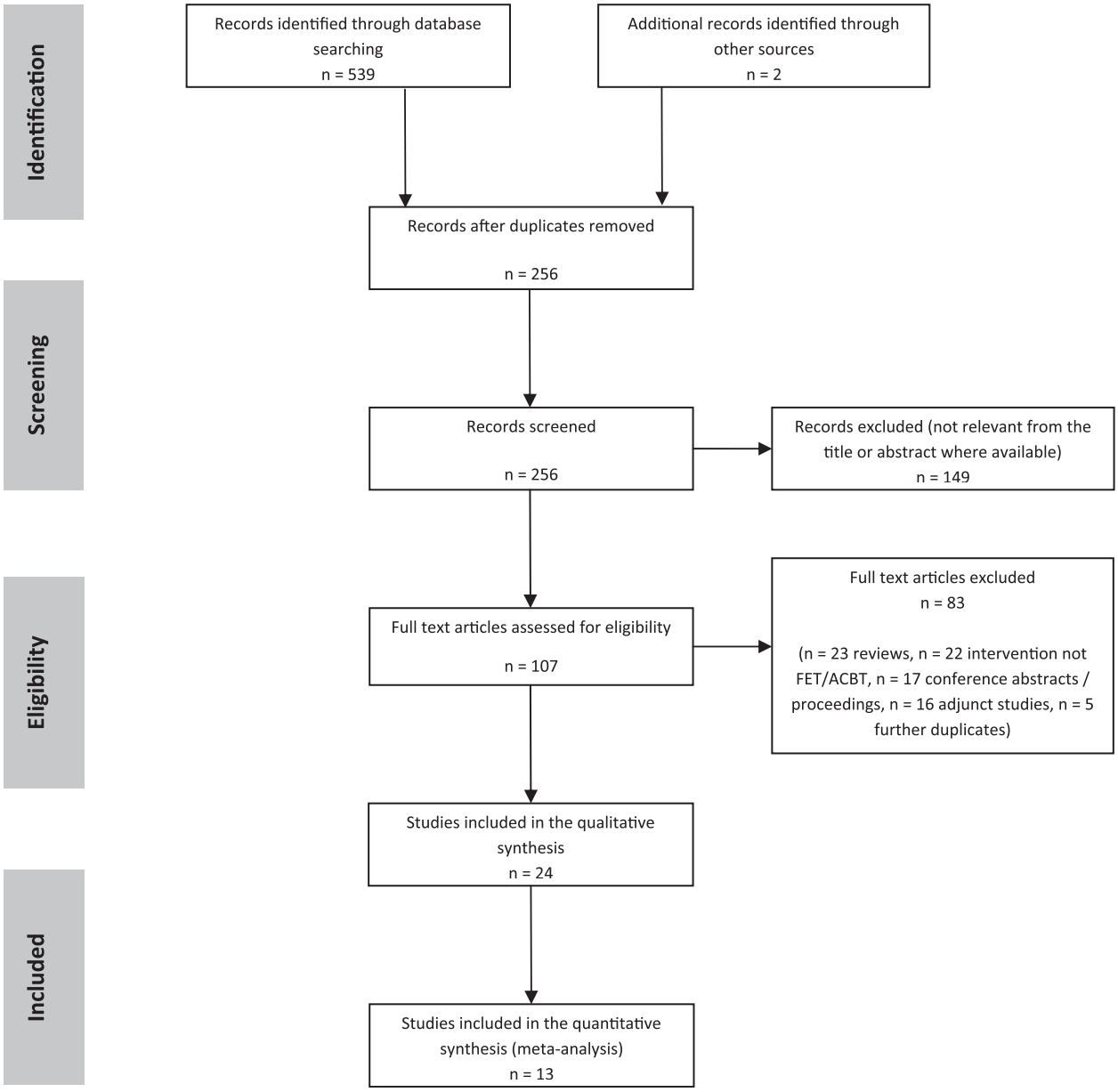

Figure 2 PRISMA chart[23] demonstrating the flow of studies through the review.

OHFO), five with CPT, four with a control, two with RIM, thoracic oscillatory devices and AD. Only one study compared ACBT to exercise prescribed for sputum clearance (Table 3).

Outcome measures

A total of 35 outcome measures were identified in the included studies. The most commonly reported outcomes were sputum wet weight (n = 17), FVC (n = 12), FEV_1 (n = 12), and patient preference or acceptability of treatment (n = 10) (Table 4). As previously outlined, outcomes relating to lung function are more likely to reflect combined therapeutic strategies. Therefore, the outcomes of participant preference and acceptability of treatment and sputum wet weight were further explored for the purposes of this review.

Participant preference/acceptability

Ten studies involving 182 participants reported participant preference or acceptability.[6,7,25,29,31,35,37–40] The study by Carr et al[25] contained a five item questionnaire to assess participant views on the self chest clapping component of the intervention rather than the ACBT. The main findings for participant preference and acceptability in relation to FET/ACBT are summarised in Table 5.

Sputum wet weight

Description of studies

Seventeen studies reported the primary outcome of sputum wet weight. Two studies that investigated sputum wet

Table 1 Methodological quality of studies based on the LOW[a] critical appraisal tool for experimental studies.

Study	1	2	3	4	5	6	7	8	9a	9b	Total (0–9)
Pryor & Webber 1979[3]	Y	Y	N	N	N	N	N	N	Y	Y	4
Inal-Ince et al 2004[42]	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	9
Savci et al 2000[43]	Y	Y	N	Y	Y	N	Y	N	Y	Y	7
Blomquist et al 1986[24]	Y	Y	N	N	N	N	Y	Y	Y	Y	6
Carr et al 1995[25]	Y	Y	N	N	N	Y	Y	Y	N	Y	6
Pryor et al 1990[15]	Y	N	N	N	N	N	Y	N	N	N	2
Webber et al 1986[27]	Y	Y	N	N	N	N	Y	Y	N	Y	5
Murphy et al 1983[28]	Y	N	N	N	N	N	N	N	Y	N	2
Eaton et al 2007[6]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Falk et al 1984[29]	Y	Y	N	N	N	Y	N	Y	N	Y	5
Lannefors & Wollmer 1992[30]	Y	N	N	N	N	N	N	Y	N	Y	3
Patterson et al 2005[38]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Phillips et al 2004[7]	Y	Y	N	N	N	Y	Y	Y	N	Y	6
Steen et al 1991[31]	Y	Y	N	N	N	N	N	Y	Y	Y	5
Thompson et al 2002[39]	Y	Y	Y	N	N	Y	N	N	N	Y	5
van Hengstum et al 1988[32]	Y	N	N	N	N	N	Y	Y	Y	Y	5
Chatham et al 2004[33]	Y	Y	N	N	N	Y	Y	N	N	Y	5
Hofmeyr et al 1986[34]	Y	Y	N	N	N	Y	N	N	N	Y	4
Milne & Eales 2004[35]	Y	Y	N	N	N	Y	N	Y	Y	Y	6
Steven et al 1992[36]	Y	Y	N	N	N	N	N	Y	N	Y	4
Patterson et al 2004[40]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
van Hengstum et al 1990[8]	Y	N	N	N	N	Y	Y	Y	Y	Y	6
van Hengstum et al 1991[41]	Y	N	N	N	N	N	Y	N	Y	Y	4
Miller et al 1995[37]	Y	Y	N	N	N	Y	Y	N	Y	Y	6

[a] LOW tool summary of criteria: 1. Did the study address a clearly focused issue? 2. Were the participants recruited in an acceptable way? 3. Was there a sufficient number of participants? 4. Was there a separate control group? 5. Was there equal chance of participants being allocated into either group? 6. Were the baseline measures stable? 7. Were the outcomes measured accurately to minimize bias? 8. Have the confounding factors been accounted for? 9a. Were the results presented so the effect size was shown or could be calculated? 9b. Do you subjectively believe the results?.

weight pre- and post ACBT did not report standard deviations and were therefore unable to be included in the meta-analysis.[25,26] One study reported median values only and was subsequently excluded.[29] One further study reported a significant beneficial effect of FET when compared to two alternative interventions (Equi-med percussor and PD $p < 0.05$, manual percussion and PD $p < 0.05$).[28] However, this study was completed on only two participants, and it was unclear how the authors dealt with such a small sample in the statistical analyses (LOW score 2/9). This study was therefore excluded from the meta-analysis. A total of 13 studies involving 232 participants were included in the final meta-analysis.

Nine studies reported sputum wet weight during and up to 1 h post FET/ACBT.[3,6,7,31,33,34,36,38,40] Three studies reported 24 h post-treatment sputum wet weight[8,32,35] and one study reported four week accumulated sputum wet weight.[39]

Available data and subsequent analyses

Two studies provided sufficient data (SDs for intervention and comparator groups and for the mean difference between groups) to enable calculation of correlation coefficients between the intervention and comparator groups (Eaton et al[6] calculated correlation coefficient 0.80, Milne et al[35] 0.90). Five studies reported sufficient data (SDs for the intervention and comparator groups) to allow for calculation of the SMD, but an imputed correlation coefficient midway between the available coefficients (0.85) was used to enable calculation of the $SE_{(SMD)}$ for these studies.[8,31–33,40] The remaining six studies contained insufficient data (no reported SDs), and the imputed correlation was used to subsequently calculate both the SMD and the $SE_{(SMD)}$ to allow for inclusion of these studies in the meta-analysis.[3,7,34,36,38,39]

FET/ACBT versus all comparators

During and up to 1 h post-treatment

Nine studies involving 192 participants were included in the final meta-analysis for sputum wet weight during and up to 1 h post-treatment. One study[7] provided two data sets (morning and evening treatments), therefore 10 data sets were included in the analysis. The FET/ACBT resulted in no significant difference in sputum yield during and up to 1 h post-treatment SMD 0.14 (95%CI -0.20–0.48) with the studies demonstrating significant heterogeneity ($p < 0.00001$).

Up to 24 h post-treatment

Three studies involving 23 participants reported 24 h sputum wet weight. There was no significant difference between FET/ACBT and the comparators in 24 h sputum wet weight, SMD 0.18 (95%CI -0.08–0.44), and the studies were shown to be homogeneous ($p = 0.11$).

Table 2 Summary of all included studies.

Study	Study design	*n*	Participant type and age (years)	Description of intervention and comparators	Outcomes measured
Pryor & Webber 1979[3]	Randomised crossover trial (2 way)	16	CF Age 20.5 (14—28)	1. CPT (PD, self percussion, coughing, percussion and shaking) + thoracic expansion exercises 2. ACBT (+PD, self percussion)	treatment time, sputum wet weight
Inal-Ince et al 2004[42]	Randomised controlled trial	34 (2 groups of $n = 17$)	Intensive care in-patients with acute hypercapnic respiratory failure Age group 1: 65 ± 8 Age group 2: 65 ± 13	Group 1: ACBT (+vibrations and shaking if copious secretions) + non-invasive ventilation Group 2: Control (non-invasive ventilation only)	length of time requiring non-invasive ventilation, acute physiology score, arterial blood gas values, ICU length of stay
Savci et al 2000[43]	Randomised controlled trial	30 ($n = 15$ each group)	COPD *Group 1*: Age 58.3 ± 8, FEV_1(%predicted): 39 ± 14 *Group 2*: Age 61.3 ± 7.9, FEV_1(%predicted): 41 ± 18	Group 1: AD Group 2: ACBT (+PD, percussion and shaking)	lung function (FVC, FEV_1, PEFR, FEF_{25-75}, FEF_{75-85}), oxygen saturation, arterial blood gas information, 6 min walk test, dyspnoea (modified Borg scale)
Blomquist et al 1986[24]	Same subjects, two step design	14	CF Age: 17.8 (13—23) FEV_1(%predicted): 63.4 (44.2—112.9)	*Phase A (6 months):* CPT (PD, percussion, chest compressions) + increasing physical activity. *Phase B (6 months):* ACBT (relaxed controlled breathing, 3-4 deep breaths + percussion, relaxed controlled breathing, 1—2 huffs with self percussion + PD).	lung function (FVC, FEV_1), regional lung function, arterial blood gas data
Carr et al 1995[25]	Same subjects, pre/post design	12	CF Age 25.8 (18—50) FEV_1(%predicted): 31.8 (16—60)	ACBT + self percussion until nil sputum clearance, in patient's choice of PD position	lung function (FEV_1, FVC), SaO2, 6 MWT, sputum weight, patient views
Pryor et al 1990[26]	Same subjects, pre/post design	20	CF Age: 26.2 (19—34) FEV_1: 1.08 (0.60—2.40)	ACBT + PD	sputum weight, SaO_2
Webber et al 1986[27]	Same subjects (pre/post design)	12	CF Age: 19.5 ± 4.1 FEV_1(%predicted): 61.5 ± 20.7	FET (+PD, percussion, shaking)	lung function (FEV_1, FVC, TLC, RV, FRC, ERV, alveolar volume, PEFR, MEF_{50-75}, PIFR, index of gas trapping)

Murphy et al 1983[28]	Randomised crossover trial (3 way)	2	CF Age: 19.5 ± 3.5	1. PD and assisted percussion (equi-med percussor) 2. PD and percussion by a physiotherapist 3. ACBT (+PD)	sputum wet weight, lung function (FEV_1, FVC, PEFR)
Eaton et al 2007[6]	Randomised crossover trial (3 way)	36	Non-CF bronchiectasis Age: 62 ± 10 FEV_1(%predicted): 57.8 ± 19.8	1: Flutter 2: ACBT 3: **ACBT (+PD)**	sputum wet weight, sputum wet volume, patient preference and acceptability, lung function (FVC, FEV_1), oxygen saturation, dyspnoea (Borg score)
Falk et al 1984[29]	Randomised crossover trial (4 way)	14	CF Age: 18 (14–30) FEV_1(% predicted): 54 (15–55)	1: PD, percussion and vibrations 2: PEP (+PD) 3: PEP (sitting position) 4: FET (pursed lip and diaphragm breathing in sitting with forced expirations with open glottis)	sputum wet weight, number of coughs, peripheral oxygen delivery (percutaneous oxygen), lung function (FVC, FEV_1, PEFR), patient acceptability, review of radiographs
Lannefors & Wollmer 1992[30]	Randomised crossover trial (3 way)	9	CF Age: 24.8 ± 7.7 FEV_1(%predicted): 51 ± 20.2	1: ACBT (+PD) 2: PEP (sitting) + FET (PD) 3: physical exercise bike ergometer + FET (PD)	mucus clearance (gamma camera)
Patterson et al 2005[38]	Randomised crossover trial (2 way)	20	stable, productive bronchiectasis Age: 58 ± 11 FEV_1(%predicted): 64 ± 22	1: ACBT (+PD) 2: acapella	sputum wet weight, lung function (FEV_1, FVC, PEFR), oxygen saturation, breathlessness (15 point score), no. of coughs, patient preference, treatment times
Phillips et al 2004[7]	Randomised crossover design (2 way)	10	CF Age: 59 ± 9 FEV_1(%predicted): 56.1 ± 23.3	1. supervised use of the Hayek oscillator 2. supervised ACBT (+PD)	sputum wet weight, lung function (FVC, FEV_1), heart rate, oxygen saturation, blood pressure, patient preference
Steen et al 1991[31]	Randomised crossover trial (4 way)	28	CF Age: 14 (8–21) FEV_1(%predicted): 68 (15–114)	1: FET (+PD, percussion) 2: PEP (+PD, percussion, FET) 3: **PEP (sitting)** 4: PEP and FET (sitting).	sputum wet weight, lung function (PEFR, FEV_1, FVC), patient preference

(*continued on next page*)

Table 2 (*continued*)

Study	Study design	*n*	Participant type and age (years)	Description of intervention and comparators	Outcomes measured
Thompson et al 2002[39]	Randomised crossover trial (2 way)	17	non-CF bronchiectasis Flutter first group: Age 59 ± 8, FEV_1(%predicted): 67 ± 38. ACBT first group: Age 68 ± 16, FEV_1(%predicted): 70 ± 42	1. Flutter 2. ACBT (+PD)	sputum wet weight, treatment time, lung function (PEFR, FEV_1, FVC), dyspnoea (Borg scale), chronic respiratory disease questionnaire, patient preference
van Hengstum et al 1988[32]	Randomised crossover trial (2 way)	8	CF (n = 6) Agammaglobulinaemia (n = 2) Age: 23 (15—27) FEV_1(%predicted): 65 ± 29	1: CPT (PD, percussion, directed coughing) + deep breathing 2: ACBT (+PD, chest compressions)	regional clearance, tracheobronchial clearance
Chatham et al 2004[33]	Randomised crossover trial (2 way)	20	CF Adults	1: ACBT(+PD and percussion) 2: RIM at 80% of maximal sustained inspiratory pressure	sputum wet weight
Hofmeyr et al 1986[34]	Randomised crossover trial (3 way)	18	CF Age: 22.5 (13—37) FEV_1: 1.3 (0.45—3.25)	1: ACBT (+PD) 2: PEP (+PD, breathing control, FET) 3: **PEP (sitting, breathing control, FET)**	sputum wet weight, lung function (FEV_1, FVC), oxygen saturation
Milne & Eales 2004[35]	Randomised crossover trial (2 way)	7	CF Age: 28 (16—42) FEV_1: 1.23 (no SD reported)	1: Flutter (10—15 exhalations) + FET 2: ACBT	lung function (FEV_1, FVC, PEFR, FEF_{25-75}, FIF_{50}), sputum wet weight, patient preference
Steven et al 1992[36]	Randomised crossover trial (3 way)	24	CF Age: 25 (17—33) FEV_1: 1.11 (0.44—2.72)	1. sit and cough (breathing control in-between coughs) 2. **ACBT (+PD)** 3. ACBT (sitting)	sputum wet weight, lung function (FEV_1, FVC, FEF_{50}, FEF_{75}), oxygen saturation
Patterson et al 2004[40]	Randomised crossover trial (2 way)	20	non-CF bronchiectasis Age: 54.4 ± 14.4	1: ACBT (+PD, vibrations) 2: RIM at 80% of maximal sustained inspiratory pressure (test of incremental respiratory endurance)	sputum wet weight, lung function (FEV_1, FVC, PEFR), oxygen saturation, patient preference
van Hengstum et al 1990[8]	Randomised crossover trial (3 way)	8	Chronic bronchitis Age: 60 (44—76) FEV_1(%predicted): 68 ± 27	1: ACBT (+PD) 2: **oral high frequency oscillation** 3: **control (breathing humidified air and huffing)**	sputum wet weight, sputum dry weight, tracheobronchial clearance, lung function (FEV_1, FVC, MEF_{50})
van Hengstum et al 1991[41]	Randomised crossover trial (3 way)	7	Chronic bronchitis Age: 62 (48—73) FEV1(%predicted): 56+-21	1: PEP (+FET) 2ACBT (+PD) 3: control (only spontaneous cough)	regional clearance

Miller et al 1995[37]	Randomised crossover trial (2 way)	18	CF Age: (11–32)	1: ACBT (+PD, self percussion) 2: AD (sitting or supine)	oxygen saturation, heart rate, patient preference, lung function (FVC, FEF_{25-75}), sputum wet weight, regional clearance

Bold type indicates the intervention and comparator interventions included in the meta-analysis in cases where the study has more than two treatment arms, AD Autogenic drainage, CF Cystic Fibrosis, COPD Chronic obstructive pulmonary disease, CPT Conventional physiotherapy, ERV Expiratory reserve volume, FEF Forced expiratory flow, FEV_1 Forced expiratory volume in 1 s, FIF Forced inspiratory flow, FRC Functional residual capacity, FVC Forced vital capacity, ICU Intensive care unit, MEF Maximal expiratory flow, PD Postural drainage, PEFR Peak expiratory flow rate, PEP Positive expiratory pressure, RIM Resisted inspiratory manoeuvres, RV Residual volume, SaO_2 Arterial oxygen saturation, TLC Total lung capacity, 6 MWT Six minute walk test.

FET/ACBT versus individual comparators

The results of FET/ACBT compared to the individual comparators are summarised in Table 6.

FET/ACBT versus RIM

During and up to 1 h post-treatment

Two studies involving 40 participants investigated sputum wet weight up to 30 min post-treatment with ACBT and RIM.[33,40] There was no significant difference, SMD -1.08 (95%CI -3.85 to 1.70), with the studies demonstrating significant heterogeneity ($p < 0.00001$). Considering these studies separately, RIM resulted in a significant increase in sputum wet weight compared to ACBT in patients with an exacerbation of CF,[33] SMD -2.5 (95%CI -2.99 to −2.01), whereas ACBT resulted in a significant increase in sputum wet weight compared to RIM in participants with chronic bronchitis,[31] SMD 0.33 (95%CI 0.08−0.58).

FET/ACBT versus CPT

During and up to 1 h post-treatment

One study involving 16 exacerbated CF participants compared sputum wet weight up to 30 min post-treatment between the interventions of ACBT and CPT.[3] ACBT resulted in a significant increase in sputum wet weight when compared with CPT, SMD 0.32 (95%CI 0.05−0.59).

Up to 24 h post-treatment

One study involving eight CF participants compared 24 h sputum wet weight between the interventions of ACBT and CPT.[32] There was no significant difference in 24 h sputum yield between ACBT or CPT, SMD 0.07 (95%CI -0.30−0.44).

FET/ACBT versus PEP

During and up to 1 h post-treatment

Two studies involving 46 CF participants investigated sputum wet weight during treatment with FET/ACBT as opposed to PEP.[31,34] There was no significant difference between the two interventions for sputum wet weight, SMD 0.26 (95%CI -0.11−0.63), and the studies demonstrated significant heterogeneity ($p = 0.04$). Considering these studies separately, ACBT resulted in a significant increase in sputum wet weight in exacerbated CF participants,[34] SMD 0.47 (95%CI 0.18−0.79), and there was no significant difference between the interventions in stable CF participants,[31] SMD 0.09 (−0.11−0.29).

FET/ACBT versus oral oscillatory devices

During and up to 1 h post-treatment

Two studies involving 56 participants with bronchiectasis investigated sputum wet weight up to 30 min post-treatment with ACBT and the oral oscillatory devices of flutter[6] and acapella.[38] There was no significant difference between the two interventions for sputum wet weight, SMD

Table 3 Comparators for each of the included studies.

Study	Intervention	CPT	RIM	Oral devices	Thoracic devices	Exercise	AD	Control
Pryor & Webber 1979[3]	ACBT							
Inal-Ince et al 2004[42]	ACBT							NIV
Savci et al 2000[43]	ACBT							
Blomquist et al 1986[24]	ACBT							
Carr et al 1995[25]	ACBT pre/post							
Pryor et al 1990[26]	ACBT pre/post							
Webber et al 1986[27]	FET pre/post							
Murphy et al 1983[28]	ACBT				Equi-med			
Eaton et al 2007[6]	ACBT			Flutter				
Falk et al 1984[29]	FET			PEP				
Lannefors & Wollmer 1992[30]	ACBT			PEP				
Patterson et al 2005[38]	ACBT			Acapella				
Phillips et al 2004[7]	ACBT				Hayek			
Steen et al 1991[31]	FET			PEP				
Thompson et al 2002[39]	ACBT			Flutter				
van Hengstum et al 1988[32]	ACBT							
Chatham et al 2004[33]	ACBT							
Hofmeyr et al 1986[34]	ACBT			PEP				
Milne & Eales 2004[35]	ACBT			Flutter				
Steven et al 1992[36]	ACBT							sit & cough
Patterson et al 2004[40]	ACBT							
van Hengstum et al 1990[8]	ACBT			OHFO				humid air, huff
van Hengstum et al 1991[41]	ACBT			PEP				cough
Miller et al 1995[37]	ACBT							

Shaded cells denote the included comparator for each study.
ACBT Active cycle breathing technique, AD Autogenic drainage, CPT Conventional physiotherapy, NIV Non-invasive ventilation, OHFO Oral high flow oscillation, PEP Positive expiratory pressure, RIM Resisted inspiratory manoeuvres.

0.33 (95%CI -0.04—0.71), and the studies demonstrated significant heterogeneity ($p = 0.02$).

Up to 24 h post-treatment

Two studies involving 15 participants investigated 24 h sputum wet weight post-treatment with ACBT and the oral oscillatory devices of flutter[35] and OHFO.[8] There was no significant difference between ACBT and oral devices for sputum wet weight, SMD 0.16 (95%CI -0.38—0.70), and the studies demonstrated significant heterogeneity ($p = 0.04$). Considering the studies separately, there was no difference in 24 h sputum weight between ACBT and flutter for exacerbated CF participants, SMD -0.10 (95%CI -0.41 to 0.21), and a significant increase in 24 h sputum weight in the ACBT compared to OHFO in participants with chronic bronchitis,[8] SMD 0.45 (95%CI 0.04—0.86).

Four week accumulated sputum wet weight

One study involving 17 non-CF bronchiectasis participants compared four week accumulated sputum wet weight between ACBT and the flutter device.[39] There was no significant difference between the two interventions in four week sputum yield, SMD 0.04 (95%CI -0.21—0.29).

FET/ACBT versus external oscillatory devices

During and up to 1 h post-treatment

One study involving 10 exacerbated CF participants compared sputum wet weight up to 15 min post-treatment between ACBT and the Hayek oscillator.[7] This study collected data from both morning and evening treatments, and these data sets were treated separately in the meta-analysis. The ACBT demonstrated a significant increase in sputum yield when compared to the Hayek oscillator, SMD 0.75 (95%CI 0.48—1.02), with these studies shown to be homogeneous ($p = 0.45$).

FET/ACBT versus control

During and up to 1 h post-treatment

One study involving 24 exacerbated CF participants compared during treatment sputum wet weight between ACBT and a control.[36] ACBT resulted in a significant increase in sputum wet weight when compared with the control, SMD 0.24 (95%CI 0.02—0.46).

Up to 24 h post-treatment

One study involving eight participants with chronic bronchitis compared 24 h sputum wet weight between ACBT and a control.[8] There was no significant difference, SMD 0.38 (95%CI -0.01—0.77).

Sensitivity analysis

In studies where raw or grouped paired data were not available, paired analyses were approximated by assuming a level of correlation between the intervention and

Table 4 Outcome measures found in multiple studies.

Study	Study design	Sputum wet weight	FVC FEV1	Patient values	SaO_2	PEFR	Regional clearance	Radio aerosol retention	Sputum clearance rate	pH	FEF_{25-75}, FEF_{75-85}	Borg	Airways conductance
Pryor & Webber 1979[3]	Crossover	■							■				
Inal-Ince et al 2004[42]	RCT									■			
Savci et al 2000[43]	RCT		■		■	■				■	■	■	
Blomquist et al 1986[24]	Two step		■										
Carr et al 1995[25]	Pre/post	■		■	■								
Pryor et al 1990[26]	Pre/post	■			■								
Webber et al 1986[27]	Pre/post						■	■					■
Murphy et al 1983[28]	Crossover	■	■			■							
Eaton et al 2007[6]	Crossover	■		■									
Falk et al 1984[29]	Crossover	■		■					■				
Lannefors & Wollmer 1992[30]	Crossover						■						
Patterson et al 2005[38]	Crossover	■	■	■	■	■							
Phillips et al 2004[7]	Crossover	■	■	■									
Steen et al 1991[31]	Crossover	■	■	■		■							
Thompson et al 2002[39]	Crossover	■	■	■		■						■	
van Hengstum et al 1988[32]	Crossover	■	■				■	■					
Chatham et al 2004[33]	Crossover	■											
Hofmeyr et al 1986[34]	Crossover	■	■		■								
Milne & Eales 2004[35]	Crossover	■	■	■		■					■		
Steven et al 1992[36]	Crossover	■			■								
Patterson et al 2004[40]	Crossover	■	■	■	■	■							
van Hengstum et al 1990[8]	Crossover	■	■					■					■
van Hengstum et al 1991[41]	Crossover						■	■					■
Miller et al 1995[37]	Crossover			■					■				

Shaded cells denote the included outcome measures for each study.
FEF Forced expiratory flow, FEV_1 Forced expiratory volume in 1 s, FVC forced vital capacity, PEFR Peak expiratory flow rate, RCT Randomised controlled trial, SaO_2 Arterial oxygen saturation.

Table 5 Summary of participant preference findings from the included studies.

Study	*n*	Intervention/comparator	Participant preference/ acceptability
Eaton et al 2007[6]	36	ACBT + PD, ACBT, Flutter	33% preferred ACBT + PD, 22% ACBT, 44% flutter
Falk et al 1984[29]	14	FET, CPT, PEP + PD, PEP (sitting)	79% preferred PEP (sitting)
Patterson et al 2005[38]	20	ACBT, Acapella	A greater proportion of participants preferred acapella to ACBT but this was not significant (MD 0.4, 95%CI −0.04–0.71)
Phillips et al 2004[7]	10	ACBT, Hayek oscillator	All participants reported that the ACBT was comfortable, 60% reported the Hayek oscillator was uncomfortable, and 80% reported that it was difficult to clear secretions with the Hayek oscillator compared to ACBT
Steen et al 1991[31]	28	FET, PEP + PD, PEP (sitting), PEP + FET	96% of participants chose PEP + FET as their long term treatment program at the completion of the study
Thompson et al 2002[39]	17	ACBT, Flutter	65% preferred flutter versus ACBT for long term use
Milne & Eales 2004[35]	7	ACBT, Flutter	43% preferred ACBT, 29% flutter, 29% no preference
Patterson et al 2004[40]	20	ACBT, RIM	55% reported that ACBT was more effective, 20% RIM, 25% no preference. 50% preferred ACBT and 50% preferred RIM for home treatment
Miller et al 1995[37]	18	ACBT, AD	44% preferred ACBT, 50% AD, 6% no preference

AD Autogenic drainage, CPT Conventional physiotherapy, PEP Positive expiratory pressure, PD Postural drainage, RIM Resisted inspiratory manoeuvres.

comparator outcomes.[45] In this review, a correlation of 0.85 was assumed which was the mean of the two available correlation coefficients.[6,35] Sensitivity analyses were performed to assess the impact of the assumed correlation on the meta-analysis by repeating the analysis assuming zero correlation.[21,22] As to be expected by assuming such a conservative correlation, there was a general widening of the confidence intervals. In studies where the intervention and comparator group standard deviations were unavailable, the assumed correlation was used to calculate the

Table 6 Sputum wet weight effect estimates per comparator.

Comparator	Sputum weight collection time	Studies (*n*)	Participants (*n*)	Overall effect estimate SMD (95%CI)	Heterogeneity
RIM	During − 30 min	2	40	−1.08 (−3.85 to 1.70)	$p < 0.00001$
CPT	During − 30 min	1	16	0.32 (0.05 to 0.59)	N/A
	24 h	1	8	0.07 (−0.30 to 0.44)	N/A
PEP	During − 30 min	2	46	0.26 (−0.11 to 0.63)	$p = 0.04$
Oral devices	During − 30 min	2	56	0.33 (−0.04 to 0.71)	$p = 0.02$
	24 h	2	15	0.16 (−0.38 to 0.70)	$p = 0.04$
	4 week	1	17	0.04 (−0.21, 0.29)	N/A
External devices	During − 30 min	1[a]	10	0.75 (0.48 to 1.02)	$p = 0.40$
Control	During − 30 min	1	24	0.24 (0.02 to 0.46)	N/A
	24 h	1	8	0.38 (−0.01 to 0.77)	N/A

CPT Conventional physiotherapy, N/A not applicable, PEP Positive expiratory pressure, RIM Resisted inspiratory manoeuvres, SMD Standardised mean difference Shaded cells denote significant overall effect ($p < 0.05$).

[a] Phillips et al., 2004 contained morning and evening data sets which were treated separately in the meta-analysis.

SMD as well as the $SE_{(SMD)}$, therefore there was an obvious effect on the overall effect estimate (Table 7). Two studies showed a moderate increase in the effect estimate with the conservative correlation,[7,34] with the remaining studies demonstrating differences of small magnitude. These differences did not impact greatly on the significance of the findings, with only two studies losing significance of the overall effect of ACBT with the conservative estimation due to a small shift in the confidence intervals.[8,40]

Discussion

The techniques of FET/ACBT were shown to have a more beneficial short-term effect on sputum wet weight when compared to CPT, external oscillatory devices and a control. There was no clear evidence of a beneficial short-term effect on sputum wet weight when compared to RIM and PEP, or in the 24 h post-treatment when compared to CPT, oral devices or a control. There was limited evidence that the participants in the majority of studies preferred other treatment techniques to FET/ACBT.

The FET/ACBT were investigated against a wide range of comparator interventions, which made comparison of the various studies difficult. There was only one study which investigated the efficacy of FET/ACBT compared to exercise prescribed specifically for sputum clearance. There were a small number of studies which compared the intervention to a control intervention. In order to investigate the true efficacy of FET/ACBT, more studies are needed that investigate the technique against a control rather than a comparator intervention with similar treatment aims. Whether it is ethical to include a control (no airway clearance intervention) is likely to be controversial especially in protocols which seek to recruit people with chronic respiratory conditions during an acute exacerbation or during longitudinal cohort studies. If the experimental control is defined as 'no prescribed intervention', this could be inferred to mean that the participants can only cough, huff, exercise or perform formal airway clearance techniques as required. As people with chronic secretion-producing respiratory diseases will by necessity cough or huff, a control intervention might essentially mean airway clearance techniques are still performed but in a less prescribed way. While there is a lack of compelling long term studies of airway clearance techniques in slowing disease progression or reducing reliance of health care for people with chronic secretion producing conditions, it is currently unlikely that ethical approval would be granted to conduct studies that prospectively plan a control intervention in conditions such as cystic fibrosis. It is possible that such studies could be conducted in participants with non-CF bronchiectasis, as there is no consensus about the prescription or efficacy of airway clearance techniques in this population.[46]

Two protocols for systematic reviews of airway clearance techniques have recently been published. The primary aim of these protocols is to determine the effects of airway clearance techniques on the rate of exacerbations, hospitalisations and quality of life in people with acute and stable COPD[47] and bronchiectasis[46] respectively. While these reviews, once completed, are likely to include the airway clearance techniques of FET/ACBT, the comparators planned will not consider alternative airway clearance techniques, other than cough alone. Hence the overlap between the current review and the prospectively planned reviews is likely to be minimal.

Given the range of proposed mechanisms for FET/ACBT, it was unclear whether the corpus of studies would be skewed toward assessment of outcomes at the ultimate endpoint (i.e. quality of life or exercise tolerance) or the

Table 7 Sensitivity analyses for the primary outcome of sputum wet weight.

Study	Meta-analysis (correlation coefficient 0.85) SMD (95%CI)	Sensitivity analysis (correlation coefficient 0.00) SMD (95%CI)
Pryor & Webber 1979[3]	**0.32 [0.05 to 0.59]**	**0.83 [0.03 to 1.63]**
Eaton et al 2007[6]	**0.52 [0.30 to 0.74]**	**0.52 [0.30 to 0.74]**
Patterson et al 2005[38]	0.14 [−0.10 to 0.38]	0.37 [-0.28 to 1.02]
Phillips et al 2004[a,7]	**0.86 [0.47 to 1.25]**	**2.20 [0.57 to 3.83]**
Phillips et al 2004[b,7]	**0.65 [0.28 to 1.02]**	**1.67 [0.32 to 3.02]**
Steen et al 1991[31]	0.09 [−0.11 to 0.29]	0.09 [−0.44 to 0.62]
Thompson et al 2002[39]	0.04 [−0.21 to 0.29]	0.10 [-0.57 to 0.77]
van Hengstum et al 1988[32]	0.07 [−0.30 to 0.44]	0.07 [-0.91 to 1.05]
Chatham et al 2004[33]	−2.50 [−2.99 to −2.01]	−2.50 [−3.07 to −1.93]
Hofmeyr et al 1986[34]	**0.47 [0.18 to 0.76]**	**1.20 [0.34 to 2.06]**
Milne & Eales 2004[35]	−0.10 [−0.41 to 0.21]	−0.10 [−0.41 to 0.21]
Steven et al 1992[36]	**0.24 [0.02 to 0.46]**	**0.78 [0.13 to 1.43]**
Patterson et al 2004[40]	**0.33 [0.08 to 0.58]**	0.33 [−0.30 to 0.96]
van Hengstum et al 1990[a,8]	**0.45 [0.04 to 0.86]**	0.45 [−0.57 to 1.47]
van Hengstum et al 1990[b,8]	0.38 [−0.01 to 0.77]	0.38 [−0.64 to 1.40]

SMD Standardised mean difference.
Effect estimates shown in bold denote significant overall effect ($p < 0.05$).
Shaded cells represent studies where the SMD and the $SE_{(SMD)}$ were calculated using an estimated correlation coefficient.
[a] First data set.
[b] Second data set.

proximal end of the causal chain (sputum clearance, ventilation), on the assumption that changes at this level would be likely to result in long term beneficial outcomes. As a rule, assessment of the effectiveness of interventions should take place at the distal end of the putative chain thus avoiding assumptions about links between intermediate steps. Unfortunately, measuring outcomes at the distal end of the causal chain often requires long-term follow-up studies, and outcomes are not always as measurable as those at the proximal end. In this review, the impact of FET/ACBT was assessed using a variety of outcome measures. When these are allocated along the causal chain, the paucity of outcomes assessing the ultimate endpoint becomes apparent. The most common outcome variable was sputum wet weight which reflected the short term outcome of the interventions. The potential limitations of sputum wet weight as an outcome measure has been previously documented with concerns over day to day variability, and measurement inaccuracies associated with underestimation (swallowing of sputum), or overestimation (saliva).[6] Despite the potential for measurement inaccuracy, sputum wet weight has been shown to be as reliable as dry sputum,[1,48] and a common and clinically useful outcome of airway clearance techniques.[11]

The lung function variables of FVC and FEV_1 were commonly evaluated but it could be argued that these outcomes are of limited value in assessing the efficacy of airway clearance techniques given the short-term duration of the majority of studies and the documented day to day variance in these measures. Such great variability in these outcomes could mean that only massive changes would reach statistical significance. There was a distinct lack of studies reporting the impact of FET/ACBT on goals such as quality of life, survival, or exercise tolerance. Single studies only were available which assessed exercise tolerance or health-related quality of life. Therefore, the majority of studies investigating the intervention were concerned with short term rather than longer term outcomes.

This systematic review aimed to consider the body of evidence underpinning FET/ACBT rather than in specific populations or clinical situations. Accordingly, this review restricted inclusion of studies to research design and intervention. The likelihood of missing studies was minimised through a comprehensive search strategy and consultation with experts in the field. The intent and findings of this review do not negate the existence of other forms of research evidence. Additionally, studies were excluded if they investigated FET/ACBT in conjunction with other techniques such as PEP or CPT. Therefore the implications of this review may only be applied to situations where the techniques of FET/ACBT are applied as the sole intervention and should not be extrapolated to regimens which incorporate these techniques as part of a combined therapy.

This review used a modified version of the NHMRC[15] body of evidence matrix to assist in classifying the overall volume and consistency of the evidence. The overall volume of evidence for FET/ACBT was classified as good. The majority of the studies included in this review (54%) were classified as Level 1b which is the second highest level that experimental study designs can be placed in the Lloyd-Smith[17] hierarchy. The consistency of the evidence was also classified as good as indicated by consistency of the findings across most studies. Some heterogeneity was present which most likely results from the diversity of study designs, comparator interventions, and outcome variables included in the studies.

Implications for clinical practice

This review clearly indicates that there is high level, variable risk of bias evidence which indicates that FET/ACBT is at least comparable with other airway clearance techniques for short term improvements in secretion removal. Based on these findings, clinicians planning to use FET/ACBT as an airway clearance technique for short-term secretion removal can be confident of the efficacy of the technique in comparison with other airway clearance techniques. However, it is important that clinicians monitor patient acceptability and therefore adherence to treatment, due to the limited evidence that patients prefer other airway clearance techniques over FET/ACBT. There is currently insufficient evidence to make clinical recommendations concerning the use of FET/ACBT for longer-term outcomes such as quality of life or improved exercise tolerance.

Implications for research

This review has highlighted the piecemeal nature of experimental research concerning the FET/ACBT. There were only a small number of studies which investigated participant preference, with the majority of participants preferring to use alternative techniques for secretion clearance over the FET/ACBT. Given the necessary adherence to treatment in conditions such as CF, further research is warranted in this area. Of the 24 included studies, only four investigated the FET/ACBT in isolation, with the remainder investigating the technique in conjunction with PD, percussion or shaking. The inclusion of other techniques with FET/ACBT, while possibly indicative of clinical practice, makes comparison of studies, and the effects of the FET/ACBT difficult to isolate. Other airway clearance techniques such as PEP and flutter were shown in this review to be preferred by patients for airway clearance. It would be useful for further research to investigate FET/ACBT $+/-$ PD which could be completed independently, with other airway clearance techniques.

While the current review demonstrates a reasonable body of evidence around the intermediate outcome of sputum wet weight, this is insufficient to draw evidence based guidelines for the FET/ACBT. There is a need for studies investigating FET/ACBT, possibly compared to a parallel control or placebo intervention, and for studies with longer-term treatment arms. There is an obvious deficiency in the lack of information concerning longer-term outcomes and FET/ACBT. In light of these deficiencies, the effectiveness of FET/ACBT in people with mild, moderate and severe pulmonary impairment needs to be further explored.

Conflict of interest statement

On behalf of all of the authors of the manuscript titled: 'The active cycle of breathing technique: a systematic review and meta-analysis', there are no conflicts of interest.

Appendix. Search strategy

Databases: AMED, MEDLINE, CINAHL, Scopus, Web of Science and the Cochrane Library.

The search strategy included all commonly used terms for the FET/ACBT interventions. A reference to the type of therapy was included with the huffing search terms in order to specifically target the airways clearance technique of huffing rather than the forced expiratory manoeuvre required in pulmonary function testing.

Database	Search terms and strategy
AMED and MEDLINE n:107	1 ACBT 2 "active cycle breathing technique$" 3 "active cycle of breathing" 4 "forced expirat$ technique$" 5 {(huff or huffing) AND (chest or lung or respirat$ or expirat$ or breath$)}
	Limit to human studies in the English language
CINAHL n:41	1 ACBT 2 active cycle breathing technique* 3 active cycle of breathing 4 forced expirat* technique* 5 {(huff or huffing) AND (chest or lung or respirat* or expirat* or breath*)}
	Limit to the English language
Scopus n:150	1 ACBT 2 active cycle breathing technique* 3 active cycle of breathing 4 forced expirat* technique* 5 {(huff or huffing) AND (chest or lung or respirat* or expirat* or breath*)}
	Limit to the English language
Web of Science n:128	1 ACBT 2 active cycle breathing technique* 3 active cycle of breathing 4 forced expirat* technique* 5 {(huff or huffing) AND (chest or lung or respirat* or expirat* or breath*)}
	Limit to the English language
The Cochrane Library *n*:113	1 ACBT 2 active cycle breathing technique* 3 active cycle of breathing 4 forced expirat* technique* 5 {(huff or huffing) AND (chest or lung or respirat* or expirat* or breath*)}
	Limit to the English language

ACBT Active cycle breathing technique.
$* — truncation symbols for the relevant databases.

References

1. Cecins NM, Jenkins SC, Pengelley J, Ryan G. The active cycle of breathing techniques-to tip or not to tip? *Respir Med* 1999;**93**:660—5.
2. Elkins M, Jones A, van der Schans CP. Positive expiratory pressure physiotherapy for airway clearance in people with cystic fibrosis. *Cochrane Database Syst Rev* 2006. doi:10.1002/14651858.CD003147. Issue 2: Art. No.: CD003147.
3. Pryor JA, Webber BA. An evaluation of the forced expiration technique as an adjunct to postural drainage. *Physiotherapy* 1979;**65**:304—7.
4. Pryor J, Webber B, Bethune D. Physiotherapy techniques. In: Pryor J, Prasad S, editors. *Physiotherapy for respiratory and cardiac problems*. 3rd ed. Edinburgh: Churchill Livingstone; 2002.
5. Fauroux B, Boule M, Lofaso F, Zerah F, Clement A, Harf A. Chest physiotherapy in cystic fibrosis: improved tolerance with nasal pressure support ventilation. *Pediatrics* 1999;**103**:E321—9.
6. Eaton T, Young P, Zeng I, Kolbe J. A randomized evaluation of the acute efficacy, acceptability and tolerability of flutter and active cycle of breathing with and without postural drainage in non-cystic fibrosis bronchiectasis. *Chron Respir Dis* 2007;**4**:23—30.
7. Phillips GE, Pike SE, Jaffe A, Bush A. Comparison of active cycle of breathing and high-frequency oscillation jacket in children with cystic fibrosis. *Pediatr Pulmonol* 2004;**37**:71—5.
8. van Hengstum M, Festen J, Beurskens C, Hankel M, Van Den Broek W, Corstens F. No effect of oral high frequency oscillation combined with forced expiration manoeuvres on tracheobronchial clearance in chronic bronchitis. *Eur Respir J* 1990;**3**:14—8.
9. Flume P, Robinson K, O'Sullivan B, Finder J, Vender R, Willey-Courand D, White T, Marshall B. Cystic fibrosis pulmonary guidelines: airway clearance therapies. *Respir Care* 2009;**54**:522—37.
10. Tierney S, Riley D, Jones A, Webb A, Horne M. Differing perspectives of sputum and its expectoration: a qualitative study involving patients with cystic fibrosis and physiotherapists. *Physiother Theory Pract* 2011;**27**:278—86.
11. Fifoot S, Wilson C, MacDonald J, Watter P. Respiratory exacerbations in children with cystic fibrosis: physiotherapy treatment outcomes. *Physiother Theory Pract* 2005;**21**:103—11.
12. Murray M, Turnbull K, MacQuarrie S, Hill A. Assessing response to treatment of exacerbations of bronchiectasis in adults. *Eur Respir J* 2009;**33**:312—7.
13. Tsang K, Tipoe G. Bronchiectasis: not an orphan disease in the east. *Int J Tuberc Lung Dis* 2004;**8**:691—702.
14. Williams M. Chest physiotherapy and cystic fibrosis: why is the most effective form of treatment still unclear? *Chest* 1994;**106**:1872—82.
15. National Health and Medical Research Council. *NHMRC additional levels of evidence and grades for recommendations for developers of guidelines*, http://www.nhmrc.gov.au/consult/_files/levels_grades05.pdf; 2005.
16. Lewis LK, Williams MT, Olds T. Short-term effects on the mechanism of intervention and physiological outcomes but insufficient evidence of clinical benefits of breathing control: a systematic review. *Aust J Physiother* 2007;**53**:219—27.
17. Lloyd-Smith W. Evidence-based practice and occupational therapy. *Br J Occup Ther* 1997;**60**:474—8.
18. Hall G, Gandevia B. Relationship of the loose cough sign to daily sputum volume, observer variation and its detection. *Brit J Prev Soc Med* 1971;**25**:109—13.
19. Ashcroft T. Daily variations in sputum volume in chronic bronchitis. *Bri Med J* 1965;**1**:288—90.

20. Conway J, Fleming J, Perring S, Holgate S. Humidification as an adjunct to chest physiotherapy in aiding tracheobronchial clearance in patients with bronchiectasis. *Respir Med* 1992;**86**: 109—14.
21. Main E, Prasad A, van der Schans CP. Conventional chest physiotherapy compared to other airway clearance techniques for cystic fibrosis. *Cochrane Database Syst Rev* 2005;(1). doi:10.1002/14651858.CD002011. Art. No.: CD002011.
22. Elbourne DR, Altman DG, Higgins JPT, Curtin F, Worthington HV, Vail A. Meta-analyses involving cross-over trials: methodological issues. *Int J Epidemiol* 2002;**31**:140—9.
23. Moher D, Liberarti A, Tetzlaff J, Altman DG. The PRISMA group. preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;**6**:e1000097. doi:10.1371/journal.pmed1000097.
24. Blomquist M, Freyschuss U, Wiman L, Standvik B. Physical activity and self treatment in cystic fibrosis. *Arch Dis Child* 1986;**61**:362—7.
25. Carr J, Pryor JA, Hodson ME. Self chest clapping: patients' views and the effects on oxygen saturation. *Physiotherapy* 1995;**81**:753—7.
26. Pryor JA, Webber BA, Hodson ME. Effect of chest physiotherapy on oxygen saturation in patients with cystic fibrosis. *Thorax* 1990;**45**:77.
27. Webber BA, Hofmeyr JL, Morgan MD, Hodson ME. Effects of postural drainage, incorporating the forced expiration technique, on pulmonary function in cystic fibrosis. *Br J Dis Chest* 1986;**80**:353—9.
28. Murphy MB, Concannon D, Fitzgerald MX. Chest percussion: help or hindrance to postural drainage? *Ir Med J* 1983;**76**:189—90.
29. Falk M, Kelstrup M, Andersen JB. Improving the ketchup bottle method with positive expiratory pressure, (PEP), in cystic fibrosis. *Euro J Respir Dis* 1984;**65**:423—32.
30. Lannefors L, Wollmer P. Mucus clearance with three chest physiotherapy regimes in cystic fibrosis: a comparison between postural drainage, PEP and physical exercise. *Eur Respir J* 1992;**5**:748—53.
31. Steen HJ, Redmond AO, O'Neill D, Beattie F. Evaluation of the PEP mask in cystic fibrosis. *Acta Paediatr Scand* 1991;**80**:51—6.
32. van Hengstum M, Festen J, Beurskens C, Hankel M, Beekman F, Corstens F. Conventional physiotherapy and forced expiration manoeuvres have similar effects on tracheobronchial clearance. *Eur Respir J* 1988;**1**:758—61.
33. Chatham K, Ionescu AA, Nixon LS, Shale DJ. A short-term comparison of two methods of sputum expectoration in cystic fibrosis. *Eur Resp J* 2004;**23**:435—9.
34. Hofmeyr JL, Webber BA, Hodson ME. Evaluation of positive expiratory pressure as an adjunct to chest physiotherapy in the treatment of cystic fibrosis. *Thorax* 1986;**41**:951—4.
35. Milne SM, Eales CJ. A pilot study comparing two physiotherapy techniques in patients with cystic fibrosis. *South Afr J Physiother* 2004;**60**:3—6.
36. Steven MH, Pryor JA, Webber BA, Hodson MR. Physiotherapy versus cough alone in the treatment of cystic fibrosis. *New Zealand J Physiother* 1992;**20**(31):35—7.
37. Miller S, Hall DO, Clayton CB, Nelson R. Chest physiotherapy in cystic fibrosis: a comparative study of autogenic drainage and the active cycle of breathing techniques with postural drainage. *Thorax* 1995;**50**:165—9.
38. Patterson JE, Bradley JM, Hewitt O, Bradbury I, Elborn JS. Airway clearance in bronchiectasis: a randomized crossover trial of active cycle of breathing techniques versus acapella. *Respiration* 2005;**72**:239—42.
39. Thompson CS, Harrison S, Ashley J, Day K, Smith DL. Randomised crossover study of the flutter device and the active cycle of breathing technique in non-cystic fibrosis bronchiectasis. *Thorax* 2002;**57**:446—8.
40. Patterson JE, Bradley JM, Elborn JS. Airway clearance in bronchiectasis: a randomized crossover trial of active cycle of breathing techniques (incorporating postural drainage and vibration) versus test of incremental respiratory endurance. *Chron Respir Dis* 2004;**1**:127—30.
41. van Hengstum M, Festen J, Beurskens C, Hankel M, Beekman F, Corstens F. Effect of positive expiratory pressure mask physiotherapy (PEP) versus forced expiration technique (FET/PD) on regional lung clearance in chronic bronchitis. *Eur Respir J* 1991;**4**:651—4.
42. Inal-Ince D, Savci S, Topeli A, Arikan H. Active cycle of breathing techniques in non-invasive ventilation for acute hypercapnic respiratory failure. *Aust J Physiother* 2004;**50**: 67—73.
43. Savci S, Ince DI, Arikan H. A comparison of autogenic drainage and the active cycle of breathing techniques in patients with chronic obstructive pulmonary diseases. *J Cardiopulm Rehabil* 2000;**20**:37—43.
44. Global Initiative for Chronic Obstructive Lung Disease. *Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease*, http://www.goldcopd.org; 2010 [accessed 11.09.11].
45. Higgins JPT, Green S, editors. *Cochrane handbook for systematic reviews of interventions version 5.0.2 [updated September 2009]. The Cochrane Collaboration*. Available from: www.cochrane-handbook.org; 2008.
46. Lee AL, Burge A, Jones AP, Rowe BH, Holland AE. Airway clearance techniques for bronchiectasis (Protocol). *Cochrane Database Syst Rev* 2010. doi:10.1002/14651858.CD008351. Issue 2. Art. No.: CD008351.
47. Osadnik CR, McDonald CF, Jones AP, Rowe BH, Holland AE. Airway clearance techniques for chronic obstructive pulmonary disease (Protocol). *Cochrane Database Syst Rev* 2010. doi:10.1002/14651858.CD008328. Issue 1. Art. No.: CD008328.
48. Moran F, Moffitt K, Piper A, Bradley J. Is sputum load a useful outcome measure for clinical trials in bronchiectasis? *Thorax* 2006;**61**:1—133.