

# Preoperative physical therapy for elective cardiac surgery patients (Review)

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[Intervention Review]

# Preoperative physical therapy for elective cardiac surgery patients

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## ABSTRACT

### Background

After cardiac surgery, physical therapy is a routine procedure delivered with the aim of preventing postoperative pulmonary complications.

### Objectives

To determine if preoperative physical therapy with an exercise component can prevent postoperative pulmonary complications in cardiac surgery patients, and to evaluate which type of patient benefits and which type of physical therapy is most effective.

### Search methods

Searches were run on the Cochrane Central Register of Controlled Trials (CENTRAL) on *the Cochrane Library* (2011, Issue 12 ); MEDLINE (1966 to 12 December 2011); EMBASE (1980 to week 49, 2011); the Physical Therapy Evidence Database (PEDro) (to 12 December 2011) and CINAHL (1982 to 12 December 2011).

### Selection criteria

Randomised controlled trials or quasi-randomised trials comparing preoperative physical therapy with no preoperative physical therapy or sham therapy in adult patients undergoing elective cardiac surgery.

### Data collection and analysis

Data were collected on the type of study, participants, treatments used, primary outcomes (postoperative pulmonary complications grade 2 to 4: atelectasis, pneumonia, pneumothorax, mechanical ventilation > 48 hours, all-cause death, adverse events) and secondary outcomes (length of hospital stay, physical function measures, health-related quality of life, respiratory death, costs). Data were extracted by one review author and checked by a second review author. Review Manager 5.1 software was used for the analysis.

## Main results

Eight randomised controlled trials with 856 patients were included. Three studies used a mixed intervention (including either aerobic exercises or breathing exercises); five studies used inspiratory muscle training. Only one study used sham training in the controls. Patients that received preoperative physical therapy had a reduced risk of postoperative atelectasis (four studies including 379 participants, relative risk (RR) 0.52; 95% CI 0.32 to 0.87;  $P = 0.01$ ) and pneumonia (five studies including 448 participants, RR 0.45; 95% CI 0.24 to 0.83;  $P = 0.01$ ) but not of pneumothorax (one study with 45 participants, RR 0.12; 95% CI 0.01 to 2.11;  $P = 0.15$ ) or mechanical ventilation for > 48 hours after surgery (two studies with 306 participants, RR 0.55; 95% CI 0.03 to 9.20;  $P = 0.68$ ). Postoperative death from all causes did not differ between groups (three studies with 552 participants, RR 0.66; 95% CI 0.02 to 18.48;  $P = 0.81$ ). Adverse events were not detected in the three studies that reported on them. The length of postoperative hospital stay was significantly shorter in experimental patients versus controls (three studies with 347 participants, mean difference -3.21 days; 95% CI -5.73 to -0.69;  $P = 0.01$ ). One study reported a reduced physical function measure on the six-minute walking test in experimental patients compared to controls. One other study reported a better health-related quality of life in experimental patients compared to controls. Postoperative death from respiratory causes did not differ between groups (one study with 276 participants, RR 0.14; 95% CI 0.01 to 2.70;  $P = 0.19$ ). Cost data were not reported on.

## Authors' conclusions

Evidence derived from small trials suggests that preoperative physical therapy reduces postoperative pulmonary complications (atelectasis and pneumonia) and length of hospital stay in patients undergoing elective cardiac surgery. There is a lack of evidence that preoperative physical therapy reduces postoperative pneumothorax, prolonged mechanical ventilation or all-cause deaths.

## PLAIN LANGUAGE SUMMARY

### Preoperative physical therapy for elective cardiac surgery patients

Patients undergoing cardiac surgery are at risk of postoperative pulmonary complications such as pneumonia. These complications prolong postoperative recovery and may even lead to death. Increased physical fitness improves people's functional capacity, including their lungs, and could result in individuals being better prepared to withstand the consequences of the physical stress of surgery.

The authors of this review evaluated the efficacy and safety of preoperative physical therapy with an exercise component in cardiac surgery patients. From the pertinent literature, eight studies met the inclusion criteria, comprising a total of 856 participants. The results showed that preoperative physical therapy reduced the number of patients who experienced atelectasis or pneumonia but not the number of patients who experienced pneumothorax, prolonged ventilation or postoperative death. Patients who had preoperative physical therapy had an earlier (on average by more than three days) discharge from the hospital. Information on adverse events was limited but those studies that did report on adverse events reported none. None of the studies reported on the costs of preoperative physical therapy.

The authors concluded that preoperative physical therapy, especially inspiratory muscle training, prevents some postoperative complications including atelectasis, pneumonia, and length of hospital stay.

## BACKGROUND

### Description of the condition

Cardiac surgery is among the most common surgical procedures in the world and accounts for more resources being expended in cardiovascular medicine than any other single procedure (Eagle

2004). From 1979 to 2005, the total number of inpatient cardiovascular operations and procedures increased 484% in the United States ([www.americanheart.org](http://www.americanheart.org)). The National Center for Health Statistics estimated that in 2005, 6,989,000 inpatient cardiovascular operations and procedures were performed (1,271,000 inpatient angioplasty procedures, 469,000 inpatient bypass procedures, 1,322,000 inpatient diagnostic cardiac catheterizations,

98,000 inpatient implantable defibrillators, and 180,000 inpatient pacemaker procedures) ([www.americanheart.org](http://www.americanheart.org)). The estimated cost of coronary heart disease was USD 156.4 billion in 2008. This included health expenditures (direct costs, which include the cost of physicians and other professionals, hospital and nursing home services, medications, home health care and other medical durables) and lost productivity resulting from morbidity and mortality (indirect costs) ([www.americanheart.org](http://www.americanheart.org)).

Patients undergoing cardiac surgery are at risk of postoperative pulmonary complications, which lead to increased postoperative morbidity and mortality (Brooks-Brunn 1995; Ephgrave 1993; Hart 1989; Taylor 1990; Weissman 1999; Weismann 2004), increased use of medical resources, length of hospital stay and healthcare costs (Davies 1991; Ephgrave 1993; Taylor 1990). The incidence of postoperative pulmonary complications varies between 20% to 95% after cardiac surgery (Brooks-Brunn 1995), depending in part on the type of surgery, specific criteria used to define postoperative pulmonary complications and on the diagnostic techniques to document them (Brooks-Brunn 1995; Weissman 1999; Wynne 2004). Surgery represents a major stressor for patients, causing loss of muscle mass, deconditioning, hypoxaemia, mental disturbances and sleep disorders. Changes in the respiratory system (during and after the surgical intervention) occur as a result of the effects of anaesthetics and of analgesia (Hedenstierna 2005) and include changes in lung volumes, diaphragmatic dysfunction, a decrease in respiratory muscle strength (Dureuil 1987; Laghi 2003; Ragnarsdottir 2004; Sykes 1993; Van Belle 1992), changes in ventilation pattern (Ford 1993; Imanaka 2004; Nishino 1998) and alterations in gas exchange and response to carbon dioxide and oxygen concentrations (Kjaergaard 2004; Knill 1988; Sykes 1993; Tenling 1998). In addition, cardiac surgical patients are subject to distinct factors that predispose them to postoperative pulmonary complications. Unique to cardiac surgery are the effects of median sternotomy incision, topical cooling, internal mammary artery dissection and often the use of cardiopulmonary bypass (Wynne 2004). The most reported patient-related preoperative risk factors for postoperative pulmonary complications are age over 70 years, diabetes mellitus, body mass index > 28 or morbid obesity, preoperative arrhythmia or unstable angina, chronic lung disease, smoking history and hepatic insufficiency (Nilsson 2006).

As a result of the high incidence of postoperative pulmonary complications and the cost they incur during the hospital stay, efforts have been made to identify those patients who have a higher risk of developing such complications (Ferguson 1999) and to find interventions to prevent the complications (Sowden 1997; Weismann 2004), but there is no consensus on the most appropriate or effective therapy (Johnson 1996; Pasquina 2003; Stiller 1992).

## Description of the intervention

Over the past 25 years a number of investigators (Convertino 1997; Krasnoff 1999; Powell 1994) have determined that physical

activity is essential to maintaining optimal functioning of most organ systems of the body. Surgery is a substantial risk to the healthy functioning of those systems. Within certain limits, persons can be trained to become more physically fit (Topp 2002). Increased physical activity can improve the functional capacity of a number of organ systems and result in an increased preparedness to withstand external stressors (Carli 2005; Topp 2002). This concept is translated by several authors (Arthur 2000; Weiner 1998) to the cardiac surgery patient and especially to the training of the inspiratory muscle system. The inspiratory muscles can be trained using an inspiratory threshold-loading device. With this device, patients inspire against a threshold load whereas expiration is unimpeded. Physical therapy focused on maximising functional capacity when threatened by problems in oxygen transport is now thought to best start in the preoperative period in order to reduce the risk of postoperative pulmonary complications (Hulzebos 2006A; Rajendran 1998). A few studies have demonstrated that preoperative physical therapy (pulmonary rehabilitation) has advantages over postoperative care alone in cardiac surgery patients (Arthur 2000; Hulzebos 2006A).

## How the intervention might work

Breathing exercises (with or without the aid of equipment and manual techniques) compensate for and normalise abnormal breathing patterns and may help to reduce the risk of atelectasis and pneumonia (Craig 1991; Craven 1974; Simmons 1982). The inspiratory muscles can be trained for both strength and endurance, similar to skeletal muscles (McConnel 2004; Weiner 1998). Improvements in the strength and endurance of the inspiratory muscles may lead to increased resistance to fatigue and improved ventilatory function through decreased work of breathing and increased respiratory reserve (Shekleton 1996). Regular exercise and physical conditioning have been shown to cause positive changes in cardiorespiratory function and other regulatory mechanisms with associated enhancement of physical performance, in general populations and in populations at risk such as the elderly.

## Why it is important to do this review

There is still controversy about whether physical therapy can decrease postoperative pulmonary complications. However, a wide array of physical therapy techniques are usually given after surgery, whereas the preferred strategy would be to identify patients at high risk and give them physical therapy with an exercise component before surgery (Carli 2005; Rajendran 1998). The purpose of this review was, therefore, to systematically examine the published evidence for the efficacy of preoperative physiotherapy with an exercise component in elective cardiac surgery patients in order to prevent postoperative pulmonary complications.

## OBJECTIVES

The objective of this review is to evaluate the effect of preoperative physical therapy to prevent postoperative pulmonary complications in adults undergoing elective cardiac surgery. In addition, we wanted to know if the effectiveness differed in patients at low risk of postoperative pulmonary complications versus patients at high risk of postoperative pulmonary complications, and to examine the effect of different types of physical therapy.

## METHODS

### Criteria for considering studies for this review

#### Types of studies

All randomised controlled trials or quasi-randomised controlled trials that involved the use of preoperative physical therapy, for example incentive spirometry, breathing exercises, respiratory muscle training or exercise training.

#### Types of participants

Adult patients (age > 18 years) undergoing elective cardiac surgery (for example coronary artery surgery or valvular surgery). Both on-pump and off-pump procedures were considered for inclusion.

#### Types of interventions

Studies that included one treatment group in which preoperative physical therapy with an exercise component was applied (for example incentive spirometry, breathing or coughing exercises, respiratory muscle training, cardiorespiratory exercise training) compared to a control group with no preoperative physical therapy or receiving sham therapy. The postoperative regimen had to be similar in both groups. Preoperative physical therapy with an exercise component was defined as all therapy given to the patient before surgery which included at least one of the following: incentive spirometry, breathing or coughing exercises, respiratory muscle training, exercise training. Education about the postoperative period, instructions in various physical therapy techniques delivered directly preoperatively and to be used postoperatively, preoperative lifestyle advice including general advice on physical exercise, or electrical nerve stimulation were not defined as preoperative physical therapy, nor were smoking cessation or weight loss interventions.

## Types of outcome measures

### Primary outcomes

The primary outcomes were the occurrence of postoperative pulmonary complications grades 2, 3 or 4 (Kroenke 1992), all-cause mortality and adverse events. In the literature, the terms dysfunction and complications are frequently used interchangeably. We maintain that a distinction between postoperative pulmonary dysfunction and a postoperative pulmonary complication is necessary. Postoperative pulmonary dysfunction refers to expected alterations in pulmonary function such as increased work of breathing, shallow respiration, ineffective cough, and hypoxaemia. The diagnosis of a postoperative pulmonary complication requires symptomatic pulmonary dysfunction and associated clinical findings that meet the specified criteria of a particular diagnosis (Wynne 2004). In this study we defined postoperative pulmonary complications as any pulmonary abnormality occurring in the postoperative period that produces identifiable disease or dysfunction and that is clinically significant and adversely affects the clinical course (O'Donohue 1992). We used the classification of Kroenke (Kroenke 1992). Only grades 2, 3 and 4 were identified as clinically significant because they adversely affect the clinical course (Johnson 1996; Narayan 2005).

### Secondary outcomes

The secondary outcomes were: (a) length of (postoperative) hospital stay, (b) physical function measures, (c) postoperative respiratory mortality, (d) health-related quality of life and (e) economic costs.

## Search methods for identification of studies

### Electronic searches

The following electronic databases were searched on 12 December 2011 to identify relevant studies:

- Cochrane Central Register of Controlled Trials (CENTRAL) (2011, Issue 12) through Ovid®;
- MEDLINE (1966 up to 12 December 2011);
- EMBASE through Ovid® (1980 up to week 49, 2011);
- PEDro (Physiotherapy Evidence Database) (from the earliest achievable data to 12 December 2011);
- CINAHL through EBSCOhost® (1982 up to 12 December 2011).

No language restrictions were applied.

The search strategies that were used to search CENTRAL, MEDLINE, EMBASE, PEDro and CINAHL are given in [Appendix 1](#), [Appendix 2](#), [Appendix 3](#) and [Appendix 4](#).

### Searching other resources

We searched the metaRegister of controlled trials ([www.controlled-trials.com/mrct](http://www.controlled-trials.com/mrct)), Clinicaltrials.gov ([www.clinicaltrials.gov](http://www.clinicaltrials.gov)) and the World Health Organization (WHO) International Clinical Trials Registry Platform (ICTRP) ([apps.who.int/trialsearch/](http://apps.who.int/trialsearch/)) for ongoing trials.

The library of the Dutch Institute of Allied Health Care and reference lists of relevant existing clinical practice guidelines (for example clinical practice guidelines that have been drafted by the American Association for Respiratory Care for Postural Drainage, Incentive Spirometry and Directed Cough) were reviewed.

All the references in selected trials and identified systematic reviews were checked for identification of other relevant articles.

Institutions and experts known to have expertise in physiotherapy techniques were contacted for further information and unpublished studies.

## Data collection and analysis

### Selection of studies

Two review authors (EH and YS) independently screened the search results for potentially eligible studies. When titles and abstracts suggested a study was potentially eligible for inclusion, a full text copy of the report was obtained. Disagreements were resolved by discussion until consensus was reached or, where necessary, a third review author (NvM) acted as mediator.

### Data extraction and management

Data were extracted by one review author (YS) and cross-checked by a second review author (EH). Information regarding the study method, the study setting, patient characteristics (age range, eligibility criteria, risk factors), types of intervention and outcomes were collected. If data were missing or further information was required, we wrote to the corresponding study author to request the required information. The data extracted for the length of hospital stay were either data on the length of postoperative stay or data on the length of hospital stay, as available. When both measures were available we chose data on the postoperative length of stay. Data on atelectasis or pleural effusion were only extracted when we considered it likely that the authors had classified: (a) atelectasis as a postoperative pulmonary complication grade 2 (and not as micro-atelectasis, or postoperative pulmonary complication grade 1); (b) pleural effusion as a postoperative pulmonary complication grade 3 (pleural effusion resulting in thoracocentesis) ([Kroenke 1992](#)).

If data on physical function measures were available at more than one time point we chose the latest in hospital time point available. Disagreements were discussed by the two review authors until a consensus was reached. If no consensus was reached, a third review author (NvM) acted as mediator.

### Assessment of risk of bias in included studies

The risk of bias assessment was performed as recommended by the *Cochrane Handbook for Systematic Reviews of Interventions* ([Higgins 2011](#)) using risk of bias tables. The domains these risk of bias tables assessed were: sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and providers (performance bias), blinding of outcome assessor (detection bias), incomplete outcome data (attrition bias), selective outcome reporting (reporting bias) and other sources of bias. The first part of the tool involves describing what was reported to have happened in the study. The second part of the tool involves assigning a judgement related to the risk of bias for that entry in terms of low, high or unclear risk. Each domain was assessed for each study in one of three categories: (1) low risk of bias; (2) high risk of bias; (3) unclear risk of bias.

### Measures of treatment effect

Statistical analyses were performed using RevMan 5.1 software, and in accordance with the Cochrane Heart Review Group. For all dichotomous outcomes the fixed-effect model was used in the meta-analysis to determine the relative risk (RR). For continuous outcomes, the fixed-effect model was used in the meta-analysis to determine the weighted mean difference (MD). If different continuous measures had been reported for the same outcome (for example different tests of physical function or measures for quality of life) we would have determined a standardized mean difference of postoperative between-group differences. Heterogeneity of the effect size between studies was tested for with each outcome measure. If statistical heterogeneity was present ( $I^2 > 50\%$ ) ([Higgins 2003](#)) the random-effects model was applied and, if possible, the source of heterogeneity was explored through subgroup analyses.

### Subgroup analysis and investigation of heterogeneity

If we had had enough trials, we would have analysed differences in the weighted average effect size between different types of interventions (that is types of physical therapy with an exercise component) and between studies that included low- versus high-risk patients. If more trials are found in subsequent updates we will include subgroup analysis.

### Sensitivity analysis

If we had found enough trials, we would have conducted sensitivity analyses for studies with an adequate randomisation procedure

(that is an unbiased method for random sequence generation) versus studies without an adequate randomisation procedure. If more trials are found in subsequent updates we will include sensitivity analysis.

## RESULTS

### Description of studies

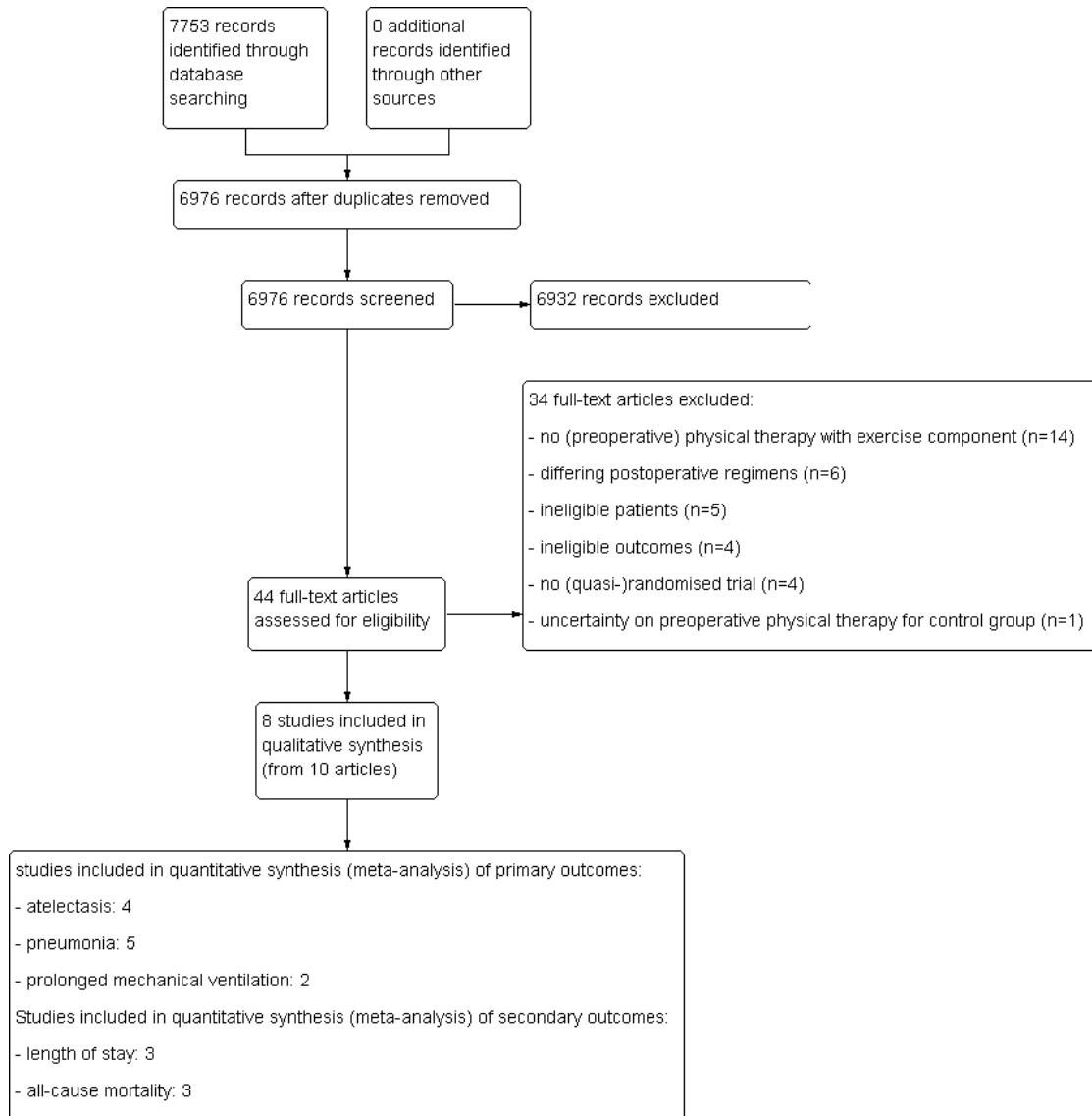
See: [Characteristics of included studies](#); [Characteristics of excluded studies](#).

### Results of the search

A total of 6976 single citations were screened for relevancy, out of which 37 abstracts were selected as possibly being appropriate for inclusion. After reading the full text papers, 29 studies were excluded from this review. Reasons for exclusion of these studies are listed in the table '[Characteristics of excluded studies](#)'. Eight randomised controlled trials with 856 adult patients awaiting elective cardiac surgery were included in this review. Details of these studies are shown in the table '[Characteristics of included studies](#)'. [Figure 1](#) shows the study flow diagram.



**Figure 1. Study flow diagram.**



## Included studies

### Sample sizes and settings

Four studies included less than 50 patients (Carvalho 2011; Ferreira 2009; Hulzebos 2006B; Rajendran 1998); one study included between 50 and 100 patients (Weiner 1998); and three studies included between 100 and 200 patients (Arthur 2000; Hulzebos 2006A; Rosenfeldt 2011). All studies were single centre studies conducted in either Australia (Rosenfeldt 2011), Brazil

(Carvalho 2011; Ferreira 2009), Canada (Arthur 2000), India (Rajendran 1998), Israel (Weiner 1998) or the Netherlands (Hulzebos 2006A; Hulzebos 2006B).

### Participants

Based on diverse risk models, one study included low-risk patients (Arthur 2000) and three studies included high-risk patients (Carvalho 2011; Hulzebos 2006A; Hulzebos 2006B). Whereas Arthur 2000 and Carvalho 2011 did not define low risk and high

risk, respectively, [Hulzebos 2006A](#) and [Hulzebos 2006B](#) defined high risk as having either a forced vital capacity < 80% of the predicted value or two or more of the following characteristics: age over 70 years; cough and expectoration; diabetes; smoker; chronic obstructive pulmonary disease. A further three studies did not report whether high- or low-risk patients were included and gave too few patient details to make a definite assessment of patient risk ([Ferreira 2009](#); [Rosenfeldt 2011](#); [Weiner 1998](#)). Although patients in the last study were also not classified as low- or high-risk, all had chronic obstructive pulmonary disease and thus we assessed the patients as at high risk for postoperative pulmonary complications ([Rajendran 1998](#)).

Patients who died after coronary artery bypass graft surgery (CABG) or who needed mechanical ventilation for more than 24 hours, whether or not related to pulmonary complications, were excluded from the analysis in [Rajendran 1998](#).

All patient characteristics that were reported on were evenly distributed per treatment group, except in one study ([Ferreira 2009](#)) where the experimental group had fewer males (60% versus 87% in the control group;  $P < 0.01$ ). In one other study the median age in the experimental group was lower, although not significantly so, compared to the median age of controls (62.5 versus 68 years;  $P = 0.06$ ) ([Rosenfeldt 2011](#)).

## Interventions

In three studies the intervention was mixed, either with an aerobic exercise component ([Arthur 2000](#); [Rosenfeldt 2011](#)) or with breathing exercises ([Rajendran 1998](#)); whereas in the other five studies the intervention was inspiratory muscle training with a threshold loading device ([Carvalho 2011](#); [Ferreira 2009](#); [Hulzebos 2006A](#); [Hulzebos 2006B](#); [Weiner 1998](#)). The mixed intervention in [Arthur 2000](#) consisted of: (a) individually prescribed aerobic exercise training under supervision and in a group, twice a week for eight weeks, at 40% to 70% of a person's functional capacity; and (b) a supportive educational component with two moments of preoperative teaching, monthly telephone contact by nurse clinicians and encouragement to stop smoking. The mixed intervention in [Rosenfeldt 2011](#) consisted of: (a) low intensity aerobic exercise, supervised training at approximately 50% of maximum oxygen uptake for one hour, twice a week for two weeks, plus encouragement to complete two weekly personal sessions for at least 30 minutes on at least two other occasions each week, including after the discontinuation of the supervised programme; and (b) a mental stress reduction programme consisting of four individualised one hour sessions including education and relaxation techniques, such as deep breathing and meditation, for the first two weeks after placement on the surgery waiting list. The mixed intervention in [Rajendran 1998](#) consisted of health education, exercise reconditioning and support, instruction about respiratory disease and its treatment, breathing retraining (diaphragmatic breathing

and pursed lip breathing), dyspnoea control, nutritional counselling, energy conservation, work simplification techniques and stress management with relaxation training in daily sessions for one week under the guidance of a specialist, and advice to practice for 10 minutes every waking hour.

The other five studies that applied inspiratory muscle training with a threshold loading device did so:

- at 30% of peak inspiratory pressure, for two weeks, seven days a week, twice a day, three sets of 10 repetitions ([Carvalho 2011](#));
- at 40% of peak inspiratory pressure, over at least two weeks, seven days a week, thrice daily, five sets of 10 repetitions ([Ferreira 2009](#));
- starting at 30% of peak inspiratory pressure with an incremental increase, for at least 20 minutes, daily for at least two weeks ([Hulzebos 2006A](#); [Hulzebos 2006B](#));
- starting at 15% of peak inspiratory pressure for one week, then an incremental 5% increase each session up to 60%, daily sessions of 30 minutes for two to four weeks.

Control treatments were always usual care, except in [Weiner 1998](#) where sham therapy was used. In that study the control patients followed a training protocol with a threshold loading device that was similar to patients in the experimental group but with no resistance.

## Outcomes

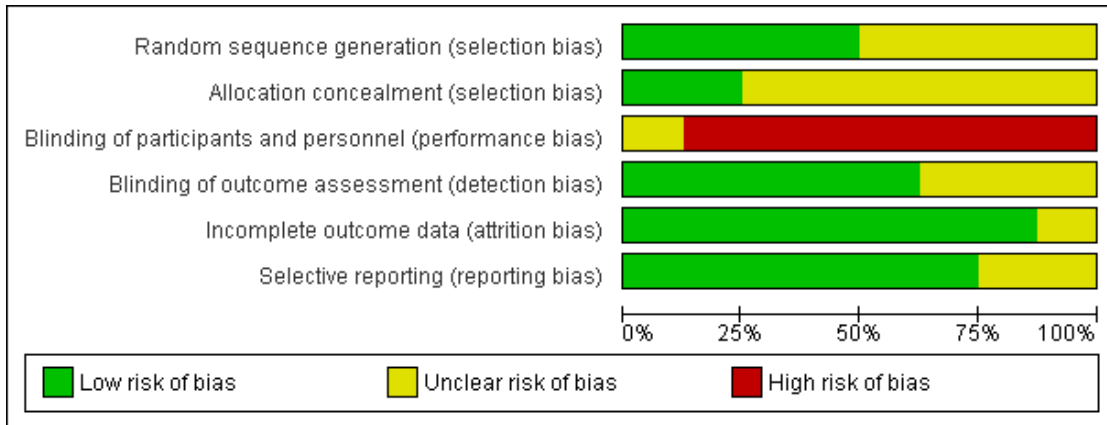
Six studies reported data on postoperative pulmonary complications according to Kroenke's criteria ([Carvalho 2011](#); [Ferreira 2009](#); [Hulzebos 2006A](#); [Hulzebos 2006B](#); [Rajendran 1998](#); [Weiner 1998](#)). Four studies reported on atelectasis; five studies reported on pneumonia; one study reported on pneumothorax; and two studies reported on ventilatory support for > 48 hours. Three studies reported on all-cause mortality ([Arthur 2000](#); [Ferreira 2009](#); [Hulzebos 2006A](#)). Three studies reported on adverse events ([Ferreira 2009](#); [Hulzebos 2006A](#); [Hulzebos 2006B](#)).

Five studies reported data on secondary outcomes ([Arthur 2000](#); [Hulzebos 2006A](#); [Hulzebos 2006B](#); [Rajendran 1998](#); [Rosenfeldt 2011](#)). Five studies reported on length of stay (data from three studies could be used in the meta-analysis); one study reported on physical function measures; two studies on health-related quality of life (data from one study could be used in the meta-analysis); and one study reported on mortality due to respiratory causes. No studies reported on costs.

## Risk of bias in included studies

[Figure 2](#) shows the authors' (EH and YS) judgments on each methodological quality item, presented as percentages across all included studies. [Figure 3](#) shows the authors' judgments per domain for each study.

**Figure 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.**



**Figure 3. Risk of bias summary: review authors' judgements about each risk of bias item for each included study.**

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)
Arthur 2000	+	+	-	+	+	+
Carvalho 2011	?	?	-	?	?	+
Ferreira 2009	?	?	-	?	+	?
Hulzebos 2006A	+	+	-	+	+	+
Hulzebos 2006B	+	?	-	+	+	+
Rajendran 1998	?	?	-	+	+	?
Rosenfeldt 2011	+	?	-	+	+	+
Weiner 1998	?	?	?	?	+	+

## Allocation

### Random sequence generation (selection bias)

Four studies used an adequate method to avoid bias through the sequence generation process (Arthur 2000; Hulzebos 2006A; Hulzebos 2006B; Rosenfeldt 2011). The other four studies did not describe the random sequence generation process, so the risk of bias in this domain could not be assessed (Carvalho 2011; Ferreira 2009; Rajendran 1998; Weiner 1998).

### Allocation concealment (selection bias)

Two studies used an adequate method of allocation concealment. The first of these studies used sealed opaque envelopes, opened in sequence (Arthur 2000). In the second of these studies the envelopes were not explicitly described as opaque but they were picked by an investigator who was not involved in the study (Hulzebos 2006A). Six studies did not describe the allocation concealment (Carvalho 2011; Ferreira 2009; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998; Rosenfeldt 2011; Weiner 1998).

## Blinding

### Blinding of participants and providers (performance bias)

One study used sham therapy in patients in the control group but did not describe whether the personnel were blinded, so the risk of performance bias was assessed as 'unclear' (Weiner 1998). The other seven studies did not use any form of control treatment so the risk of performance bias was assessed as 'high' (Arthur 2000; Carvalho 2011; Ferreira 2009; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998; Rosenfeldt 2011).

### Blinding of outcome assessor (detection bias)

In five studies the risk of detection bias was low because either blinded outcome assessors were used or outcome data were extracted from the medical records (Arthur 2000; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998; Rosenfeldt 2011). In three studies the risk of detection bias was unclear because there was insufficient information available (Carvalho 2011; Ferreira 2009; Weiner 1998).

## Incomplete outcome data

Seven studies reported all predefined outcomes, so the risk of attrition bias was low (Arthur 2000; Ferreira 2009; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998; Rosenfeldt 2011; Weiner 1998). The eighth study was only published as an abstract and did not have enough information to assess the risk of attrition bias (Carvalho 2011).

## Selective reporting

In six studies the risk of reporting bias was low (Arthur 2000; Carvalho 2011; Hulzebos 2006A; Hulzebos 2006B; Rosenfeldt 2011; Weiner 1998). Two studies did not provide enough information to assess the risk of reporting bias (Ferreira 2009; Rajendran 1998).

## Other potential sources of bias

We did not identify any other sources of bias.

## Effects of interventions

### Primary outcomes

#### Postoperative pulmonary complications grade 2

Information about postoperative atelectasis was available in four studies including 379 patients (Carvalho 2011; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998). The risk of postoperative atelectasis was lower in the groups receiving preoperative physical therapy, with three out of four studies using inspiratory muscle training (RR 0.52; 95% CI 0.32 to 0.87;  $P = 0.01$ ) (Analysis 1.1). One study with 276 participants had information on any type of postoperative pulmonary complication grade 2, which was similar to the rate of atelectasis in this study (Hulzebos 2006A). The risk of any type of postoperative pulmonary complication grade 2 was not reduced (RR 0.77; 95% CI 0.40 to 1.48;  $P = 0.43$ ) (Analysis 1.2).

#### Postoperative pulmonary complications grade 3

Five studies including 448 patients gave information on postoperative pneumonia (Carvalho 2011; Ferreira 2009; Hulzebos 2006A; Hulzebos 2006B; Weiner 1998). The risk of postoperative pneumonia was significantly reduced in the groups that received preoperative physical therapy (inspiratory muscle training in all five studies) (RR 0.45; 95% CI 0.24 to 0.83;  $P = 0.01$ ) (Analysis 1.3). One study with 45 patients had information on the

risk of postoperative pneumothorax, which was not reduced (RR 0.12; 95% CI 0.01 to 2.11; P = 0.15) (Analysis 1.4) (Rajendran 1998). One study with 276 participants had information on any type of postoperative pulmonary complication grade 3 (Hulzebos 2006A). The risk of any type of postoperative pulmonary complication grade 3 was significantly reduced in this study (RR 0.41; 95% CI 0.20 to 0.83; P = 0.01) (Analysis 1.5).

#### Postoperative pulmonary complications grade 4

Two studies including 306 patients gave information on mechanical ventilation for > 48 hours after surgery (Ferreira 2009; Hulzebos 2006A). The risk of prolonged mechanical ventilation after surgery was not reduced by preoperative physical therapy (RR 0.55; 95% CI 0.03 to 9.20; random-effects analysis; P = 0.68) (Analysis 1.6). The small number of studies precluded a meaningful exploration of statistical heterogeneity. One study had information on any type of postoperative pulmonary complication grade 4, which was similar to the rate of mechanical ventilation for > 48 hours in this study (Hulzebos 2006A). The risk of any type of postoperative pulmonary complication grade 4 was not reduced in this study (RR 0.16; 95% CI 0.02 to 1.35; P = 0.09) (Analysis 1.7).

#### Postoperative pulmonary complications $\geq$ grade 2

One study with 276 patients had information on any type of postoperative pulmonary complication  $\geq$  grade 2 (Hulzebos 2006A). The risk of any type of postoperative pulmonary complication  $\geq$  grade 2 was reduced in the group that received preoperative physical therapy (RR 0.51; 95% CI 0.34 to 0.78; P = 0.02).

#### Postoperative all-cause mortality

Three studies with 552 patients gave information on postoperative mortality from all causes (Arthur 2000; Ferreira 2009; Hulzebos 2006A). The risk of all-cause mortality was similar after preoperative physical therapy or without preoperative physical therapy (RR 0.66; 95% CI 0.02 to 18.48; random-effects analysis; P = 0.81) (Analysis 1.9). The small number of studies precluded a meaningful exploration of statistical heterogeneity.

#### Adverse outcomes

Three studies reported on adverse events (Ferreira 2009; Hulzebos 2006A; Hulzebos 2006B). Ferreira 2009 reported that none of the patients had to leave the programme due to adverse events. Hulzebos 2006A and Hulzebos 2006B stated that no adverse events occurred.

## Secondary outcomes

#### Length of postoperative hospital stay

Five studies gave information on the length of hospital stay (Arthur 2000; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998; Rosenfeldt 2011). Arthur 2000 reported a significantly shorter median postoperative stay for the patients that received preoperative physical therapy (MD -1.0 days; 95% CI -1.00 to -0.98; P = 0.001). Rosenfeldt 2011 reported no difference in the length of hospital stay between groups, which was a mean or a median of six days (P = 0.54). The mean length of stay in the remaining three studies (347 patients) could be pooled in a meta-analysis (Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998). There was a significant reduction in length of stay for patients treated with preoperative physical therapy (MD -3.21 days; 95% CI -5.73 to -0.69; random effects analysis; P = 0.01) (Analysis 1.10). The heterogeneity between these studies may be caused by a twice as long postoperative hospital stay in the Rajendran 1998 study compared to the two studies by Hulzebos et al.

#### Physical function measures

One study (32 patients) reported on the six-minute walk test (Carvalho 2011). The patients that received preoperative physical therapy performed worse on the six-minute walk test postoperatively compared to the control group: -101.30 metres (95% CI -163.78 to -38.82 metres; P < 0.001) (Analysis 1.11).

#### Postoperative mortality from respiratory causes

One study with 276 patients gave information on the risk of death from respiratory causes after surgery (Hulzebos 2006A). The risk did not differ across groups (RR 0.14; 95% CI 0.01 to 2.70; P = 0.19) (Analysis 1.12).

#### Health-related quality of life

One study with 117 patients reported between-group differences in health-related quality of life (Rosenfeldt 2011). Patients who had received preoperative physical therapy scored significantly better on the Short Form-36 physical composite score: 1.30 points (95% CI 0.88 to 1.72; P < 0.001) (Analysis 1.13).

#### Economic costs

There were no studies that reported on economic costs.

#### Subgroup and sensitivity analyses

The small number of studies per outcome precluded any meaningful subgroup analyses. There were no studies with inadequate random sequence generation so the sensitivity analysis could not be performed.

## DISCUSSION

### Summary of main results

We included eight studies of preoperative physical therapy with an exercise component in 856 elective cardiac surgery patients. Five studies on inspiratory muscle training and two studies with a mixed intervention including respiratory exercises provided information on one of our primary outcomes. Preoperative physical therapy reduced postoperative atelectasis (four studies, RR 0.52; 95% CI 0.32 to 0.87;  $P = 0.01$ ) and pneumonia (five studies, RR 0.45; 95% CI 0.24 to 0.83;  $P = 0.01$ ) but not pneumothorax (one study, RR 0.10; 95% CI 0.00 to 2.02;  $P = 0.13$ ), prolonged mechanical ventilation (RR 0.55; 95% CI 0.03 to 9.20;  $P = 0.68$ ;  $n = 2$ ) or all-cause postoperative death (RR 0.66; 95% CI 0.02 to 18.48; random-effects analysis;  $P = 0.81$ ;  $n = 3$ ). In the three studies that reported on adverse events, no adverse events occurred. Five studies (Arthur 2000; Hulzebos 2006A; Hulzebos 2006B; Rajendran 1998; Rosenfeldt 2011) gave information on the secondary outcome length of hospital stay. Preoperative physical therapy reduced length of hospital stay: -3.21 days (95% CI -5.73 to -0.69; random-effects analysis;  $P = 0.01$ ).

### Overall completeness and applicability of the evidence

Unfortunately, meaningful subgroup analyses were precluded by the small number of studies and by the small number of relevant outcomes described in each study. Thus the evidence remains incomplete for different patient groups (patients at low risk for pulmonary complications versus patients at high risk) or different types of physical therapy with an exercise component.

### Quality of the evidence

Overall, eight studies with 856 included patients were eligible for inclusion in this review. However, only one to three studies contributed data to the meta-analyses of the different outcomes except for the outcomes atelectasis and pneumonia, where four and five studies contributed data respectively. In addition, the size of the included trials might be too small to detect a difference in less frequent postoperative complications, such as death or pneumothorax, with four studies including less than 50 patients (Carvalho 2011; Ferreira 2009; Hulzebos 2006B; Rajendran 1998). The risk of bias of the included studies was generally assessed as 'low', except for the performance bias domain. Only one study used a form of sham therapy in the control group, giving a threshold inspiratory muscle trainer without resistance. Sham therapy should be used more frequently to assure that neither participants nor care givers know the assigned experimental group. None of the studies described the blinding of personnel to the interventions that

patients received. The non-blinding of personnel may influence some outcomes, especially length of stay and also the detection of postoperative pulmonary complications.

Besides the quality of the methodology, we recommend that future meta-analyses assess the validity of the therapeutic intervention as well. Recently a new measure (CONTENT) (Hoogeboom 2012) was developed to assess the validity of therapeutic exercise programs. This measure consists of nine yes or no questions (for example was the therapeutic exercise monitored and adjusted when considered necessary?). Differences in effectiveness across studies may be explained by varying therapeutic validity of the interventions applied.

## AUTHORS' CONCLUSIONS

### Implications for practice

Evidence derived from small trials suggests that preoperative physical therapy reduces postoperative pulmonary complications (atelectasis and pneumonia) and length of hospital stay in patients undergoing elective cardiac surgery. There is lack of evidence that preoperative physical therapy reduces postoperative pneumothorax, prolonged mechanical ventilation or all-cause deaths.

### Implications for research

Future studies on the effect of preoperative physical therapy should consider the following.

- Using a standardized and uniform definition for postoperative pulmonary complications.
- Including patients at high risk of pulmonary complications, as they are most likely to benefit.
- Including patients who are undergoing other types of surgery with a high risk of postoperative pulmonary complications, such as thoracic surgery and upper abdominal surgery.
- Assessing the validity of a therapeutic exercise program with a standardized checklist.
- Studying the effect of respiratory muscle training combined with other types of exercise therapy strategies.

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**Van Belle 1992**

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**Weissman 1999**

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Wynne R, Botti M. Postoperative pulmonary dysfunction after cardiac surgery with cardiopulmonary bypass: Clinical significance and implications for practice. *American Journal of Critical Care* 2004; **13**(5):384–93.

\* Indicates the major publication for the study

## CHARACTERISTICS OF STUDIES

### Characteristics of included studies [ordered by study ID]

#### Arthur 2000

Methods	RCT Setting: single centre, Canada Recruitment period: July 1995 to October 1997
Participants	Inclusion: low-risk patients on a waiting list for elective CABG with a scheduled surgery at least 10 weeks from study recruitment (low-risk was not further defined) Exclusion: previous CABG, combined CABG and valve surgery, ejection fraction < 40%, geographic inaccessibility or physical limitations that would preclude participation in the intervention Number of patients: - Experimental: 123 - Control: 123 Mean age (standard deviation) (NS) - Experimental: 61.8 (8.4) - Control: 63.8 (7.8) Sex (NS) - Experimental: 87% male - Control: 83% male Current smoker (NS) - Experimental: 20.3% - Control: 13.0% Diabetes (NS) - Experimental: 16.4% - Control: 25.6%
Interventions	Experimental: supervised group exercise sessions: twice a week, 8 weeks long in a hospital. Individualised, prescribed exercise training: 10 minutes walking warm-up; 10 minutes general range of motion exercises; 10 minutes stretching; 30 minutes aerobic interval training on treadmills etc.; 10 minutes cooling down; 40-70% functional capacity. Supportive-educational component: preoperative teaching at study entry and 1 week presurgery; monthly telephone contact by nurse clinicians; encouragement to stop smoking Control: usual care
Outcomes	Median postoperative length of stay (days) - Experimental: 5 (IQR: 5-6) - Control: 6 (IQR: 5-7) - Estimated difference in medians: 1.0 days (95% CI 0.98 to 1.0; P=0.001) Total days in hospital - Experimental: 6 (IQR: 5-7) - Control: 7 (IQR: 6-8) - Estimated difference in medians: 1.0 days (95% CI 0.0 to 1.0; P=0.002) Quality of life data published in a figure, no between-group differences tested. The corresponding point estimates were no longer available

Arthur 2000 (Continued)

	All-cause postoperative mortality - Experimental: 0 - Control: 0
Notes	Postoperative care for both groups: usual care (cardiac rehabilitation) Adverse events: not reported on

**Risk of bias**

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "A consultant prepared the randomization schedule"
Allocation concealment (selection bias)	Low risk	Quote: "assignments were sealed in opaque envelopes that were opened in sequence"
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not reported on. The blinding of participants is assessed by reviewers as unlikely to have happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Obtained from medical records or questionnaires, review authors do not believe this will introduce bias
Incomplete outcome data (attrition bias) All outcomes	Low risk	26 patients withdrew during waiting time (E:10, C:16). 10 had their surgery cancelled; 12 had a change in status from elective to urgent and 4 patients withdrew at the preoperative measurement point. The review authors do not believe this will introduce bias
Selective reporting (reporting bias)	Low risk	All predefined outcomes were reported on

**Carvalho 2011**

Methods	RCT (only published as an abstract and poster presentation) Setting: not described, likely a single centre study in Brazil Recruitment period: not described
Participants	Inclusion: persons referred for CABG at high risk (unspecified) for pulmonary complications Exclusion: unspecified Number of patients: - Experimental: 16 - Control: 16

	<p>Mean age (standard deviation) (NS)</p> <ul style="list-style-type: none"> <li>- Experimental: 62.0 (9.9)</li> <li>- Control: 62.0 (10.9)</li> </ul> <p>Sex (NS)</p> <ul style="list-style-type: none"> <li>- Experimental: 63% male</li> <li>- Control: 69% male</li> </ul> <p>LVEF &gt;50% (NS)</p> <ul style="list-style-type: none"> <li>- Experimental: 75.0%</li> <li>- Control: 87.5%</li> </ul> <p>Cigarette smoking (NS)</p> <ul style="list-style-type: none"> <li>- Experimental: 25.0%</li> <li>- Control: 37.5%</li> </ul> <p>Diabetes (NS)</p> <ul style="list-style-type: none"> <li>- Experimental: 37.5%</li> <li>- Control: 37.5%</li> </ul>	
Interventions	<p>Experimental: inspiratory muscle training with threshold device and a workload 30% of the peak inspiratory pressure, during two weeks prior to surgery, seven days a week, twice a day, three sets of ten repetitions. Setting and supervision were not described</p> <p>C: not specified</p>	
Outcomes	<p>Atelectasis</p> <ul style="list-style-type: none"> <li>- Experimental: 3</li> <li>- Control: 7</li> <li>- p&lt;0.05</li> </ul> <p>Pneumonia</p> <ul style="list-style-type: none"> <li>- Experimental: 1</li> <li>- Control: 3</li> <li>- P&lt;0.05</li> </ul> <p>6-minute walk test on the 7th postoperative day (standard deviation)</p> <ul style="list-style-type: none"> <li>- Experimental: 257.8 (98.9)</li> <li>- Control: 359.1 (80.5)</li> <li>- P&lt;0.01</li> </ul>	
Notes	<p>Postoperative care for both groups: not described</p> <p>Adverse events: not reported on</p> <p>The authors kindly provided point estimates for atelectasis and pneumonia and stated that pneumonia was confirmed by X-thorax</p>	
<b><i>Risk of bias</i></b>		
<b>Bias</b>	<b>Authors' judgement</b>	<b>Support for judgement</b>
Random sequence generation (selection bias)	Unclear risk	Randomisation procedure was not described
Allocation concealment (selection bias)	Unclear risk	Allocation procedure was not described

**Carvalho 2011** (Continued)

Blinding of participants and personnel (performance bias) All outcomes	High risk	Not reported on. The blinding of participants is assessed by reviewers as unlikely to have happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Not reported on
Incomplete outcome data (attrition bias) All outcomes	Unclear risk	Not enough data to assess
Selective reporting (reporting bias)	Low risk	All predefined outcomes were reported on

**Ferreira 2009**

Methods	RCT Setting: single centre, Brazil Recruitment period: not reported
Participants	Inclusion: persons aged 50 years or more awaiting CABG or valvuloplasty Exclusion: unstable angina, congestive decompensated heart failure, lack of physical or intellectual capacity to adequately perform the prescribed exercises, complex ventricular and uncontrolled arrhythmia, blood pressure >140/90 mmHg, myocardial infarction or cerebrovascular accident less than 3 years ago, high grade atrioventricular blockade or exercise-induced bronchial spasm, submission to cardiac surgery before completing at least two weeks of respiratory muscle training Number of patients: - Experimental: 15 - Control: 15 Mean age (standard deviation) (NS) - Experimental: 62.5 (6.1) - Control: 63.1 (7.9) Sex (P<0.01) - Experimental: 60% male - Control: 87% male Mean BMI (standard deviation) (NS) - Experimental: 26.6 (5.2) - Control: 28.3 (3.2) Smoker (NS) - Experimental: 20.0% - Control: 6.7% Diabetes (NS) - Experimental: 40.0% - Control: 40.0%
Interventions	Experimental: inspiratory muscle training with threshold device and a load of 40% of the peak inspiratory pressure, during at least two weeks prior to surgery, thrice daily, five



	series of 10 repetitions. In addition, general presurgery advice. Setting and supervision: not reported C: general presurgery advice (on surgery, postoperative period, tobacco smoking, deep inspiration exercises without special equipment and daily walks up to their own limits)	
Outcomes	Pneumonia - Experimental: 1 - Control: 0 - P=1.000 Prolonged ventilation (>48 hours) - Experimental: 1 - Control: 0 - P=1.000 All-cause deaths - Experimental: 3 - Control: 1 - P=0.598	
Notes	Postoperative care for both groups: routine physical therapy programme Adverse events: none of the patients had to leave the programme due to adverse events	
<b>Risk of bias</b>		
<b>Bias</b>	<b>Authors' judgement</b>	<b>Support for judgement</b>
Random sequence generation (selection bias)	Unclear risk	Randomisation procedure was not described
Allocation concealment (selection bias)	Unclear risk	Allocation procedure was not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not reported on. The blinding of participants is assessed by reviewers as unlikely to have happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	The blinding of outcome assessment was not described. The reviewers consider the risk for the outcome deaths to be low
Incomplete outcome data (attrition bias) All outcomes	Low risk	Quote: "There were no missing values for any collected data"
Selective reporting (reporting bias)	Unclear risk	All predefined outcomes were reported on

## Hulzebos 2006A

Methods	RCT Setting: single centre, the Netherlands Recruitment period: July 2002 to August 2005
Participants	Inclusion: high-risk patients undergoing primary elective CABG High-risk was defined as 2 or more of the following: age>70 years; cough and expectoration; diabetes; smoker; COPD (FEV <sub>1</sub> <75% <i>predicted</i> or pulmonary medication used). High-risk was also: FEV <sub>1</sub> <80% <i>predicted</i> and FEV <sub>1</sub> /FVC<70% <i>predicted</i> Exclusion: surgery within 2 weeks of initial contact; history of CVA; use of immunosuppressive medication in the past 30 days; neuromuscular disorders; cardiovascular instability or aneurysm Number of patients - Experimental: 139 - Control: 137 Mean age (standard deviation) (NS) - Experimental: 66.5 (9.0) - Control: 67.3 (9.2) Sex (NS) - Experimental: 78% male - Control: 78% male Mean BMI (SD) (NS) - Experimental: 28.3 (5.5) - Control: 28.1 (3.2) History of cigarette smoking (NS) - Experimental: 32.4% - Control: 38.0% History of COPD (NS) - Experimental: 19.4% - Control: 21.9% Diabetes (NS) - Experimental: 43.9% - C: 32.8% On-pump CABG (NS) - Experimental: 80.6% - Control: 83.2%
Interventions	Experimental: inspiratory muscle training, education in active cycle of breathing techniques and forced expiration techniques. Daily inspiratory muscle training sessions of at least 20 minutes for at least two weeks, starting at 30% of maximal inspiratory pressure with an incremental increase. Setting and supervision: supervision by a physical therapist once a week C: usual care the day before surgery (instruction on deep breathing manoeuvres, coughing and early mobilization)
Outcomes	Atelectasis - Experimental: 14 - Control: 18 - P=0.02 Pneumonia - Experimental: 9

Hulzebos 2006A (Continued)

	<ul style="list-style-type: none"> <li>- Control: 22</li> <li>- P=0.01</li> </ul> <p>Mechanical ventilation &gt; 48 hours</p> <ul style="list-style-type: none"> <li>- Experimental: 1</li> <li>- Control: 6</li> </ul> <p>PPC grade 2</p> <ul style="list-style-type: none"> <li>- Experimental: 14</li> <li>- Control: 18</li> <li>- P=0.02</li> </ul> <p>PPC grade 3</p> <ul style="list-style-type: none"> <li>- Experimental: 10</li> <li>- Control: 24</li> <li>- P=0.01</li> </ul> <p>PPC grade 4</p> <ul style="list-style-type: none"> <li>- Experimental: 1</li> <li>- Control: 6</li> <li>- p=0.09</li> </ul> <p>PPC grade <math>\geq</math> 2</p> <ul style="list-style-type: none"> <li>- Experimental: 25</li> <li>- Control: 48</li> <li>- P=0.02</li> </ul> <p>Mean postoperative length of stay (standard deviation)</p> <ul style="list-style-type: none"> <li>- Experimental: 7.89 (2.17)</li> <li>- Control: 9.94 (8.27)</li> <li>- P= 0.02</li> </ul> <p>Death from respiratory causes:</p> <ul style="list-style-type: none"> <li>- Experimental: 0</li> <li>- Control: 3</li> </ul> <p>All-cause deaths:</p> <ul style="list-style-type: none"> <li>- Experimental: 0</li> <li>- Control: 4</li> </ul>	
Notes	<p>Postoperative care for both groups: usual care</p> <p>Adverse events: none occurred</p> <p>Erik Hulzebos provided additional data on the number of patients with atelectasis, a mechanical ventilation &gt; 48 hours and on the mean postoperative length of stay</p> <p>Though the recruitment period overlaps with the other study by the same author (<a href="#">Hulzebos 2006B</a>), this study included different patients</p>	
<b>Risk of bias</b>		
<b>Bias</b>	<b>Authors' judgement</b>	<b>Support for judgement</b>
Random sequence generation (selection bias)	Low risk	Quote: "A computer generated randomization table was used"
Allocation concealment (selection bias)	Low risk	Quote: "individual allocations were placed in sealed envelopes. An external investigator blinded to the allocation sequence"

**Hulzebos 2006A** (Continued)

		picked consecutive allocation envelopes for consecutive patients". Though the envelopes were not explicitly described as opaque, they were picked by an investigator who was not involved in the study
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not reported on. The blinding of participants is assessed by reviewers as unlikely to have happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Primary outcomes and length of hospital stay were assessed by independent, blinded assessors. This was not stated for mortality but authors do not believe this will introduce bias
Incomplete outcome data (attrition bias) All outcomes	Low risk	All included patients were reported on. 3 patients were excluded after randomisation because they died before surgery (one from the experimental group and 2 from the control group)
Selective reporting (reporting bias)	Low risk	All predefined outcomes were reported on

**Hulzebos 2006B**

Methods	RCT Setting: single centre, the Netherlands Recruitment period: October to December 2002
Participants	Inclusion: high-risk patients undergoing primary elective CABG High-risk was defined with a weighted risk factor scale including the following risk factors: age $\geq 70$ years; cough and expectoration; diabetes; history of smoking; inspiratory vital capacity $< 75\%$ of predicted and maximal expiratory pressure $< 75\%$ of predicted Exclusion: surgery within 2 weeks of initial contact; history of CVA; use of immunosuppressive medication in the past 30 days; previous pulmonary surgery; neuromuscular disorders; cardiovascular instability or aneurysm Number of patients - Experimental: 14 - Control: 12 Sex (NS) - Experimental: 50% male - Control: 50% male Mean age (standard deviation) (NS) - Experimental: 70.14 (9.86) - Control: 70.50 (10.10) Mean BMI (standard deviation) (NS)

**Hulzebos 2006B** (Continued)

	<p>- Experimental: 26.13 (2.93)          - Control: 28.32 (3.47)          History of cigarette smoking (NS)          - Experimental: 29%          - Control: 25%          History of COPD (NS)          - Experimental: 43%          - Control: 17%          Diabetes (NS)          - Experimental: 14%          - Control: 25%</p>	
Interventions	<p>Experimental: preoperative inspiratory muscle training with an inspiratory threshold-loading device at home, one daily session of 20 minutes for at least two weeks with one weekly session supervised by a physiotherapist. Subjects started breathing at a resistance of 30% of their maximal inspiratory pressure. Resistance was increased incrementally          Control: usual care one day before surgery (instructions on deep breathing manoeuvres, coughing, and early mobilization)</p>	
Outcomes	<p>Atelectasis          - Experimental: 2          - Control: 6          - P=0.05          Pneumonia (NS)          - Experimental: 1          - Control: 1          Length of hospital stay (standard deviation)          - Experimental: 7.93 days (1.94)          - Control: 9.92 days (5.78)          - P=0.24</p>	
Notes	<p>Postoperative care for both groups: usual care          Adverse events: no cardiovascular complications or side effects occurred          Though the recruitment period overlaps with the other study by the same author (<a href="#">Hulzebos 2006A</a>), this study included different patients</p>	
<b>Risk of bias</b>		
<b>Bias</b>	<b>Authors' judgement</b>	<b>Support for judgement</b>
Random sequence generation (selection bias)	Low risk	Quote: "using a computer-generated randomized block design"
Allocation concealment (selection bias)	Unclear risk	Allocation concealment was not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	The trial was described as 'single-blind', this single blindness referred to outcome assessment. The blinding of participants is assessed by reviewers as unlikely to have

**Hulzebos 2006B** (Continued)

		happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	The detection of the outcomes atelectasis, pneumonia and length of hospital stay is considered to be subject to a low risk of bias by the reviewers
Incomplete outcome data (attrition bias) All outcomes	Low risk	All included patients were reported on
Selective reporting (reporting bias)	Low risk	All predefined outcomes were reported on

**Rajendran 1998**

Methods	RCT Setting: single centre, India Recruitment period: December 1992 to September 1994
Participants	Inclusion: COPD patients undergoing CABG Exclusion: death after CABG Number of patients - Experimental: 25 - Control: 20 Mean age (standard deviation) - Experimental: 55.4 (6.9) - Control: 58.7 (7.0) Weight (standard deviation) - Experimental: 70.2 (7.6) - Control: 69.6 (11.9)
Interventions	Experimental: preoperative medication including bronchodilators; health education, exercise reconditioning and support, instruction about respiratory disease and its treatment, breathing retraining (diaphragmatic breathing and pursed lip breathing), dyspnoea control, nutritional counselling, energy conservation, work simplification techniques and stress management with relaxation training. Daily sessions for one week under the guidance of a specialist, and advice to practice for 10 minutes every waking hour Control: preoperative medication including bronchodilators
Outcomes	Postoperative hospital stay (standard deviation) - Experimental: 12.4 (3.6) - Control: 18.6 (6.6) - P<0.001 Atelectasis - Experimental: 0 - Control: 4 Pneumothorax - Experimental: 0

**Rajendran 1998** (Continued)

	- Control: 3	
Notes	Postoperative care for both groups: pulmonary rehabilitation Adverse events: not reported We did not meta-analyse the outcome 'consolidation' as we could not classify this with certainty as a pneumonia	
<b>Risk of bias</b>		
<b>Bias</b>	<b>Authors' judgement</b>	<b>Support for judgement</b>
Random sequence generation (selection bias)	Unclear risk	The randomisation procedure was not described
Allocation concealment (selection bias)	Unclear risk	Allocation concealment was not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	The blinding of participants is assessed by reviewers as unlikely to have happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	Blinding of outcome assessment was not described. As atelectasis and pneumothorax findings were confirmed by X-thorax the review authors consider the risk of bias low
Incomplete outcome data (attrition bias) All outcomes	Low risk	All included patients were reported on
Selective reporting (reporting bias)	Unclear risk	All predefined outcomes were reported on

**Rosenfeldt 2011**

Methods	RCT Setting: single centre, Australia Recruitment period: November 2004 to June 2006
Participants	Inclusion: patients scheduled for CABG or valve surgery Exclusion: urgent or emergency surgery, severe aortic valve stenosis, limited English, NYHA class IV heart failure Number of patients - Experimental: 60 - Control: 57 Median age (0.06) - Experimental: 62.5 - Control: 68 Sex (NS) - Experimental: 78% male - Control: 70% male

	Diabetes (NS) - Experimental: 20% - Control: 29%
Interventions	Experimental: holistic therapy consisting of light physical exercise sessions (low intensity aerobic exercise training of approximately 50% of maximum oxygen uptake). Two supervised, one hour outpatient sessions per week for two weeks, plus encouragement to complete two weekly personal sessions of at least 30 minutes on at least two other occasions each week, including after the discontinuation of the supervised programme. In addition, a mental stress reduction programme (four individualised 1 hour sessions including education and relaxing techniques such as deep breathing techniques and meditation), for the first two weeks after placement on the surgery waiting list Control: usual care
Outcomes	Length of hospital stay - Experimental: 6 - Control: 6 - P=0.54 Mean postoperative Short Form -36 Physical composite score (standard deviation) - Experimental: 44.1 (1.0) - Control: 42.8 (1.3) - P=0.45
Notes	Postoperative care for both groups: not described Adverse events: not reported on It was unclear whether the length of hospital stay was reported as a mean or a median, and no standard deviation was given. We wrote to the authors but did not receive an answer

**Risk of bias**

Bias	Authors' judgement	Support for judgement
Random sequence generation (selection bias)	Low risk	Quote: "Patients were randomised, using a computer-generated code"
Allocation concealment (selection bias)	Unclear risk	Allocation procedure was not described
Blinding of participants and personnel (performance bias) All outcomes	High risk	Not reported on. The blinding of participants is assessed by reviewers as unlikely to have happened, as no sham/placebo therapy was described
Blinding of outcome assessment (detection bias) All outcomes	Low risk	The blinding of outcome assessors was not reported on. The reviewers assess the risk as low because quality of life was assessed with a questionnaire and length of stay and post-operative atrial fibrillation were assessed using patients' medical records



**Rosenfeldt 2011** (Continued)

Incomplete outcome data (attrition bias) All outcomes	Low risk	All included patients were recorded on
Selective reporting (reporting bias)	Low risk	All predefined outcomes were reported on. One outcome that was not predefined was reported on (troponin at 24 hours) but this outcome did not differ significantly between groups and was not mentioned in the text nor in the abstract

**Weiner 1998**

Methods	RCT Setting: not reported. Likely a single centre study in Israel Recruitment period: not reported
Participants	Inclusion: patients scheduled for CABG Exclusion: not described Number of patients - Experimental: 42 - Control: 42 Mean age (standard deviation) - Experimental: 59.2 (3.8) - Control: 63.8 (3.1)
Interventions	Experimental: inspiratory muscle training, 30 minutes per day for two to four weeks, under supervision of a physician, with a threshold inspiratory muscle trainer. Training started at a resistance equal to 15% of maximal inspiratory mouth pressure for one week. Resistance was then increased incrementally with 5% each session up to 60 % of their maximal inspiratory mouth pressure Control: equal training protocol with the same device but with no resistance (sham training)
Outcomes	Pleural effusion (unclear whether pleural effusion resulted in thoracentesis, excluded from meta-analysis) - Experimental: 5 - Control: 3 - NS (P value not reported) Pneumonia - Experimental: 1 - Control: 3 - NS (P value not reported) Mechanical ventilation >24 hours - Experimental: 2 - Control: 11 - P value not reported

Weiner 1998 (Continued)

Notes	Postoperative care for both groups: not described Adverse events: not reported on	
<b>Risk of bias</b>		
<b>Bias</b>	<b>Authors' judgement</b>	<b>Support for judgement</b>
Random sequence generation (selection bias)	Unclear risk	The randomisation procedure was not described
Allocation concealment (selection bias)	Unclear risk	Allocation procedure was not described
Blinding of participants and personnel (performance bias) All outcomes	Unclear risk	Not reported on, however, a sham therapy was used
Blinding of outcome assessment (detection bias) All outcomes	Unclear risk	Blinding of outcome assessment was not described
Incomplete outcome data (attrition bias) All outcomes	Low risk	Drop outs not reported on. As all outcomes were short-term outcomes the reviewers assess this risk as low
Selective reporting (reporting bias)	Low risk	All predefined outcomes were reported on

BMI = body mass index; C = control group; CABG = coronary artery bypass grafting; CI = confidence interval; COPD = chronic obstructive pulmonary disease; DM = diabetes mellitus; E = experimental group; FEV<sub>1</sub> = forced expiratory volume in the first second of expiration; FVC = forced vital capacity; IQR = interquartile range; LOS = length of postoperative hospital stay; LVEF = left ventricular ejection fraction; N = number of patients; NS = not significant; NYHA = New York Heart Association; PPC = postoperative pulmonary complication; RCT = randomised controlled trial

**Characteristics of excluded studies [ordered by study ID]**

Study	Reason for exclusion
Anderson 1987	No preoperative physical therapy
Buijs van den 2004	Other types of outcome
Castillo 1985	No randomisation or quasi-randomisation: treatment allocation was based on the individual surgeon's routine policy
Cisar 1983	Case-report

(Continued)

Crawford 1993	Other types of outcome
Dias 2011	No preoperative physical therapy
Dowds 2009	Not on cardiac surgery patients
Fitileva 1982	No preoperative physical therapy
Fujimura 1980	Not a randomised trial
Gosselink 1998	Not on cardiac surgery patients
Herdy 2008	The postoperative regimen differed
Iankelevich 1967	On children only
Ingwersen 1993	Only postoperative physical therapy
Jenkins 1989	The postoperative regimen differed (study mainly on postoperative physical therapy)
Ku 2002	The postoperative regimen differed
Leserman	No physical therapy
Mahler 1998	No physical therapy
Matte 2000	No preoperative physical therapy
Nomori 1994	No cardiac surgery patients
Oulton 1981	No preoperative physical therapy
Recker 1994	No preoperative physical therapy
Rice 1992	Other intervention (self-instruction exercise booklet on how to perform coughing, deep breathing, leg movement and ambulation exercises)
Savci 2011	The postoperative physical therapy programme differed
Sheveleva 1965	No control group
Shuldham 2002	Other intervention (pre-operative educational intervention)
Sivaraman 2010	Uncertain whether both groups received preoperative physical therapy as the requested information on whether conventional care respiratory therapy was given preoperatively, postoperatively or both and what its nature was, was not received

(Continued)

Smetana 2003	No preoperative physical therapy
Stein 1970	No cardiac surgery patients (patients with thoracic surgery were included, but it was unclear whether these were cardiac surgery patients); postoperative treatment differed
Stiller 1994	The postoperative physical therapy programme differed (mainly a study on postoperative physical therapy with one preoperative instruction session)
Uglov 1992	No preoperative physical therapy with an exercise component
Vraicu 1977	The postoperative physical therapy programme differed (mainly a study on postoperative physical therapy with one preoperative instruction session)
Walther 2010	The outcomes length of stay and quality of life were mentioned in the abstract but not reported on
Winten 1995	Other types of outcome (atelectasis was described but results of chest roentgenogram or temperature were not described so this was considered a grade 1 pulmonary complication)
Zamotrinsky 1997	No physical therapy

## DATA AND ANALYSES

### Comparison 1. Preoperative physical therapy versus no preoperative physical therapy

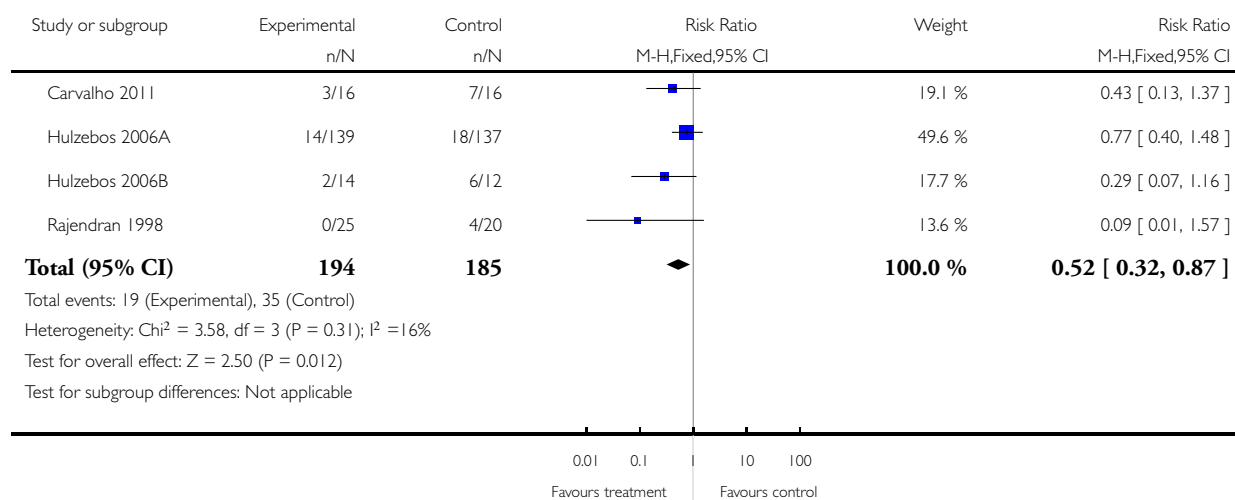
Outcome or subgroup title	No. of studies	No. of participants	Statistical method	Effect size
1 PPC grade 2 (atelectasis)	4	379	Risk Ratio (M-H, Fixed, 95% CI)	0.52 [0.32, 0.87]
2 PPC grade 2 (any type)	1	276	Risk Ratio (M-H, Fixed, 95% CI)	0.77 [0.40, 1.48]
3 PPC grade 3 (pneumonia)	5	448	Risk Ratio (M-H, Fixed, 95% CI)	0.45 [0.24, 0.83]
4 PPC grade 3 (pneumothorax)	1	45	Risk Ratio (M-H, Fixed, 95% CI)	0.12 [0.01, 2.11]
5 PPC grade 3 (any type)	1	276	Risk Ratio (M-H, Fixed, 95% CI)	0.41 [0.20, 0.83]
6 PPC grade 4 (mechanical ventilation > 48 hours)	2	306	Risk Ratio (M-H, Random, 95% CI)	0.55 [0.03, 9.20]
7 PPC grade 4 (all type)	1	276	Risk Ratio (M-H, Fixed, 95% CI)	0.16 [0.02, 1.35]
8 PPC grade $\geq 2$ (any type)	1	276	Risk Ratio (M-H, Fixed, 95% CI)	0.51 [0.34, 0.78]
9 Postoperative death (all causes)	3	552	Risk Ratio (M-H, Random, 95% CI)	0.66 [0.02, 18.48]
10 Length of postoperative hospital stay (days)	3	347	Mean Difference (IV, Random, 95% CI)	-3.21 [-5.73, -0.69]
11 Physical function measures (six minute walking test)	1	32	Mean Difference (IV, Fixed, 95% CI)	-101.30 [-163.78, -38.82]
12 Postoperative death (respiratory causes)	1	276	Risk Ratio (M-H, Fixed, 95% CI)	0.14 [0.01, 2.70]
13 Quality of life (short-form-36 physical composite score)	1	117	Mean Difference (IV, Fixed, 95% CI)	1.30 [0.88, 1.72]

### Analysis 1.1. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 1 PPC grade 2 (atelectasis).

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 1 PPC grade 2 (atelectasis)

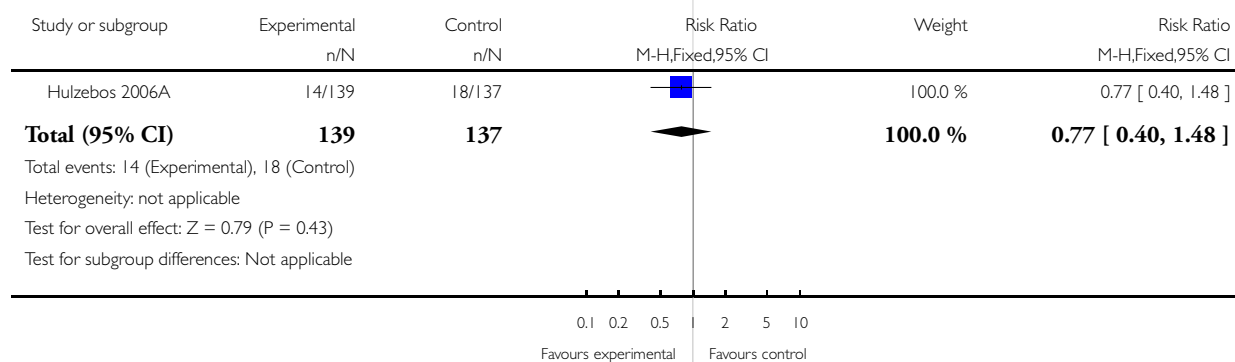


### Analysis 1.2. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 2 PPC grade 2 (any type).

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 2 PPC grade 2 (any type)

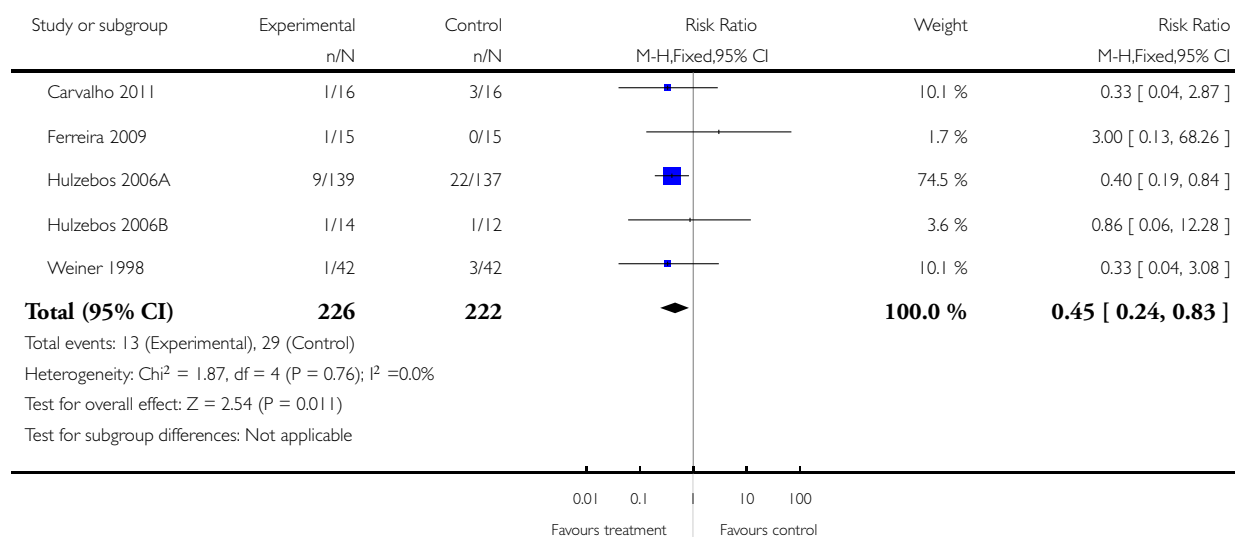


**Analysis 1.3. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 3 PPC grade 3 (pneumonia).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 3 PPC grade 3 (pneumonia)

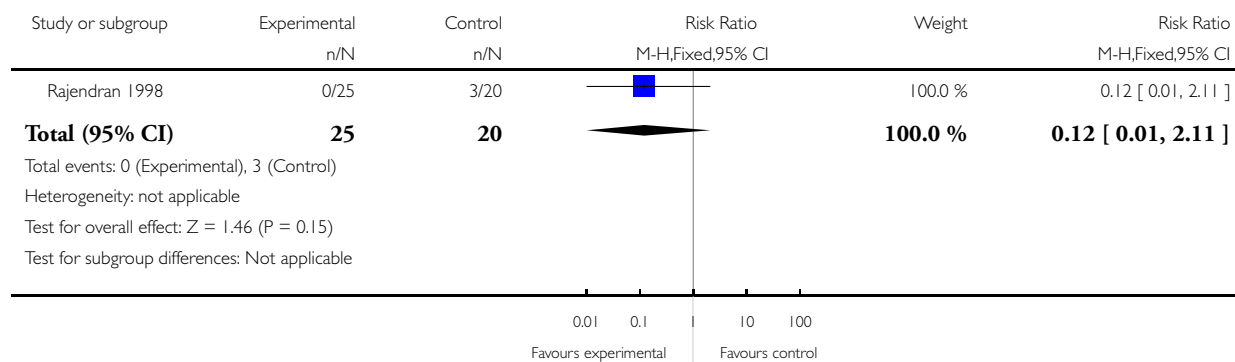


**Analysis 1.4. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 4 PPC grade 3 (pneumothorax).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 4 PPC grade 3 (pneumothorax)

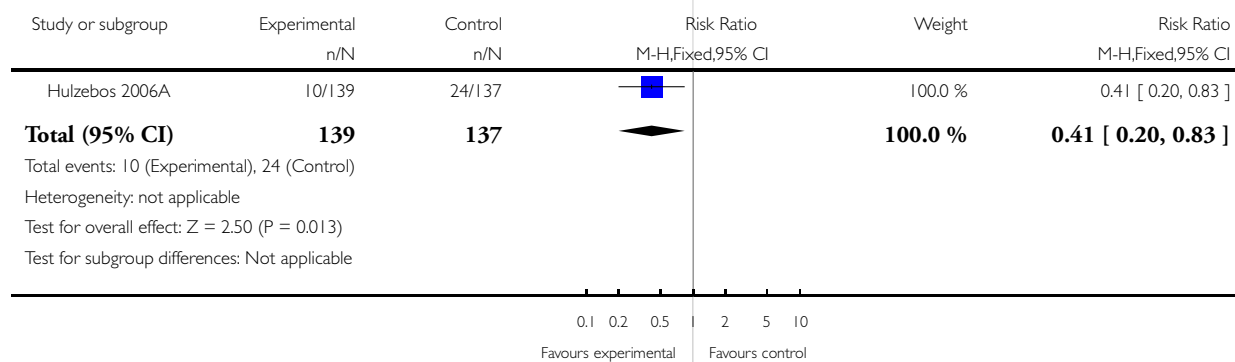


**Analysis 1.5. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 5 PPC grade 3 (any type).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 5 PPC grade 3 (any type)



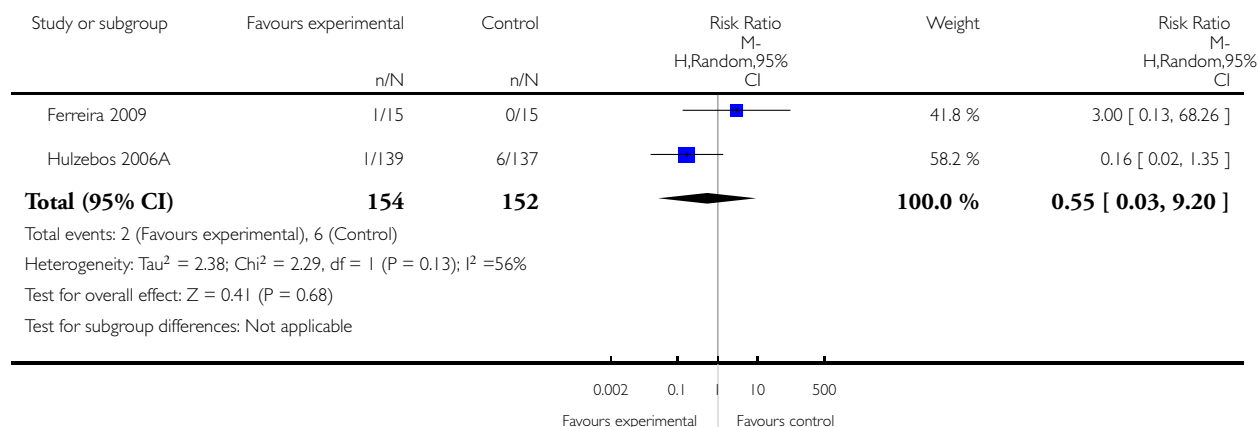


### Analysis 1.6. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 6 PPC grade 4 (mechanical ventilation > 48 hours).

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 6 PPC grade 4 (mechanical ventilation > 48 hours)

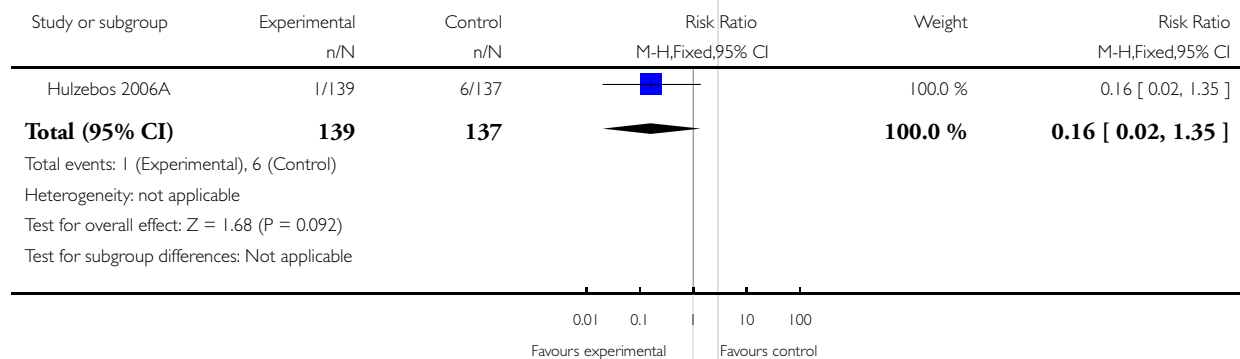


### Analysis 1.7. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 7 PPC grade 4 (all type).

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 7 PPC grade 4 (all type)

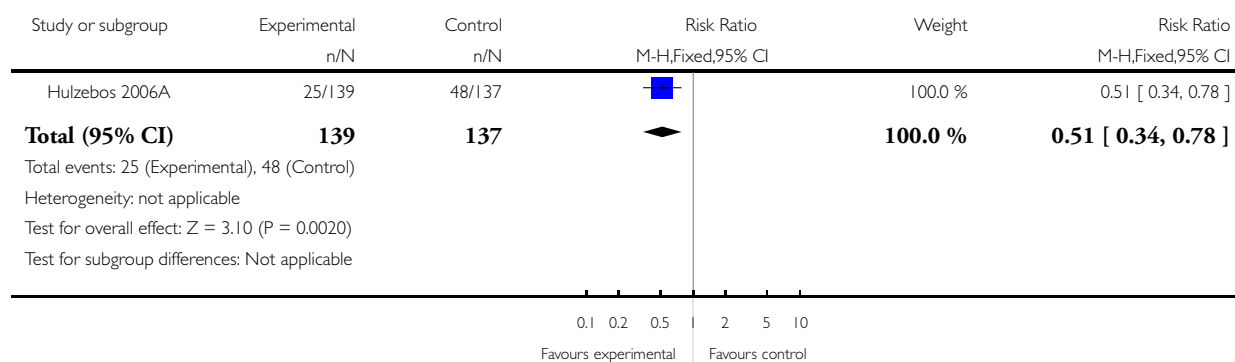


**Analysis 1.8. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 8 PPC grade  $\geq 2$  (any type).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 8 PPC grade  $\geq 2$  (any type)

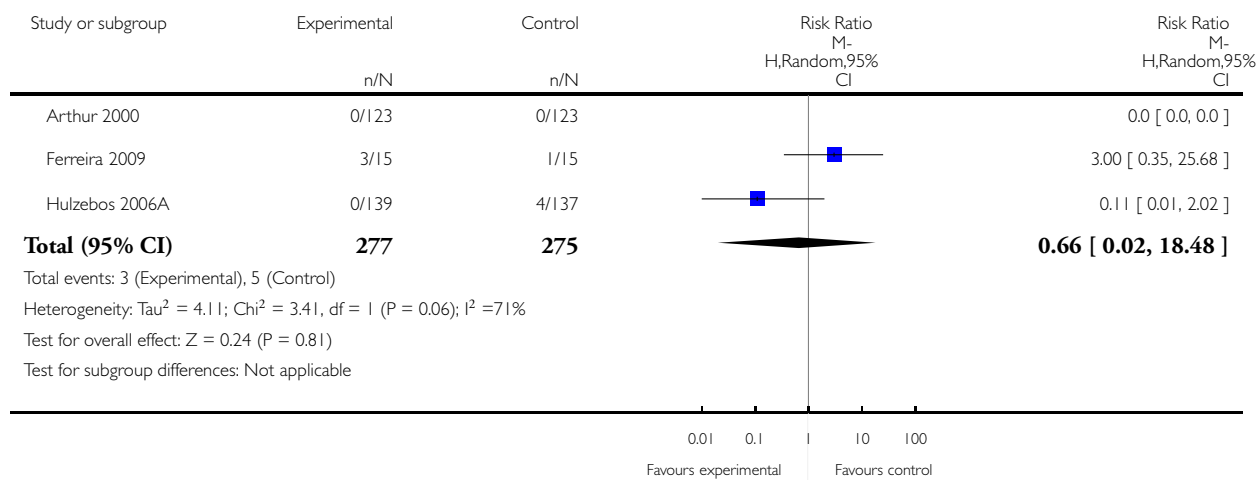


**Analysis 1.9. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 9 Postoperative death (all causes).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 9 Postoperative death (all causes)

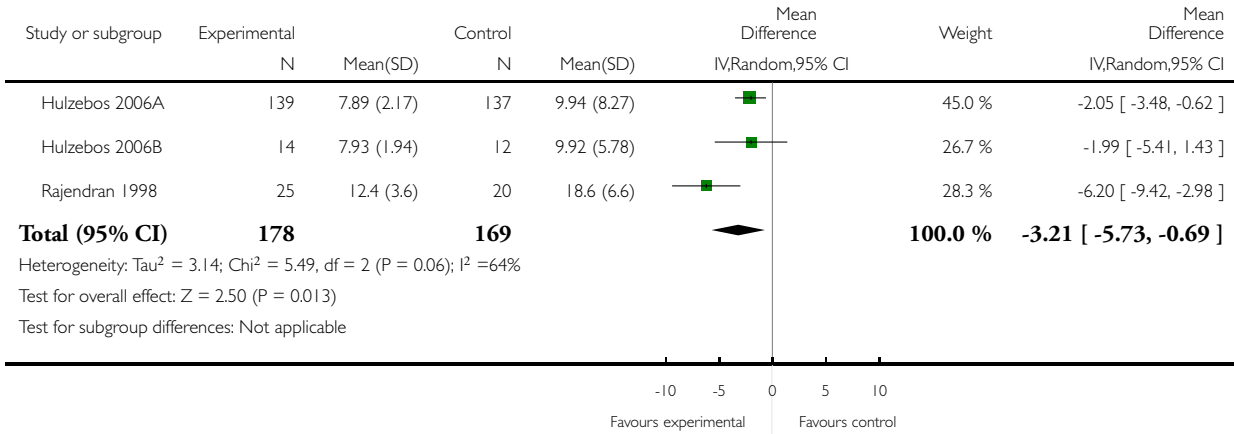


**Analysis 1.10. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 10 Length of postoperative hospital stay (days).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 10 Length of postoperative hospital stay (days)

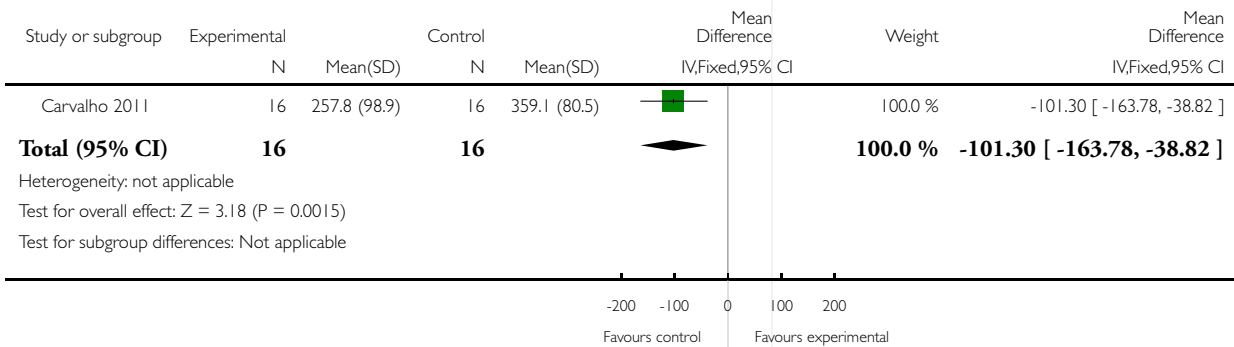


**Analysis 1.11. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 11 Physical function measures (six minute walking test).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 11 Physical function measures (six minute walking test)

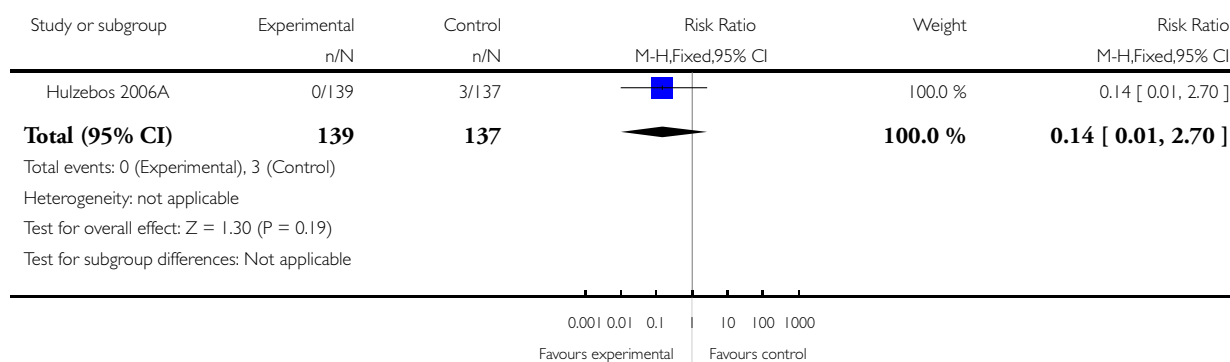


**Analysis 1.12. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 12 Postoperative death (respiratory causes).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 12 Postoperative death (respiratory causes)

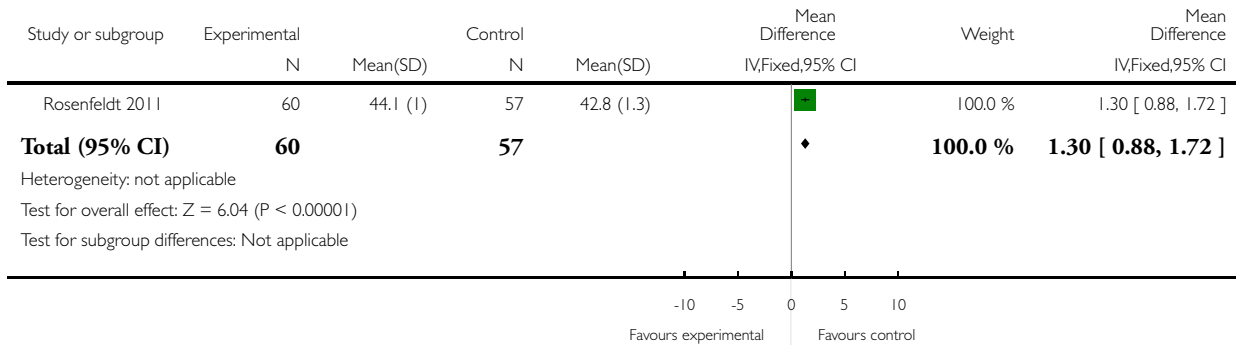


**Analysis 1.13. Comparison 1 Preoperative physical therapy versus no preoperative physical therapy, Outcome 13 Quality of life (short-form-36 physical composite score).**

Review: Preoperative physical therapy for elective cardiac surgery patients

Comparison: 1 Preoperative physical therapy versus no preoperative physical therapy

Outcome: 13 Quality of life (short-form-36 physical composite score)



**APPENDICES**

**Appendix I. MEDLINE and CENTRAL search strategy**

("Thoracic Surgery"[Mesh] OR "Cardiac Surgical Procedures"[Mesh] OR ((cardiac OR cardiac OR heart) AND (surgery OR operation OR surgical)) OR "Heart Valve Prosthesis Implantation"[Mesh] OR "Myocardial Revascularization"[Mesh] OR "Myocardial Reperfusion"[Mesh] OR CABG OR (bypass AND coronary AND (surgery OR operation OR surgical)) OR (bypass AND cardia\*) OR "Coronary Artery Bypass"[Mesh] OR "Heart Defects, Congenital/surgery"[Mesh] OR (heart AND transplant\*) OR (cardia\* AND transplant\*) OR "Heart Transplantation"[Mesh]) AND ("Rehabilitation"[Mesh] OR rehabilitat\* OR "Heart Valve Prosthesis Implantation/rehabilitation"[Mesh] OR "Coronary Artery Bypass/rehabilitation"[Mesh] OR "Myocardial Revascularization/rehabilitation"[Mesh] OR "Heart Defects, Congenital/rehabilitation"[Mesh] OR "Cardiac Surgical Procedures/rehabilitation"[Mesh] OR "Heart Transplantation/rehabilitation"[Mesh] OR "Physical Exertion"[Mesh] OR "Physical Fitness"[Mesh] OR (physical AND (activity OR activities)) OR "Exercise Test"[Mesh] OR "Exercise Tolerance"[Mesh] OR exertion\* OR "Physical Endurance"[Mesh] OR (physical\* AND endur\*) OR ((strengthening OR stretching) AND muscle\*) OR (weight\* AND train\*) OR "Sports"[Mesh] OR sport\* OR training OR "Pliability"[Mesh] OR gait OR rolfing OR jog\* OR swim\* OR bicycle\* OR cycle\* OR cycling OR walk\* OR row OR rowing OR "Exercise"[Mesh] OR exercis\* OR "Exercise Therapy"[Mesh] OR ((exercise OR manual OR manipul\* OR zone) AND (therapy OR therapies)) OR "Physical Therapy Modalities"[Mesh] OR physiotherap\* OR (physical AND therap\*) OR "Respiratory Function Tests"[Mesh] OR (lung AND function) OR "Spirometry"[Mesh] OR \*spiromet\* OR \*spirograph\* OR (breath\* AND exercis\*) OR (breath\* AND measure\*) OR (incentive AND breath\*) OR "Breathing Exercises"[Mesh] OR Spirocare OR triflo OR (breath\* AND device\*) OR "Forced Expiratory Flow Rates"[Mesh] OR (maxim\* AND inspira\*) OR "Respiratory Therapy"[Mesh: noexp] OR (respirat\* AND therap\*) OR train\*) AND ("Preoperative Care"[Mesh] OR "Preoperative Period"[Mesh] OR prehabilitat\* OR presurg\* OR pre-surg\* OR preoperati\* OR pre-operati\* OR (pre- AND surg\*) OR (pre- and operati\*) OR (before AND surg\*) OR (before AND surg\*)) AND (randomized controlled trial [pt] OR controlled clinical trial [pt] OR randomized [tiab] OR placebo [tiab] OR drug therapy [sh] OR randomly [tiab] OR trial [tiab] OR groups [tiab]) NOT (animals[mh] NOT (animals[mh] AND humans [mh]))

## Appendix 2. EMBASE search strategy

- 1 exp Spirometry/ (21399)
- 2 Spirography/ (1157)
- 3 spiromet\$.tw. (15351)
- 4 exp Lung function test/ (57959)
- 5 Bronchospirography/ (564)
- 6 bronchospirograph\$.tw. (20)
- 7 bronchospirimet\$.tw. (194)
- 8 lung function.tw. (22966)
- 9 (breath\$ adj3 exercise\$).tw. (1791)
- 10 (breath\$ adj3 measur\$).tw. (3462)
- 11 (incentive adj3 breath\$).tw. (41)
- 12 Breathing Exercise.tw. (139)
- 13 spirograph\$.tw. (652)
- 14 spirocare.tw. (3)
- 15 Forced Expiratory Flow/ (1791)
- 16 (breath\$ adj3 device\$).tw. (407)
- 17 triflo.tw. (17)
- 18 (maxim\$ adj3 inspira\$).tw. (2186)
- 19 respiratory therap\$.tw. (1853)
- 20 exp Physical Therapy Modalities/ (42989)
- 21 physiotherap\$.sh. (47107)
- 22 exp exercise/ (162192)
- 23 exp Physical Exertion/ (162192)
- 24 exp Rehabilitation/ (173584)
- 25 exp Physical Fitness/ (21827)
- 26 exp Exercise Test/ (34346)
- 27 exp Exercise Tolerance/ (8404)
- 28 exp SPORTS/ (76752)
- 29 exp PLIABILITY/ (1821)
- 30 exp Physical Endurance/ (12549)
- 31 ((physical adj3 therap\*) or physiotherap\* or physio-therap\*).ti,ab. (33368)
- 32 ((exercise or manual or manipulat\* or zone) adj3 (therapy or therapies)).ti,ab. (6350)
- 33 exertion\$.ti,ab. (14768)
- 34 exercis\$.ti,ab. (197537)
- 35 sport\$.ti,ab. (45299)
- 36 training.ti,ab. (230926)
- 37 ((endurance or strength) adj3 training).ti,ab. (7260)
- 38 (physical adj3 (activity or activities)).ti,ab. (53301)
- 39 gait.ti,ab. (25406)
- 40 rolfging\*.ti,ab. (27)
- 41 ((physical or motion) adj5 (fitness or therapy or therapies)).ti,ab. (21038)
- 42 (physical\$ adj2 endur\$).ti,ab. (484)
- 43 physical therapy.sh. (0)
- 44 exercise.sh. (142627)
- 45 rehabilitation.sh. (32415)
- 46 jog\$.ti,ab. (1668)
- 47 swim\$.ti,ab. (23895)
- 48 bicycl\$.ti,ab. (21278)
- 49 (cycle\$ or cycling).ti,ab. (384670)
- 50 walk\$.ti,ab. (65085)
- 51 (row or rowing).ti,ab. (10296)

52 (weight adj3 train\$).ti,ab. (1735)  
 53 (muscle adj3 strength\$).ti,ab. (13180)  
 54 ((strengthening or stretching) adj4 muscle\$).ti,ab. (1799)  
 55 train\*.tw. (307874)  
 56 or/1-55 (1364933)  
 57 exp heart Surgery/ (212710)  
 58 Thorax Surgery/ (20418)  
 59 exp Coronary Artery Bypass/ (44510)  
 60 exp Coronary artery surgery/ (72586)  
 61 Cardiopulmonary Bypass/ (25750)  
 62 cabg.tw. (14781)  
 63 (coronary adj3 bypass\$).tw. (38660)  
 64 (heart adj3 bypass\$).tw. (1703)  
 65 ((coronay and artery) adj surgery).tw. (0)  
 66 (cardiopulmonary adj3 bypass\$).tw. (25384)  
 67 ((heart or cardiac or cardio\$ or myocard\$) and revasculari?ation).tw. (26443)  
 68 (cardiac and (surgery or surgical or operation)).tw. (78933)  
 69 (cardial and (surgery or surgical or operation)).tw. (361)  
 70 cardiosurgery.tw. (435)  
 71 (heart and (surgery or surgical or operation)).tw. (71926)  
 72 (thoracic and (surgery or surgical or operation)).tw. (44538)  
 73 (myocardial and (surgery or surgical or operation)).tw. (32159)  
 74 cardiomyoplasty.tw. (911)  
 75 cardioplegia.tw. (4617)  
 76 (heart adj3 transplant\$).tw. (24189)  
 77 (cardiac adj transplant\$).tw. (9559)  
 78 (cardial adj transplant\$).tw. (1)  
 79 (valve adj (surgery or surgical or operation)).tw. (4672)  
 80 or/57-79 (351016)  
 81 exp preoperative period/ (164715)  
 82 exp preoperative care/ (30209)  
 83 preoperative.mp. (218406)  
 84 (before adj3 surg\*).tw. (42884)  
 85 (pre adj3 surg\*).tw. (4990)  
 86 (before adj3 opera\*).tw. (17299)  
 87 (pre adj3 opera\*).tw. (26209)  
 88 preoperativ\*.tw. (184109)  
 89 'pre-operativ\*.tw. (21563)  
 90 presurg\*.tw. (6410)  
 91 'pre-surg\*.tw. (2188)  
 92 prehabilitat\*.tw. (58)  
 93 (pre- adj3 surg\*).tw. (4990)  
 94 (pre- adj3 opera\*).tw. (26209)  
 95 or/81-94 (346816)  
 96 56 and 80 and 95 (4101)



### Appendix 3. PEDro search strategy

PEDro was searched using the advanced search option. Searches for all (1) systematic reviews and (2) clinical trials (‘*method*’) in the indexed sub disciplines ‘*cardiothoracics*’, and ‘*no appropriate value in this field*’ were conducted, in combination with the problems ‘*difficulty with sputum clearance*’ and ‘*impaired ventilation*’.

### Appendix 4. CINAHL search strategy

Search results were not limited; Medline indexed records were excluded. Smart text search was used.

((MH “Rehabilitation+”) or (MH “Home Rehabilitation+”) or rehabilitat\* or (MH “Heart Valve Prosthesis+”) or (MH “Heart Surgery+”) or (MH “Surgery, Cardiovascular+”) or (MH “Exertion+”) or (MH “Physical Fitness+”) or (MH “Exercise Tolerance+”) or (MH “Exertion+”) or (MH “Physical Endurance+”) or (MH “Sports+”) or (MH “Pliability”) or (MH “Physical Therapy+”) or (MH “Chest Physical Therapy+”) or (MH “Physical Therapy Practice, Evidence-Based”) or (MH “Physical Therapy Practice, Research-Based”) or (MH “Research, Physical Therapy”) or (MH “Massage+”) or (MH “Respiratory Function Tests+”) or (MH “Spirometry”) or (MH “Breathing Exercises+”) or (MH “Forced Expiratory Flow Rates+”) or (MH “Research, Respiratory Therapy”) or “physical AND (activity OR activities)” or train\* or exertion\* or “physical\* AND endur\*” or “(strengthening or stretching) and muscle” or “weight\* AND train\*” or sport\* or training or gait or rolfing or jog\* or swim\* or bicycle\* or cycle\* or cycling or walk\* or row or rowing or exercise\* or “(exercise OR manual OR manipul\* OR zone) AND (therapy OR therapies)” or physiotherapy\* or “physical AND therap\*” or “(lung AND function)” or spiromet\* or spirograph\* or “(breath\* and exercise\*)” or “(breath\* and measure\*)” or “(incentive and breath\*)” or spiro care or trifle or “(breath\* and device\*)” or “(maxim\* and inspira\*)” or “(respirat\* and therap\*)” and ((MH “Myocardial Revascularization+”) or (MH “Coronary Artery Bypass+”) or (MH “Heart Surgery+”) or (MH “Heart, Artificial+”) or (MH “Heart Assist Devices+”) or (MH “Pacemaker, Artificial+”) or (MH “Defibrillators, Implantable”) or (MH “Catheter Ablation”) or (MH “Surgery, Cardiovascular”) or “valv\* and prosthesi\*” or cabg or “bypass and coronary” or “bypass and cardia\*” or “heart and transplant\*” or “cardia\* and transplant\*” or lvad or “ventric\* AND assist\* AND device\*” or “cardia\* AND assist\* AND device\*” or “heart and artificial” or “cardia\* and artificial” or “heart-assist\* AND device\*” or “vascular-assist\* AND device\*” or “heart-assist\* AND pump\*” or pacemaker or defibrillator\* or “catheter and ablation” or “(cardiac or cardinal or heart or valve or valvular) and (surgery or operation or surgical)” or “(bypass and (coronary or cardia\*))” and ((MH “Preoperative Period+”) OR “preoperative\*”))

## HISTORY

Protocol first published: Issue 9, 2012

Review first published: Issue 11, 2012

Date	Event	Description
28 April 2008	New citation required and major changes	Substantive amendment

## CONTRIBUTIONS OF AUTHORS

Conceiving the review (Hulzebos, van Meeteren)

Designing the review (Hulzebos, van Meeteren, Helders, Smit)

Coordinating the review (Hulzebos, van Meeteren, Helders)

Data collection of the review (Hulzebos, Smit)

Designing search strategies (Smit)

Undertaking searches (Smit)

Screening search results (Hulzebos, Smit)  
Organising retrieval of papers (Smit)  
Screening retrieved papers against inclusion criteria (Hulzebos, Smit)  
Appraising quality of papers (Hulzebos, Smit)  
Extracting data from papers (Hulzebos, Smit)  
Writing to authors of papers for additional information (Hulzebos, Smit)  
Providing additional data about papers (Hulzebos)  
Obtaining and screening data on unpublished studies (Hulzebos)  
Data management for the review (Hulzebos, Smit)  
Entering data into RevMan (Hulzebos, Smit)  
Analysis of data (Hulzebos, Smit)  
Interpretation of data (Hulzebos, Helders, van Meeteren, Smit)  
Providing a methodological perspective (Hulzebos, van Meeteren, Smit)  
Providing a clinical perspective (Hulzebos, van Meeteren, Helders)  
Providing a policy perspective (Helders, van Meeteren, Helders)  
Providing a consumer perspective (Hulzebos, van Meeteren, Helders)  
Writing the review (Hulzebos, Smit)  
Providing general advice on the review (Helders, van Meeteren, Smit)  
Securing funding for the review (van Meeteren)  
Performing previous work that was the foundation of the current study (Hulzebos, van Meeteren, Helders)

## **DECLARATIONS OF INTEREST**

EH, PH and NvM were involved in one or two of the included studies ([Hulzebos 2006A](#); [Hulzebos 2006B](#)).

YS has no known conflicts of interest.

## **SOURCES OF SUPPORT**

### **Internal sources**

- Rudolf Magnus Institute of Neuroscience, University Medical Center Utrecht, Netherlands.
- Department of Pediatric Physical Therapy and Exercise Physiology, University Medical Center Utrecht, Netherlands.

## External sources

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