

A clinical practice guideline for physiotherapists treating patients with chronic obstructive pulmonary disease based on a systematic review of available evidence

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Purpose: Update of a clinical practice guideline for the physiotherapy management of patients with chronic obstructive pulmonary disease supporting the clinical decision-making process.

Methods: A systematic computerized literature search was performed on different modalities for improving physical exercise capacity, reducing exertional dyspnoea, improving airway clearance and encouraging changes in physical activity behaviour. Methodological quality was scored with the PEDro Scale. Scientific conclusions were graded according to the criteria of the 'Dutch Evidence Based Guideline Development Platform'. These, together with practical considerations, were used to formulate recommendations for clinical practice.

Results: A total of 103 studies were included in the systematic review, consisting of five meta-analyses of randomized controlled trials, 84 randomized controlled trials and 14 uncontrolled studies. Twenty scientific conclusions supported six recommendations on physical exercise training. Nineteen scientific conclusions supported eight recommendations on interventions for reducing dyspnoea. Five scientific conclusions supported seven recommendations concerning treatment modalities to improve mucus clearance, and two scientific conclusions supported

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two recommendations on strategies for encouraging permanent changes in physical activity behaviour.

Conclusions: Strong recommendations support the use of physical exercise training to improve health-related quality of life and functional exercise capacity. Future research should investigate whether additional interventions for reducing exertional dyspnoea have a place as adjuncts to physical exercise training in selected patients. In addition, treatment of impaired mucus clearance, especially during acute exacerbations, requires further research. With the advance of new technologies for objective measurements of physical activities in daily life more research is needed concerning interventions to initiate and maintain physical activity behaviour change during and after supervised physical exercise training programmes

Introduction

Over the last 10 years the body of knowledge in the area of rehabilitation for patients with chronic obstructive pulmonary disease in general and physiotherapy in particular has grown tremendously. This information has strengthened the case for multidisciplinary rehabilitation as an evidence-based intervention for patients with chronic obstructive pulmonary disease.¹ In addition, recent literature has given more details on the relative contribution of the components of a multidisciplinary rehabilitation programme and selection of patients for specific components of a rehabilitation programme. Physiotherapy consists of various treatment modalities (specifically physical exercise training, peripheral and respiratory muscle training, and breathing exercises) that are considered cornerstones of the physiotherapeutic intervention. In addition, much more emphasis is now given to the assessment and treatment of a physically inactive lifestyle.

Unlike recent statements on pulmonary rehabilitation in chronic obstructive pulmonary disease^{1,2} this guideline evaluates the effectiveness of treatment modalities with a rigorous methodological framework to make evidence-based recommendations for clinical practice.³ Compared with a recently published evidence-based guideline on pulmonary rehabilitation⁴ we focused solely on physiotherapeutic interventions and discussed airway mucus clearance techniques and breathing exercises in more detail. In addition we formulated different conclusions on the effectiveness of upper limb exercises and breathing exercises.⁵

Material and methods

The included physiotherapy interventions are in accordance with multidisciplinary and transmurals guidelines for the treatment of patients with chronic obstructive pulmonary disease that were developed under the auspices of the Dutch Institute for Health Care Improvement.⁶ Search strategies were adapted from these guidelines and from the previously published Dutch physiotherapy guidelines for chronic obstructive pulmonary disease from 1998.^{6,7} In addition, reference lists of included studies were screened and citation tracking was performed for all papers. The members of the project group (RG, DL, EH) selected and graded the scientific evidence followed by a discussion within the working group. For the rating of methodological quality of randomized controlled trials the PEDro-quality scores were used.⁸ Trials were considered to be of sufficient methodological quality if they scored at least six out of ten points. The results, including the methodological quality assessment, are summarized in different levels of evidence (Table 1) according to recommendations from the Dutch Evidence Based Guideline Development Platform (under the auspices of the Dutch Institute for Health Care Improvement).

The evidence found in the literature was used to formulate graded scientific conclusions (Table 1). Tables including scientific conclusions are presented in a four-component format: population, intervention, comparison, and outcomes (PICO). They were linked to clinical questions on the improvement of physical exercise capacity, reduction of exertional dyspnoea, improvement of

Table 1 Classification of studies and grading of scientific conclusions

Classification of interventional studies based on scientific conclusiveness	
A.1	Systematic review (or meta-analysis), including at least two independent trials at quality level A2 and consistent results
A.2	RCT of good quality (PEDro >6) and sufficient power
B	RCT but not at A2 level, or controlled study (including case-control or cohort study)
C	Non-controlled study
D	Expert opinion (such as working group members)
Grading of scientific conclusions	
Level 1	Supported by one systematic review at level A1 or at least two RCTs at level A2 <i>It has been demonstrated that...</i>
Level 2	Supported by at least one trial at level A2 or two independent trials at level B <i>It is plausible that...</i>
Level 3	Supported by one trial level B or C. <i>There are indications that...</i>
Level 4	Based on the expert opinion (such as that of working group members). <i>The working group takes the view that...</i>

RCT, Randomized controlled trial.

airway clearance and facilitation of changes in physical activity behaviour according to recommendations from the National Institute for Health and Clinical Excellence (NICE).⁹

In a final step scientific conclusions were combined with other considerations concerning economic or practical issues, to formulate treatment recommendations for clinical practice.

Results

A total of 103 studies were included in the systematic review, consisting of five meta-analyses of randomized controlled trials, 84 randomized controlled trials and 14 uncontrolled studies.

Improvement of physical exercise capacity

In this section different types of physical exercise training that can be applied to improve health-related quality of life and exercise performance in patients with chronic obstructive pulmonary disease are discussed. Interventions are all based on general exercise recommendations of the American College of Sports Medicine (ACSM) for healthy (elderly) adults (Table 2). They were modified to the specific needs of patients with chronic obstructive pulmonary disease when necessary and will be discussed in relation to the

underlying pathophysiology and symptomatology.^{10,11} A total of 20 graded scientific conclusions (see online data supplement Tables W1A–W6A) support six treatment recommendations on physical exercise training.

Endurance training

Most studies report positive effects of endurance training on (functional) exercise capacity, health-related quality of life and dyspnoea during physical exercise. However, there exists considerable heterogeneity in effects between studies. Graded scientific conclusions and detailed descriptions of studies^{12–19} on the effects of endurance training are provided in the online data supplement Tables W1A and W1B.

Other considerations. The ACSM advises an initial training frequency for endurance training of at least three times per week for healthy (older) adults. Training at higher intensities during endurance type training leads to greater physiological benefits than training at lower intensities.^{20–22} Patients with severe symptoms of dyspnoea during exercise are frequently not capable of performing high-intensity (i.e. 70–80% of peak work rate) endurance type training.^{23,24} It seems that moderate intensity endurance training (i.e. 50–60% of peak work rate or perceived exertion

Table 2 Recommendations of the American College of Sports Medicine regarding the quantities and intensities of physical exercise training for developing cardiorespiratory fitness, muscular strength and flexibility in healthy (elderly) adults^{10,11}

Cardiorespiratory fitness	
Kind of activity	Any activity that uses large muscle groups that can be maintained continuously and is rhythmical and aerobic in nature. Activities include: walking, cycling, stair climbing, swimming and endurance game activities
Training frequency	3–5 days per week
Training intensity	40–60% of heart rate reserve/ $\dot{V}O_{2peak}$, or 4–5 on the modified Borg Scale
Training duration	20–60 minutes of continuous or intermittent (in sessions lasting 10 or more minutes) aerobic activity
Muscular strength	
Kind of activity	Resistance training of the major muscle groups of upper and lower limb
Training frequency	2–3 days per week
Training intensity	60–80% of the 1RM
Training duration	8–15 repetitions, multiple set regimens (2–5 sets) may provide greater benefits
Flexibility	
Kind of activity	Stretches for the major muscle groups that should include appropriate static and/or dynamic techniques
Training frequency	2–3 days per week
Training duration	4 repetitions, held for 10–30 seconds

$\dot{V}O_{2peak}$, maximal oxygen consumption measured during a maximal incremental exercise test; 1RM, one-repetition maximum.

on a modified Borg Scale of 5–6 out of 10) is minimally required to achieve changes in physical fitness. Improvements in health-related quality of life after training at moderate intensities were comparable with those observed after high intensity training.²¹ In most studies endurance training was performed either on a treadmill or on a cycle ergometer. There exists a general consensus that physical exercise training in patients with chronic obstructive pulmonary disease should be conducted partly or fully supervised at the outset of a training programme to ensure optimal physiological benefits.²¹ Patient characteristics, individual treatment goals and cost effectiveness have to be taken into account when determining the appropriate duration of supervised physical exercise training programmes. Since no studies compared different frequencies of endurance training in patients with chronic obstructive pulmonary disease, the recommendations of the ACSM should be followed.

Recommendation. Supervised endurance training either on a treadmill or on a cycle ergometer (or a combination of both) is recommended for patients in all stages of the disease who are able to perform

endurance training of at least moderate intensity. Training frequency should be three times weekly in the first weeks of an exercise programme.

Interval training

Studies comparing interval training with endurance training found comparable effects of both exercise modalities when the same total amount of work was performed. Vogiatzis *et al.* showed that patients were able to achieve high work rates during interval training while reporting fewer symptoms of dyspnoea in comparison with high-intensity endurance training.^{25,26} Graded scientific conclusions on the effects of interval training and detailed descriptions of studies^{25–29} are provided in the online data supplement Tables W2A and W2B.

Other considerations. No studies are available comparing different intensities and different work/recovery ratios of interval training. Available studies applied exercise bouts of 30–60 seconds at 90–100% of peak work rate with work/recovery ratios of 1:2. Training sessions of 2–3 minutes at lower intensities (70–80% of peak

work rate) with work/recovery ratios of 2:1 have also been described.^{30,12}

Recommendation. Interval training is recommended as an alternative to endurance training in patients with severe symptoms of dyspnoea during exercise since they are frequently not able to sustain endurance training at the recommended intensities. In other patients individual treatment goals concerning performance of daily tasks should be taken into account when choosing between (or combining) endurance and interval training. Intensity of short exercise bouts (30–180 seconds) during interval training should be high (at least 70–80% of peak work rate). Recommended frequency of training is the same as with endurance training.

Resistance training

Peripheral (lower limb) muscle function is frequently impaired even in patients with mild to moderate airflow obstruction.^{31,32} Improvements in muscle strength were reported in all studies that applied resistance training as a single intervention.^{22,33–39} Besides improvements in strength, resistance training also resulted in increased functional and maximal exercise capacity in severely deconditioned patients.^{38,39} Effects of resistance training on health-related quality of life did not differ significantly from endurance training. Randomized controlled trials comparing endurance training with combined endurance and resistance training found larger improvements of muscle strength after the combined intervention.^{36,39–42} None of these trials, however, reported differences in terms of health-related quality of life or exercise capacity when resistance training was added to endurance training. Graded scientific conclusions on the effects of resistance training and detailed descriptions of studies^{22,33,36–43} are provided in the online data supplement Tables W3A and W3B.

Other considerations. By reducing working muscle mass, resistance training reduces the metabolic demands and thus the ventilatory burden of exercise. This makes resistance training an ideal intervention for patients with peripheral muscle

weakness and pronounced symptoms of dyspnoea during exercise. Improvements in daily functioning after resistance training are only expected in patients who are functionally limited by muscle weakness. No consensus exists on the optimal method of resistance training (callisthenics, resistance weight training, isometrics or isokinetic-type training) in patients with chronic obstructive pulmonary disease. Each modality produces strength gains highly specific to the type of training. In contrast to endurance training it is not recommended to use more than three resistance training sessions per week.⁴⁴ Since no studies compared different intensities of resistance training in patients with chronic obstructive pulmonary disease, the recommendations of the ACSM should be followed.

Recommendation. It is recommended to use (lower limb) resistance training for all patients with chronic obstructive pulmonary disease two or three times a week. Exercises should be performed at 60–80% of the 1RM using 8–15 repetitions. Multiple set regimens (2–5 sets) provide greater benefits.

Neuromuscular electrical stimulation

Studies in patients with severely impaired muscle strength showed that neuromuscular electrical stimulation was effective in improving exercise capacity and muscle strength. Two randomized controlled trials evaluated the effectiveness of six weeks of neuromuscular electrical stimulation in stable chronic obstructive pulmonary disease patients with severe muscle weakness in comparison with a control group.^{45,46} Two other studies investigated the effects of neuromuscular electrical stimulation comparing active leg mobilization with mobilization in hospitalized patients.^{47,48} Graded scientific conclusions on the effects of neuromuscular electrical stimulation and detailed descriptions of studies^{45–48} are provided in the online data supplement Tables W4A and W4B.

Other considerations. More studies are required to determine the role of neuromuscular electrical stimulation in combination with other physical

exercise training interventions in less severely disabled patients.

Recommendation. Neuromuscular electrical stimulation is recommended for patients with severely impaired muscle strength unable to participate in regular physical exercise training.

Arm exercises

Arm exercises in patients with chronic obstructive pulmonary disease were shown to increase arm muscle force^{49,13} and to reduce symptoms of dyspnoea and fatigue during arm activities.^{42,50} One study showed that unsupported arm exercise was more effective than supported arm training.⁵¹ Contradictory effects on health-related quality of life have been reported when arm resistance training were added to a general physical exercise programme.^{13,52} Graded scientific conclusions on the effects of arm exercises and detailed descriptions of studies^{13,42,49,50–52} are provided in the online data supplement Tables W5A and W5B.

Other considerations. Since reliable and valid tests of arm function related to activities of daily living are currently not available⁵² individual treatment goals of patients should be taken into account when deciding to use arm exercises as an adjunct to a general physical exercise training programme. Training with free weights probably corresponds better to the daily needs of patients than supported exercises against a fixed resistance (e.g. arm ergometry).⁵¹ No studies have been conducted so far to determine an optimal training mode for arm exercises. In most studies a combination of resistance and endurance training with emphasis on the strength component was used.

Recommendation. In the absence of conclusive evidence it is recommended to use arm exercises as an adjunct to standard physical exercise training in selected patients with arm muscle weakness who aim to improve limitations in upper extremity tasks in daily life.

Training during and after acute exacerbations

Early reconditioning during or shortly after hospitalization for an acute exacerbation of disease

symptoms aims to counteract detrimental consequences on muscle function, health-related quality of life, and daily activities.^{53–55} Probst *et al.* studied the effects of daily resistance training in patients hospitalized for an acute exacerbation.⁵⁶ Resistance training seemed to be well tolerated, did not worsen systemic inflammation and was sufficient to counteract the decline in leg muscle force that is typically observed.

Six other trials (total $n = 230$) on the effects of rehabilitation after acute exacerbations have been summarized in a systematic review by Puhan *et al.*⁵⁷ In these studies rehabilitation improved health-related quality of life and exercise capacity. Larger studies with longer follow-up periods should also look into effects of early reconditioning on hospital re-admission rate. Graded scientific conclusions on the effects of training after acute exacerbations and detailed descriptions of studies^{56,57} are provided in the online data supplement Tables W6A and W6B.

Other considerations. Interventions reducing the ventilatory burden of exercise such as interval training, resistance training or transcutaneous electrical neuromuscular stimulation can be helpful in patients after an acute exacerbation who usually experience severe symptoms of dyspnoea during physical activities.

Recommendation. It is recommended to apply training strategies that enable patients to resume participation in a rehabilitation programme after an acute exacerbation as soon as possible. Resistance training, transcutaneous electrical neuromuscular stimulation or interval training are best suited for early reactivation of patients.

Interventions for reducing exertional dyspnoea

Many patients with chronic obstructive pulmonary disease are ventilatory limited during incremental⁵⁸ or high-intensity constant work rate exercise.⁵⁹ Therefore, interventions that reduce the work of breathing (dynamic hyperinflation) or increase the ventilatory capacity are of great interest, especially for patients with severe

complaints of dyspnoea during exercise training. A total of 19 scientific conclusions (see online supplement Tables W7A–W13A) support eight recommendations on interventions for reducing exertional dyspnoea.

Breathing exercises

‘Breathing exercises’ is an all-embracing term for a range of interventions such as pursed-lips breathing, active expiration, slow and deep breathing, relaxation therapy, body positions such as forward leaning, inspiratory and expiratory muscle training and diaphragmatic breathing. The aims of these exercises vary considerably and include the improvement of (regional) ventilation and gas exchange, reduction of dynamic hyperinflation, improvement of respiratory muscle function, reduction of dyspnoea and improvement of exercise tolerance and health-related quality of life.⁶⁰

Inspiratory muscle training

Positive effects of inspiratory muscle training, as a standalone therapy, on inspiratory muscle function, symptoms of dyspnoea, exercise capacity and health-related quality of life have been reported. Meta-analyses revealed, however, that only inspiratory muscle training interventions with control of the inspiratory load or threshold loading were effective to improve these outcomes.^{61–63} As an adjunct to standard physical exercise training, inspiratory muscle training resulted in increased inspiratory muscle strength but did not further improve exercise performance.^{61,63} A tendency for improved exercise performance was only observed in patients with inspiratory muscle weakness.⁶¹ Graded scientific conclusions on the effects of inspiratory muscle training and detailed descriptions of studies^{61–63,64–69} are provided in the online data supplement Tables W7A and W7B.

Other considerations. Current recommendations concerning inspiratory muscle training as a standard component of an exercise programme for patients with chronic obstructive pulmonary disease are ambiguous.^{1,2,4} More studies are required

on the effects of inspiratory muscle training as an adjunct to physical exercise training.

Recommendation. It is recommended to use inspiratory muscle training in patients with symptoms of dyspnoea who are not able to participate in standard physical exercise training. As an adjunct to exercise training it should be applied in selected patients. Ideal candidates are patients who demonstrate a significant reduction of inspiratory muscle strength and report symptoms of dyspnoea during physical activities. Intensity of the (controlled) training load should at least be 30% of the maximal inspiratory pressure.

Body position

No randomized controlled trials have tested the effectiveness of forward leaning in patients with chronic obstructive pulmonary disease. In patients who benefited from leaning forward, Sharp *et al.*⁷⁰ observed that electromyographic activity of the inspiratory accessory muscles increased significantly in standing or sitting straight. Leaning forward reduced electromyographic activity in the accessory muscles. Druz and Sharp⁷¹ and O'Neill and McCarthy⁷² also concluded that leaning forward improved the function of the diaphragm and decreased the sensation of dyspnoea. In addition, forward leaning with arm support allowed accessory muscles (pectoralis minor and major) to contribute significantly to ribcage elevation. Banzett *et al.* showed in healthy subjects that this position enhanced ventilatory capacity,⁷³ while Probst *et al.* showed a significant improvement in maximal voluntary ventilation by leaning forward on a rollator during walking.⁷⁴ This observation is particularly interesting for improving exercise performance in ventilatory limited patients. Graded scientific conclusions on the effects of the forward leaning position in patients with chronic obstructive pulmonary disease are presented in the online supplement Table W8.^{70–74,75}

Recommendation. Although evidence for forward leaning is limited, it seems effective to alleviate symptoms of dyspnoea and may be especially

helpful during walking in patients with chronic obstructive pulmonary disease.

Pursed lips breathing

Pursed lips breathing consists of a combination of (slightly) active and prolonged expiration through the half-opened lips. At rest, pursed lips breathing reduces breathing frequency and dyspnoea, increases tidal volume and oxygen saturation.^{76–79} The application of pursed lips breathing during exercise training had variable effects. While both Collins *et al.*⁸⁰ and Casciari *et al.*⁸¹ reported a strong tendency for an improvement in exercise endurance capacity, Garrod *et al.*⁸² observed that pursed lips breathing during a six-minute walking test did not increase walking distance and only resulted in a lower respiratory rate and a shorter recovery time compared with spontaneous breathing. Spahija *et al.*⁷⁸ observed that during constant work bicycle exercise a reduction in dyspnoea sensation during application of pursed lips breathing was related to observed changes in end-expiratory lung volume and pressure generation of the inspiratory muscles. Graded scientific conclusions on the effects of pursed lips breathing and detailed descriptions of studies^{76–84} are provided in the online data supplement Tables W9A and W9B.

Other considerations. In clinical practice pursed lips breathing may reduce dyspnoea in some patients, especially those with emphysema, and brings about a decrease in both end-expiratory lung volume and pressure generation by the inspiratory muscles. Responses to pursed lips breathing should be tested in individual patients.

Recommendation. Although evidence for pursed lips breathing is limited, its application should be considered in patients with emphysema during activities causing dyspnoea (e.g. stair climbing). Both clinical experiences as well as pathophysiological mechanisms are in support of this.

Diaphragmatic breathing

All studies show that patients with chronic obstructive pulmonary disease are able to change

their breathing pattern to a more abdominal movement and to a reduced thoracic excursion during diaphragmatic breathing.^{85–87} However, diaphragmatic breathing has been shown to be accompanied by increased asynchronous and paradoxical breathing movements while no changes in ventilation distribution were observed.^{87,88} Increased work of breathing, enhanced oxygen cost of breathing and reduced mechanical efficiency of breathing have also been observed.⁸⁹ In addition, dyspnoea worsened during diaphragmatic breathing in patients with severe chronic obstructive pulmonary disease,⁸⁹ whereas pulmonary function and exercise capacity remained unaltered. Graded scientific conclusions on the effects of diaphragmatic breathing and detailed descriptions of studies^{87–90} are provided in the online data supplement Tables W10A and W10B.

Recommendation. Diaphragmatic breathing is not recommended for the treatment of patients with moderate to severe chronic obstructive pulmonary disease.

Relaxation exercises

Consistent findings support short-term effects of relaxation exercises on reducing breathing frequency and improving symptoms of dyspnoea. Graded scientific conclusions on the effects of relaxation exercises and detailed descriptions of studies^{76,91–93} are provided in the online data supplement Tables W11A and W11B.

Recommendation. Relaxation exercises may be considered in patients with anxiety and dyspnoea.

Supplemental interventions during exercise training

Supplemental oxygen and non-invasive mechanical ventilation have been applied during physical exercise training in patients with chronic obstructive pulmonary disease to reduce symptoms of dyspnoea and to increase training effects.

Training with supplemental oxygen

Patients who are hypoxaemic at rest and who are receiving long-term oxygen therapy should

have this continued during physical exercise training. They will probably need oxygen supplementation exceeding resting levels to prevent further desaturation during exercise. Several studies found higher maximal exercise capacities during incremental exercise testing with oxygen supplementation in patients with or without desaturation during exercise.⁹⁴ No significant differences in maximal or functional exercise capacity or health-related quality of life after several weeks of training with supplemental oxygen have been reported in five randomized controlled trials.^{95–99} When two studies^{97,99} were pooled in a recent meta-analysis a modest, statistically significant effect on constant workload exercise time was found.¹⁰⁰ Graded scientific conclusions on the effects of oxygen supplementation and detailed descriptions of studies^{94–99} are provided in the online data supplement Tables W12A and W12B.

Other considerations. There is insufficient evidence on the safety of exercise without oxygen in patients with desaturation during exercise.¹⁰¹

Recommendation. The regular use of oxygen supplementation for patients *without* desaturation during physical exercise training is not recommended. In patients who desaturate during exercise, it is generally recommended not to let oxygen saturation fall below 90% during training. Supplemental oxygen during physical exercise training should be used in patients without resting hypoxaemia who desaturate (pulse oximetry oxygen saturation <90%) during exercise and in patients on long-term oxygen therapy.

Non-invasive mechanical ventilation

Three out of five trials in severely impaired, hypercapnic patients with chronic obstructive pulmonary disease showed that the application of positive pressure support leads to modest improvements in training effects.^{102–104} In patients with less severe airflow obstruction these findings could not be confirmed.¹⁰⁵ Graded scientific conclusions on the effects of non-invasive mechanical ventilation and detailed descriptions of studies^{102–107} are provided in the online data supplement Tables W13A and W13B.

Other considerations. The use of assisted ventilation requires careful supervision of the patient and is therefore labour intensive. Furthermore the intervention is not well tolerated by all patients. This resulted in a drop-out rate of 28% due to non-compliance with non-invasive mechanical ventilation in one study.¹⁰⁵

Recommendation. Based on the available evidence, combined with the potential burden for therapist and patient, the regular use of assisted ventilation in clinical practice is not recommended.

Improving airway mucus clearance

Physiotherapy employs a variety of methods for improving airway mucus clearance. The following techniques will be described: coughing or forced expiration, manual chest and abdominal compression, postural drainage, exercise, chest percussion and mechanical vibration, positive expiratory pressure breathing, and positive pressure oscillative ('FLUTTER') breathing. These interventions have all been investigated in small studies of mostly moderate quality. Scientific conclusions therefore have to be interpreted cautiously. A total of five scientific conclusions (see online supplement Tables W14A and W15A) support seven recommendations concerning treatment modalities to improve mucus clearance.

Forced expiratory manoeuvres

A systematic review on the effectiveness of forced expiratory techniques in patients with chronic obstructive pulmonary disease and bronchiectasis¹⁰⁸ revealed statistically significant effects on mucus removal and radio-aerosol clearance. No statistically significant effects were observed on pulmonary function. Graded scientific conclusions on the effects of forced expiratory techniques and detailed descriptions of studies^{108–110} are provided in the online data supplement Tables W14A and W14B.

Other considerations. In clinical practice patients often benefit from combinations of techniques, when practised appropriately. For example,

expiratory force applied during forced expirations has to be adapted in patients with tracheobronchial collapse. From a systematic review in patients with cystic fibrosis it was concluded that self-administered airway clearance techniques are as effective as conventional chest physiotherapy to improve mucus clearance.¹¹¹ Patients preferred techniques that made them independent from chest physiotherapy.¹¹¹ Physiotherapists should aim at maximizing the ability of the patients to practise these techniques independently.

Recommendation. Patients with chronic obstructive pulmonary disease and mucus retention who are unable to expectorate mucus effectively should be treated. The physiotherapist should make the choice for the most appropriate technique, or combination of techniques, based on observed shortcomings such as lack of expiratory force and tracheobronchial collapse. Patients should be coached to practise these techniques independently from their caregivers.

Manual chest and abdominal compression

A single uncontrolled study described effects of manual compression in 29 subjects (nine normal subjects, eight patients with chronic obstructive pulmonary disease and 12 subjects with respiratory muscle weakness).¹¹² It was concluded that manual compression increased peak cough flow in patients with muscle weakness, but decreased peak cough flow in patients with chronic obstructive pulmonary disease.

Recommendation. Manual compression during coughing or huffing should only be considered in patients with expiratory muscle weakness.

Postural drainage

Body position affects ventilation, perfusion and gas exchange. In a single randomized controlled trial (PEDro score: 4/10) in patients with bronchiectasis and excessive mucus production ($n=10$) postural drainage enhanced mucus transport and expectoration during forced expiratory manoeuvres compared with forced expiratory manoeuvres without postural drainage.¹¹³

Recommendation. Postural drainage may be considered as an additional intervention when forced expiratory manoeuvres are considered insufficiently effective and in patients with localized mucus retention (bronchiectasis).

Exercise

In a single randomized controlled trial (PEDro score: 4/10) in patients with chronic bronchitis ($n=8$) exercise did enhance mucus clearance, but was not as effective as coughing.¹¹⁴

Recommendation. Exercise is effective in stimulating mucus transport in patients with chronic obstructive pulmonary disease, but does not replace specific airway clearance techniques. Patients with impaired mucus clearance should be stimulated to participate, in addition to other interventions, in physical activities and exercise, to enhance mucus transport.

Chest percussion and vibration

Mechanical vibration may reduce mucus viscosity, stimulate coughing, or, by a resonance effect, reinforce ciliary movement.¹¹⁵ Thomas *et al.*¹¹⁶ noted improvements in ciliary function and changed mucus composition. A percussion frequency between 15 and 25 Hz is optimal for mucus transport, but this cannot be achieved manually.¹¹⁷ This most likely makes manual percussion ineffective.¹¹⁸ A single randomized controlled trial (PEDro score: 3/10) in 10 patients with chronic bronchitis showed that percussion added to postural drainage and coughing offered no benefits over postural drainage and coughing alone.¹¹⁹

Recommendation. Manual percussion is probably not an effective technique in enhancing mucus clearance in patients with chronic obstructive pulmonary disease.

Positive expiratory pressure breathing

Positive expiratory pressure breathing results in a temporary increase in functional residual capacity, reduction of (collateral) airway resistance and opening of closed small airways.¹²⁰ Graded

scientific conclusions on the effects of positive expiratory pressure and detailed descriptions of studies^{121–124} are provided in the online supplement Tables W15A and W15B.

Recommendation. There is insufficient evidence to support the use of positive expiratory pressure breathing in patients with chronic obstructive pulmonary disease. Application might be helpful in patients with excessive mucus production.

Positive pressure oscillative breathing

One randomized controlled trial (PEDro score: 3/10) compared the effects of postural drainage, positive pressure oscillate ('FLUTTER') breathing and forced expiratory techniques on oxygen saturation, pulmonary function and sputum expectoration in 10 patients with an acute exacerbation of chronic obstructive pulmonary disease symptoms.¹²⁵ All treatment modalities were equally effective in sputum expectoration, but FLUTTER breathing and forced expiration had more durable effects on mucus clearance. No effects were observed on oxygen saturation and pulmonary function. The application of FLUTTER breathing in stable patients has not been studied yet.

Recommendation. The effectiveness of positive pressure oscillate (FLUTTER) breathing has not been studied thoroughly in chronic obstructive pulmonary disease patients and can therefore not be recommended.

Improving compliance with therapy – encouraging permanent changes in physical activity behaviour

Permanent lifestyle changes are probably needed to ensure long-term maintenance of treatment effects. Two scientific conclusions (see online supplement Tables W16A and W17A) support two recommendations on strategies for improving compliance and encouraging permanent changes in physical activity behaviour.

Maintenance and follow-up

Maintenance programmes consisting of weekly telephone calls and monthly reinforcement sessions including physical exercise training for one year following eight weeks of supervised physical exercise training have so far not been successful in changing activity behaviour and maintaining treatment effects.^{126,127} Graded scientific conclusions on the effects of maintenance programmes and detailed descriptions of studies^{126,127} are provided in the online data supplement Tables W16A and W16B.

Recommendation. Based on the available data it can only be recommended to arrange regular follow-up care for patients on the completion of a supervised physical exercise training programme.

Patient education interventions to increase physical activity

Atkins *et al.* investigated the effects of strategies to improve adherence to a home-based walking programme.¹²⁸ Despite their promising findings little attention has been paid so far to the incorporation of behaviour modification strategies into the treatment plan for patients with chronic obstructive pulmonary disease. A pilot study by de Blok *et al.*¹²⁹ looked into the effects of lifestyle physical activity counselling, using physical activity self-monitoring (with pedometers), as an adjunct to pulmonary rehabilitation. They found a non-significant increase in daily steps in comparison to a control group at the end of a nine-week pulmonary rehabilitation programme. Another study on the effects of systematic activity counselling as an adjunct to pulmonary rehabilitation is currently recruiting patients.¹³⁰ Graded scientific conclusions on the effects of physical activity interventions and detailed descriptions of studies^{128,129} are provided in the online data supplement Tables W17A and W17B.

Other considerations. Several studies showed that intense physical exercise training as part of a multidisciplinary rehabilitation programme had only modest effects on participation in physical activities in daily life.^{131–135} Simply advising patients to do more physical activity without

more specific assistance and follow-up seems to be ineffective.¹³⁶ Chronic obstructive pulmonary disease education requires a physical activity intervention that is feasible, acceptable and effective in a variety of settings. Studies with successful results in chronically ill adults had in common that they used physical activity self-monitoring (e.g. with pedometers or diaries) and applied behavioural strategies to increase patient's self efficacy (confidence in one's ability to perform a desired behaviour) and self-regulatory skills.¹³⁷ A systematic review of randomized controlled trials on physical activity self-monitoring with pedometers showed an average increase of 2491 steps per day (95% confidence interval: 1098–3885 steps) above control interventions.¹³⁸ Many of these interventions used two or more interventions (e.g. self-monitoring, goal setting, diaries or counselling).

Recommendation. It is recommended to implement interventions to initiate and maintain change of physical activity behaviour. Short questionnaires or pedometers can be used during these interventions to facilitate follow-up assessment and self-monitoring of behaviour change.

Conclusions

There is strong evidence for the effectiveness of endurance, interval and strength training as core physiotherapeutic interventions for patients with chronic obstructive pulmonary disease. Future research must address potential benefits of additional interventions such as neuromuscular electrical stimulation, training of upper extremities, inspiratory muscle training, breathing exercises, non-invasive mechanical ventilation, and training with supplemental oxygen. In addition, treatment of impaired mucus clearance, especially during acute exacerbations, needs further research. With the advance of new technologies for objective measurements of physical activities in daily life more research is needed on interventions to initiate and maintain physical activity behaviour change during and after supervised physical exercise training programmes.

Clinical messages

- Physical exercise training is the cornerstone treatment to improve health related quality of life and functional exercise capacity.
- Additional interventions for reducing exertional dyspnea may have a place as adjuncts to physical exercise training in selected patients.
- Interventions to initiate and maintain physical activity behavior change during and after supervised physical exercise training programs are warranted
- Treatment of impaired mucus clearance, especially during acute exacerbations, needs further research.

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References

- 1 Nici L, Donner C, Wouters E *et al.* American Thoracic Society/European Respiratory Society statement on pulmonary rehabilitation. *Am J Respir Crit Care Med* 2006; **173**: 1390–413.
- 2 Troosters T, Casaburi R, Gosselink R, Decramer M. Pulmonary rehabilitation in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2005; **172**: 19–38.
- 3 Gosselink R, Langer D, Hendriks EJM *et al.* KNGF-Guideline for physical therapy in patients with chronic obstructive pulmonary disease. Accessed from: https://www.fysionet.nl/dossier_files/uploadFiles/RL_COPD_PRLEngels_01122008.pdf 2009
- 4 Ries AL, Bauldoff GS, Carlin BW *et al.* Pulmonary rehabilitation: Joint ACCP/AACVPR evidence-based clinical practice guidelines. *Chest* 2007; **131**: 4S–42S.
- 5 Langer D, Troosters T, Decramer M, Gosselink R. Grading recommendations: a matter of interpretation. *Chest* 2008; **133**: 830.

- 6 Dekhuijzen PNR, Smeele IJM, Smorenburg SM, Verhoeven MAWM eds. *Richtlijn Keten zorg COPD*. Stichting Ketenkwaliteit COPD, Leusden, 2005.
- 7 Bekkering GE, Hendriks HJM, Chadwick-Straver RVM, Gosselink R, Jongmans M, Paterson WJ. Richtlijn voor fysiotherapeutisch handelen bij patienten met chronische obstructive longaandoeningen. Achtergronden en evaluatie van de richtlijn COPD. Dutch Institute of Allied Health Care – NPi, 1998.
- 8 Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther* 2003; **83**: 713–721.
- 9 Richardson WS, Wilson MC, Nishikawa J, Hayward RS. The well-built clinical question: a key to evidence-based decisions. *ACP J Club* 1995; **123**: A12–A13.
- 10 American College of Sports Medicine. Position stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 1998; **30**: 975–91.
- 11 American College of Sports Medicine. Position stand: Exercise and physical activity for older adults. *Med Sci Sports Exerc* 1998; **30**: 992–1008.
- 12 Booker HA. Exercise training and breathing control in patients with chronic airflow limitation. *Physiotherapy* 1984; **70**: 258–60.
- 13 Lake FR, Henderson K, Briffa T, Openshaw J, Musk AW. Upper-limb and lower-limb exercise training in patients with chronic airflow obstruction. *Chest* 1990; **97**: 1077–82.
- 14 Cockcroft AE, Saunders MJ, Berry G. Randomised controlled trial of rehabilitation in chronic respiratory disability. *Thorax* 1981; **36**: 200–203.
- 15 McGavin CR, Gupta SP, Lloyd EL, McHardy GJR. Physical rehabilitation for the chronic bronchitic: results of a controlled trial of exercises in the home. *Thorax* 1977; **32**: 307–11.
- 16 Jones DT, Thomson RJ, Sears MR. Physical exercise and resistive breathing training in severe chronic airways obstruction—are they effective? *Eur J Respir Dis* 1985; **67**: 159–66.
- 17 Troosters T, Gosselink R, Decramer M. Short and long-term effects of outpatient pulmonary rehabilitation in COPD patients, a randomized controlled trial. *Am J Med* 2000; **109**: 207–12.
- 18 Hernandez MTE, Montemayor Rubio T, Ortega Ruiz F, Sanchez Riera H, Sanchez Gil R, Castillo Romez J. Results of a home-based training program for patients with COPD. *Chest* 2000; **118**: 106–14.
- 19 Larson JL, Covey MK, Wirtz SE *et al*. Cycle ergometer and inspiratory muscle training in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1999; **160**: 500–507.
- 20 Casaburi R, Patessio A, Ioli F, Zanaboni S, Donner CF, Wasserman K. Reductions in exercise lactic acidosis and ventilation as a result of exercise training in patients with obstructive lung disease. *Am Rev Respir Dis* 1991; **143**: 9–18.
- 21 Puente-Maestu L, Sanz ML, Sanz P, Cubillo JM, Mayol J, Casaburi R. Comparison of effects of supervised versus self-monitored training programmes in patients with chronic obstructive pulmonary disease. *Eur Respir J* 2000; **15**: 517–25.
- 22 Normandin EA, McCusker C, Connors M, Vale F, Gerardi D, ZuWallack RL. An evaluation of two approaches to exercise conditioning in pulmonary rehabilitation. *Chest* 2002; **121**: 1085–91.
- 23 Casaburi R, Porszasz J, Burns MR, Carithers ER, Chang RS, Cooper CB. Physiologic benefits of exercise training in rehabilitation of patients with severe chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1997; **155**: 1541–51.
- 24 Maltais F, Leblanc P, Jobin J *et al*. Intensity of training and physiologic adaptation in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1997; **155**: 555–61.
- 25 Vogiatzis I, Nanas S, Roussos C. Interval training as an alternative modality to continuous exercise in patients with COPD. *Eur Respir J* 2002; **20**: 12–19.
- 26 Vogiatzis I, Terzis G, Nanas S *et al*. Skeletal muscle adaptations to interval training in patients with advanced COPD. *Chest* 2005; **128**: 3838–45.
- 27 Puhon MA, Busching G, Schunemann HJ, VanOort E, Zaugg C, Frey M. Interval versus continuous high-intensity exercise in chronic obstructive pulmonary disease - A randomized trial. *Ann Intern Med* 2006; **145**: 816–25.
- 28 Coppoolse R, Schols AMWJ, Baarends EM *et al*. Interval versus continuous training in patients with severe COPD: a randomized clinical trial. *Eur Respir J* 1999; **14**: 258–63.
- 29 Kaelin ME, Barnard K, Swank A, Adams K, Ponto A. Results of 6 minute ambulation and MET tolerance of patients with severe chronic obstructive pulmonary disease (COPD) utilizing 2 different aerobic training regimes: interval training versus continuous training. Paper presented at the 2nd Annual Meeting of the American Society of Exercise Physiology, 1997.
- 30 Gosselink R, Troosters T, Decramer M. Exercise training in COPD patients: interval training vs. endurance training. *Eur Respir J* 1998; **12**: 2s.
- 31 Gosselink R, Troosters T, Decramer M. Peripheral muscle weakness contributes to exercise limitation

- in COPD. *Am J Respir Crit Care Med* 1996; **153**: 976–80.
- 32 Bernard S, Leblanc P, Whittom F *et al.* Peripheral muscle weakness in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1998; **158**: 629–34.
 - 33 Casaburi R, Bhasin S, Cosentino L *et al.* Effects of testosterone and resistance training in men with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2004; **170**: 870–78.
 - 34 Clark CJ, Cochrane JE, Mackay E. Low intensity peripheral muscle conditioning improves exercise tolerance and breathlessness in COPD. *Eur Respir J* 1996; **9**: 2590–96.
 - 35 Arnardottir RH, Sorensen S, Ringqvist I, Larsson K. Two different training programmes for patients with COPD: a randomised study with 1-year follow-up. *Respir Med* 2006; **100**: 130–39.
 - 36 Ortega F, Toral J, Cejudo P *et al.* Comparison of effects of strength and endurance training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2002; **166**: 669–74.
 - 37 Simpson K, Killian K, McCartney N, Stubbing DG, Jones NL. Randomised controlled trial of weightlifting exercise in patients with chronic airflow limitation. *Thorax* 1992; **47**: 70–75.
 - 38 Spruit M, Gosselink R, Troosters T, De Paepe K, Decramer M. Resistance vs. endurance training in patients with COPD and peripheral muscle weakness. *Eur Respir J* 2002; **19**: 1072–78.
 - 39 Wurtemberger G, Bastian K. Functional effects of different training in patients with COPD. *Pneumologie* 2001; **55**: 553–62, [in German].
 - 40 Bernard S, Whittom F, Leblanc P *et al.* Aerobic and strength training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1999; **159**: 896–901.
 - 41 Mador MJ, Bozkanat E, Aggarwal A, Shaffer M, Kufel TJ. Endurance and strength training in patients with COPD. *Chest* 2004; **125**: 2036–45.
 - 42 Ries AL, Ellis B, Hawkins RW. Upper extremity exercise training in chronic obstructive pulmonary disease. *Chest* 1988; **93**: 688–92.
 - 43 Clark CJ, Cochrane LM, Mackay E, Paton B. Skeletal muscle strength and endurance in patients with mild COPD and the effects of weight training. *Eur Respir J* 2000; **15**: 92–97.
 - 44 Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc* 2003; **35**: 456–64.
 - 45 Bourjeily-Habr G, Rochester CL, Palermo F, Snyder P, Mohsenin V. Randomised controlled trial of transcutaneous electrical muscle stimulation of the lower extremities in patients with chronic obstructive pulmonary disease. *Thorax* 2002; **57**: 1045–49.
 - 46 Neder JA, Sword D, Ward SA, Mackay E, Cochrane LM, Clark CJ. Home based neuromuscular electrical stimulation as a new rehabilitative strategy for severely disabled patients with chronic obstructive pulmonary disease (COPD). *Thorax* 2002; **57**: 333–37.
 - 47 Zanotti E, Felicetti G, Maini M, Fracchia C. Peripheral muscle strength training in bed-bound patients with COPD receiving mechanical ventilation. Effect of electrical stimulation. *Chest* 2003; **124**: 292–96.
 - 48 Vivodtzev I, Pepin JL, Vottero G *et al.* Improvement in quadriceps strength and dyspnea in daily tasks after 1 month of electrical stimulation in severely deconditioned and malnourished COPD. *Chest* 2006; **129**: 1540–48.
 - 49 Epstein SK, Celli B, Martinez FJ, Couser JI, Roa J, Pollock M. Arm training reduces the V02 and VE cost of unsupported arm exercise and elevation in chronic obstructive pulmonary disease. *J Cardiopulm Rehabil* 1997; **17**: 171–77.
 - 50 Bauldoff G, Hoffman L, Sciurba F, Zullo TG. Home-based, upper-arm exercise training for patients with chronic obstructive pulmonary disease. *Heart Lung* 1996; **25**: 288–94.
 - 51 Martinez FJ, Vogel DP, Dupont DN, Stanopoulos I, Gray A, Beamis JF. Supported arm exercise vs. unsupported arm exercise in the rehabilitation of patients with severe chronic airflow obstruction. *Chest* 1993; **103**: 1397–402.
 - 52 Holland AE, Hill CJ, Nehez E, Ntoumenopoulos G. Does unsupported upper limb exercise training improve symptoms and quality of life for patients with chronic obstructive pulmonary disease? *J Cardiopulm Rehabil* 2004; **24**: 422–27.
 - 53 Pitta F, Troosters T, Probst VS, Spruit MA, Decramer M, Gosselink R. Physical Activity and Hospitalization for Exacerbation of COPD. *Chest* 2006; **129**: 536–44.
 - 54 Seemungal TA, Donaldson GC, Paul EA, Bestall JC, Jeffries DJ, Wedzicha JA. Effect of exacerbation on quality of life in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1998; **157**: 1418–22.
 - 55 Spruit MA, Gosselink R, Troosters T *et al.* Muscle force during an acute exacerbation in hospitalised patients with COPD and its relationship with CXCL8 and IGF-I. *Thorax* 2003; **58**: 752–56.
 - 56 Probst VS, Troosters T, Celis G, Pitta F, Decramer M, Gosselink R. Effects of resistance exercise training during hospitalisation due to acute exacerbation of COPD preliminary results. *Eur Respir J* 2005; **49**: 432s.

- 57 Puhan MA, Scharplatz M, Troosters T, Steurer J. Respiratory rehabilitation after acute exacerbation of COPD may reduce risk for readmission and mortality – a systematic review. *Respir Res* 2005; **6**: 54.
- 58 Bauerle O, Chrusch CA, Younes M. Mechanisms by which COPD affects exercise tolerance. *Am J Respir Crit Care Med* 1998; **157**: 57–68.
- 59 Neder JA, Jones PW, Nery LE, Whipp BJ. Determinants of exercise endurance capacity in patients with chronic obstructive pulmonary disease. The power-duration relationship. *Am J Respir Crit Care Med* 2000; **162**: 497–504.
- 60 Gosselink R. Breathing techniques in patients with chronic obstructive pulmonary disease (COPD). *Chron Respir Dis* 2004; **1**: 163–72.
- 61 Lötters F, van Tol B, Kwakkel G, Gosselink R. Effects of controlled inspiratory muscle training in patients with COPD: a meta-analysis. *Eur Respir J* 2002; **20**: 570–76.
- 62 Geddes EL, Reid WD, Crowe J, O'Brien K, Brooks D. Inspiratory muscle training in adults with chronic obstructive pulmonary disease: a systematic review. *Respir Med* 2005; **99**: 1440–58.
- 63 O'Brien K, Geddes EL, Reid WD, Brooks D, Crowe J. Inspiratory muscle training compared with other rehabilitation interventions in chronic obstructive pulmonary disease: a systematic review update. *J Cardiopulm Rehabil Prev* 2008; **28**: 128–41.
- 64 Hill K, Jenkins SC, Philippe DL *et al*. High-intensity inspiratory muscle training in COPD. *Eur Respir J* 2006; **27**: 1119–28.
- 65 Scherer TA, Spengler C, Owassapian D, Imhof E, Boutellier U. Respiratory muscle endurance training in chronic obstructive pulmonary disease. Impact on exercise capacity, dyspnea, and quality of life. *Am J Respir Crit Care Med* 2000; **162**: 1709–14.
- 66 Heijdra YF, Dekhuijzen PN, van Herwaarden CL, Folgering HT. Nocturnal saturation improves by target-flow inspiratory muscle training in patients with COPD. *Am J Respir Crit Care Med* 1996; **153**: 260–65.
- 67 Koppers RJ, Vos PJ, Boot CR, Folgering HT. Exercise performance improves in patients with COPD due to respiratory muscle endurance training. *Chest* 2006; **129**: 886–92.
- 68 Weiner P, Magadle R, Beckerman M, Weiner M, Berar-Yanay N. Specific expiratory muscle training in COPD. *Chest* 2003; **124**: 468–73.
- 69 Weiner P, Magadle R, Beckerman M, Weiner M, Berar-Yanay N. Comparison of Specific Expiratory, Inspiratory, and Combined Muscle Training Programs in COPD. *Chest* 2003; **124**: 1357–64.
- 70 Sharp JT, Drutz WS, Moisan T, Foster J, Machnach W. Postural relief of dyspnea in severe chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1980; **122**: 201–11.
- 71 Druz WS, Sharp JT. Electrical and mechanical activity of the diaphragm accompanying body position in severe chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1982; **125**: 275–80.
- 72 O'Neill S, McCarthy DS. Postural relief of dyspnoea in severe chronic airflow limitation: relationship to respiratory muscle strength. *Thorax* 1983; **38**: 595–600.
- 73 Banzett R, Topulos G, Leith DE, Natis C. Bracing arms increases the capacity for sustained hyperpnea. *Am Rev Respir Dis* 1983; **133**: 106–109.
- 74 Probst VS, Troosters T, Coosemans I *et al*. Mechanisms of improvement in exercise capacity using a rollator in patients with COPD. *Chest* 2004; **126**: 1102–107.
- 75 Sharp JT, Druz WS, Moisan T, Foster J, Machnach W. Postural relief of dyspnea in severe chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1980; **122**: 201–11.
- 76 Tiep BL, Burns M, Kao D, Madison R, Herrera J. Pursed lips breathing training using ear oximetry. *Chest* 1986; **90**: 218–21.
- 77 Breslin EH. The pattern of respiratory muscle recruitment during pursed-lips breathing in COPD. *Chest* 1992; **101**: 75–78.
- 78 Spahija J, de Marchie M, Grassino A. Effects of imposed pursed-lips breathing on respiratory mechanics and dyspnea at rest and during exercise in COPD. *Chest* 2005; **128**: 640–50.
- 79 Reybrouck T, Wertelaers A, Bertrand P, Demedts M. Myofeedback training of the respiratory muscles in patients with chronic obstructive pulmonary disease. *J Cardiopulm Rehabil* 1987; **7**: 18–22.
- 80 Casciari RJ, Fairshier RD, Harrison A, Morrison JT, Blackburn C, Wilson AF. Effects of breathing retraining in patients with chronic obstructive pulmonary disease. *Chest* 1981; **79**: 393–98.
- 81 Collins EG, Fehr L, Bammert C *et al*. Effect of ventilation-feedback training on endurance and perceived breathlessness during constant work-rate leg-cycle exercise in patients with COPD. *J Rehabil Res Dev* 2003; **40**: 35–44.
- 82 Garrod R, Dallimore K, Cook J, Davies V, Quade K. An evaluation of the acute impact of pursed lips breathing on walking distance in non-spontaneous pursed lips breathing chronic

- obstructive pulmonary disease patients. *Chron Respir Dis* 2005; **2**: 67–72.
- 83 Bianchi R, Gigliotti F, Romagnoli I *et al*. Chest wall kinematics and breathlessness during pursed-lip breathing in patients with COPD. *Chest* 2004; **125**: 459–65.
- 84 Erpicum B, Willeput R, Sergysels R, De Coster A. Does abdominal breathing below FRC give a mechanical support for inspiration. *Clin Respir Physiol* 1984; **20**: 117.
- 85 Sackner MA, Gonzalez HF, Jenouri G, Rodriguez M. Effects of abdominal and thoracic breathing on breathing pattern components in normal subjects and in patients with COPD. *Am Rev Respir Dis* 1984; **130**: 584–87.
- 86 Grimby G. Aspects of lung expansion in relation to pulmonary physiotherapy. *Am Rev Respir Dis* 1974; **110**: 145–53.
- 87 Sackner MA, Gonzalez HF, Jenouri G, Rodriguez M. Effects of abdominal and thoracic breathing on breathing pattern components in normal subjects and in patients with COPD. *Am Rev Respir Dis* 1984; **130**: 584–87.
- 88 Grimby G, Oxhøj H, Bake B. Effects of abdominal breathing on distribution of ventilation in obstructive lung disease. *Clin Sci Mol Med* 1975; **48**: 193–99.
- 89 Gosselink RA, Wagenaar RC, Rijswijk H, Sargeant AJ, Decramer ML. Diaphragmatic breathing reduces efficiency of breathing in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1995; **151**: 1136–42.
- 90 Vitacca M, Clini E, Bianchi L, Ambrosino N. Acute effects of deep diaphragmatic breathing in COPD patients with chronic respiratory insufficiency. *Eur Respir J* 1998; **11**: 408–15.
- 91 Renfroe KL. Effect of progressive relaxation on dyspnea and state of anxiety in patients with chronic obstructive pulmonary disease. *Heart Lung* 1988; **17**: 408–13.
- 92 Gift AG, Moore T, Soeken K. Relaxation to reduce dyspnea and anxiety in COPD patients. *Nurs Res* 1992; **41**: 242–46.
- 93 Kolaczowski W, Taylor R, Hoffstein V. Improvement in oxygen saturation after chest physiotherapy in patients with emphysema. *Physiother Can* 1989; **41**: 18–23.
- 94 Bradley JM, Lasserson T, Elborn S, Macmahon J, O'Neill B. A systematic review of randomized controlled trials examining the short-term benefit of ambulatory oxygen in COPD. *Chest* 2007; **131**: 278–85.
- 95 Fichter J, Fleckenstein J, Stahl C, Sybrecht GW. Effect of oxygen (FI02: 0.35) on the aerobic capacity in patients with COPD. *Pneumologie* 1999; **53**: 121–26.
- 96 Wadell K, Henriksson-Larsen K, Lundgren R. Physical training with and without oxygen in patients with chronic obstructive pulmonary disease and exercise-induced hypoxaemia. *J Rehabil Med* 2001; **33**: 200–205.
- 97 Emtner M, Porszasz J, Burns M, Somfay A, Casaburi R. Benefits of supplemental oxygen in exercise training in nonhypoxemic chronic obstructive pulmonary disease patients. *Am J Respir Crit Care Med* 2003; **168**: 1034–42.
- 98 Garrod R, Paul EA, Wedzicha JA. Supplemental oxygen during pulmonary rehabilitation in patients with COPD with exercise hypoxaemia. *Thorax* 2000; **55**: 539–43.
- 99 Rooyackers JM, Dekhuijzen PNR, van Herwaarden CLA, Folgering HThM. Training with supplemental oxygen in patients with COPD and hypoxaemia at peak exercise. *Eur Respir J* 1997; **10**: 1278–84.
- 100 Nonoyama ML, Brooks D, Lacasse Y, Guyatt GH, Goldstein RS. Oxygen therapy during exercise training in chronic obstructive pulmonary disease. *Cochrane Database Syst Rev* 2007; (2): CD005372. DOI: 10.1002/14651858.CD005372.pub2.
- 101 Smith RP, Johnson MK, Ashley J, Rudkin ST, White RJ. Effect of exercise induced hypoxaemia on myocardial repolarisation in severe chronic obstructive pulmonary disease. *Thorax* 1998; **53**: 572–76.
- 102 Costes F, Agresti A, Court-Fortune I, Roche F, Vergnon JM, Barthelemy JC. Noninvasive ventilation during exercise training improves exercise tolerance in patients with chronic obstructive pulmonary disease. *J Cardiopulm Rehabil* 2003; **23**: 307–13.
- 103 Hawkins P, Johnson LC, Nikolettou D *et al*. Proportional assist ventilation as an aid to exercise training in severe chronic obstructive pulmonary disease. *Thorax* 2002; **57**: 853–59.
- 104 Van't Hul A, Gosselink R, Hollander P, Postmus P, Kwakkel G. Training with inspiratory pressure support in patients with severe COPD. *Eur Respir J* 2006; **27**: 65–72.
- 105 Bianchi L, Foglio K, Porta R, Vitacca M, Ambrosino N. Lack of additional effect of adjunct of assisted ventilation to pulmonary rehabilitation in mild COPD patients. *Respir Med* 2002; **96**: 359–67.
- 106 Johnson JE, Gavin DJ, Adams-Dramiga S. Effects of training with heliox and noninvasive positive pressure ventilation on exercise ability in patients with severe COPD. *Chest* 2002; **122**: 464–72.

- 107 Garrod R, Mikelsons C, Paul EA, Wedzicha JA. Randomized controlled trial of domiciliary non-invasive positive pressure ventilation and physical training in severe chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2000; **162**: 1335–41.
- 108 Jones A, Rowe BH. Bronchopulmonary hygiene physical therapy in bronchiectasis and chronic obstructive pulmonary disease: a systematic review. *Heart Lung* 2000; **29**: 125–35.
- 109 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.
- 110 van der Schans CP, Piers DA, Postma DS. Effect of manual percussion on tracheobronchial clearance in patients with chronic airflow obstruction and excessive tracheobronchial secretion. *Thorax* 1986; **41**: 448–52.
- 111 Main E, Prasad A, van der Schans C. Conventional chest physiotherapy compared to other airway clearance techniques for cystic fibrosis. *Cochrane Database Syst Rev* 2005; (1): CD002011. DOI: 10.1002/14651858.CD002011.pub2.
- 112 Sivasothy P, Brown L, Smith IE, Shneerson JM. Effect of manually assisted cough and mechanical insufflation on cough flow of normal subjects, patients with chronic obstructive pulmonary disease (COPD), and patients with respiratory muscle weakness. *Thorax* 2001; **56**: 438–44.
- 113 Sutton PP, Parker RA, Webber BA *et al*. Assessment of the forced expiration technique, postural drainage and directed coughing in chest physiotherapy. *Eur J Respir Dis* 1983; **64**: 62–68.
- 114 Oldenburg FA, Dolovich MB, Montgomery JM, Newhouse MT. Effects of postural drainage, exercise and cough on mucus clearance in chronic bronchitis. *Am Rev Respir Dis* 1979; **120**: 739–45.
- 115 Pham QT, Peslin R, Puchelle E, Salmon D, Caraux G, Benis AM. Respiratory function and the rheological status of bronchial secretions collected by spontaneous expectoration and after physiotherapy. *Bull Physiopathol Respir* 1973; **9**: 293–314.
- 116 Thomas J, DeHueck A, Kleiner M, Newton J, Crowe J, Mahler S. To vibrate or not to vibrate: usefulness of the mechanical vibrator for clearing bronchial secretions. *Physiother Can* 1995; **47**: 120–25.
- 117 Radford R, Barutt J, Billingsley JG, Hill W, Lawson H, Willich W. A rational basis for percussion-augmented mucociliary clearance. *Respir Care* 1982; **27**: 556–63.
- 118 Hansen LG, Warwick WJ. High-frequency chest compression system to aid in clearance of mucus from the lung. *Biomed Instrum Technol* 1990; **24**: 289–94.
- 119 Wollmer P, Ursing K, Midgren B, Eriksson L. Inefficiency of chest percussion in the physical therapy of chronic bronchitis. *Eur J Respir Dis* 1985; **66**: 233–39.
- 120 Groth S, Stafanger G, Dirksen H, Andersen JB, Falk M, Kelstrup M. Positive expiratory pressure (PEP-mask) physiotherapy improves ventilation and reduces volume of trapped gas in cystic fibrosis. *Clin Respir Physiol* 1985; **21**: 339–43.
- 121 Christensen EF, Nedergaard T, Dahl R. Long-term treatment of chronic bronchitis with positive expiratory pressure and chest physiotherapy. *Chest* 1990; **97**: 645–50.
- 122 Bellone A, Spagnolatti L, Massobrio M *et al*. Short-term effects of expiration under positive pressure in patients with acute exacerbation of chronic obstructive pulmonary disease and mild acidosis requiring non-invasive positive pressure ventilation. *Intensive Care Med* 2002; **28**: 581–85.
- 123 van Hengstum M, Festen J, Beurskens C *et al*. The effect of positive expiratory pressure versus forced expiration technique on tracheobronchial clearance in chronic bronchitics. *Scand J Gastroenterol Suppl* 1988; **143**: 114–18.
- 124 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 bronchitics. *Eur Respir J* 1991; **4**: 651–54.
- 125 Bellone A, Lascioli R, Raschi S, Guzzi L, Adone R. Chest physical therapy in patients with acute exacerbation of chronic bronchitis: effectiveness of three methods. *Arch Phys Med Rehabil* 2000; **81**: 558–60.
- 126 Ries AL, Kaplan RM, Myers R, Prewitt LM. Maintenance after pulmonary rehabilitation in chronic lung disease: a randomized trial. *Am J Respir Crit Care Med* 2003; **167**: 880–88.
- 127 Heppner PS, Morgan C, Kaplan RM, Ries AL. Regular walking and long-term maintenance of outcomes after pulmonary rehabilitation. *J Cardiopulm Rehabil* 2006; **26**: 44–53.
- 128 Atkins CJ, Kaplan RM, Timms RM, Reinsch S, Lofback K. Behavioural Exercise Programs in the Management of Chronic Obstructive Pulmonary-Disease. *J Consult Clin Psychol* 1984; **52**: 591–603.
- 129 de Blok BM, de Greef MH, Ten Hacken NH, Sprenger SR, Postema K, Wempe JB. The effects

- of a lifestyle physical activity counseling program with feedback of a pedometer during pulmonary rehabilitation in patients with COPD: A pilot study. *Patient Educ Couns* 2006; **61**: 48–55.
- 130 Foy CG, Wickley KL, Adair N *et al*. The Reconditioning Exercise and Chronic Obstructive Pulmonary Disease Trial II (REACT II): rationale and study design for a clinical trial of physical activity among individuals with chronic obstructive pulmonary disease. *Contemp Clin Trials* 2006; **27**: 135–46.
- 131 Pitta F, Troosters T, Spruit MA *et al*. Does pulmonary rehabilitation improve physical activities in daily life in COPD patients? *Eur Respir J* 2005; **49**: 181s.
- 132 Coronado M, Janssens JP, De Muralt B, Terrier P, Schutz Y, Fitting JW. Walking activity measured by accelerometry during respiratory rehabilitation. *J Cardiopulm Rehabil* 2003; **23**: 357–64.
- 133 Mercken EM, Hageman GJ, Schols AM, Akkermans MA, Bast A, Wouters EF. Rehabilitation decreases exercise-induced oxidative stress in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2005; **172**: 994–1001.
- 134 Sewell L, Singh SJ, Williams JE, Collier R, Morgan MD. Can individualized rehabilitation improve functional independence in elderly patients with COPD? *Chest* 2005; **128**: 1194–200.
- 135 Steele BG, Belza B, Hunziker J *et al*. Monitoring daily activity during pulmonary rehabilitation using a triaxial accelerometer. *J Cardiopulm Rehabil* 2003; **23**: 139–42.
- 136 Hillsdon M, Thorogood M, White I, Foster C. Advising people to take more exercise is ineffective: a randomized controlled trial of physical activity promotion in primary care. *Int J Epidemiol* 2002; **31**: 808–15.
- 137 Conn VS, Hafdahl AR, Brown SA, Brown LM. Meta-analysis of patient education interventions to increase physical activity among chronically ill adults. *Patient Educ Couns* 2008; **70**: 157–72.
- 138 Bravata DM, Smith-Spangler C, Sundaram V *et al*. Using pedometers to increase physical activity and improve health: a systematic review. *JAMA* 2007; **298**: 2296–304.