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Effects of Deep Breathing Exercises after Coronary Artery Bypass Surgery

BY

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Abstract

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Deep breathing exercises are widely used in the postoperative care to prevent or reduce pulmonary complications, but no scientific evidence for the efficacy has been found after coronary artery bypass grafting (CABG) surgery.

The aim of the thesis was to describe postoperative pulmonary function and to evaluate the efficacy of deep breathing exercises performed with or without a blow bottle device for positive expiratory pressure (PEP) 10 cmH₂O or an inspiratory resistance-positive expiratory pressure (IR-PEP) mask with an inspiratory pressure of -5 cmH₂O and an expiratory pressure of +10 to +15 cmH₂O.

Patients undergoing CABG were instructed to perform 30 slow deep breaths hourly during daytime for the first four postoperative days. Patient management was similar in the groups, except for the different breathing techniques.

Measurements were performed preoperatively, on the fourth postoperative day and four months after surgery. The immediate effect of the deep breathing exercises was examined on the second postoperative day. Pulmonary function was assessed by spirometry, diffusion capacity for carbon monoxide and arterial blood gases. Atelectasis was determined by chest roentgenograms or spiral computed tomography (CT).

Lung volumes were markedly reduced on the fourth postoperative day. Four months after surgery the pulmonary function was still significantly reduced. On the second and fourth postoperative day all patients had atelectasis visible on CT. A single session of deep breathing exercises performed with or without a mechanical device caused a significant reduction in atelectasis and an improvement in oxygenation. No major differences between deep breathing performed with or without a blow bottle or IR-PEP-device were found, except for a lesser decrease in total lung capacity in the blow bottle group on the fourth postoperative day. Patients who performed deep breathing exercises after CABG had significantly smaller atelectasis and better pulmonary function on the fourth postoperative day compared to a control group who performed no exercises.

Keywords: atelectasis, breathing exercises, coronary artery bypass, computed tomography, physiotherapy, postoperative care, postoperative complications, respiratory function tests, thoracic surgery

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*To Jan, Matilda, Johanna
and my parents with love*

List of Papers

This dissertation is based on the following papers, which will be referred to in the text by their Roman numerals:

- I** **Westerdahl E, Lindmark B, Almgren SO, Tenling A.**
Chest physiotherapy after coronary artery bypass graft surgery -
a comparison of three different deep breathing techniques.
J Rehab Med 2001; 33: 79-84

- II** **Westerdahl E, Lindmark B, Bryngelsson I, Tenling A.**
Pulmonary function 4 months after coronary artery bypass graft
surgery.
Respir Med 2003; 97: 317-322

- III** **Westerdahl E, Lindmark B, Eriksson T, Hedenstierna G,
Tenling A.**
The immediate effects of deep breathing exercises on atelectasis
and oxygenation after cardiac surgery.
Scand Cardiovasc J 2003; 37: 363-367

- IV** **Westerdahl E, Lindmark B, Eriksson T, Friberg Ö,
Hedenstierna G, Tenling A**
Effects of deep breathing exercises on pulmonary function and
atelectasis after coronary artery bypass surgery
Submitted

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Abbreviations

ABG	Arterial blood gas
ANOVA	Analysis of variance
AoO	Aortic occlusion
BMI	Body mass index
CABG	Coronary artery bypass grafting
CPAP	Continuous positive airway pressure
CT	Computed tomography
DLCO	Diffusing capacity for carbon monoxide
DLCO/VA	DLCO per unit alveolar volume
ECC	Extracorporeal circulation
EF	Ejection fraction
FEV 1	Forced expiratory volume in 1 second
FEV %	FEV1/VC
FRC	Functional residual capacity
FVC	Forced vital capacity
HU	Hounsfield unit
IC	Inspiratory capacity
IMA	Internal mammary artery
IPPB	Intermittent positive pressure breathing
IR-PEP	Inspiratory resistance-positive expiratory pressure
IS	Incentive spirometry
LIMA	Left internal mammary artery
NYHA	New York Heart Association classification
PaCO ₂	Arterial carbon dioxide tension
PaO ₂	Arterial oxygen tension
PEP	Positive expiratory pressure
PEP/RMT	Positive expiratory pressure/respiratory muscle training
RV	Residual volume
SaO ₂	Arterial oxygen saturation
TLC	Total lung capacity
VAS	Visual analogue scale
VC	Vital capacity

Introduction

Historical background

A majority of cardiac surgery is performed for ischemic coronary artery disease. Coronary artery bypass grafting (CABG) surgery is commonly performed via a median sternotomy. The surgical therapy is achieved by grafting a section of a saphenous vein, and/or internal mammary artery (IMA) between the aorta and the obstructed coronary artery distal to the obstructive lesion (1).

Pulmonary complications occurring after cardiac surgery is a major problem and a significant cause of postoperative morbidity (2). Patients undergoing CABG often develop atelectasis and severe reductions in lung volumes and oxygenation in the early postoperative period (3, 4). The first days after surgery is the most vulnerable period, but decrease in pulmonary function is still present several months after surgery (5, 6).

After World War I MacMahon (7) described the use of breathing exercises in the treatment of patients with traumatic chest injuries. Chest physiotherapy was initially aimed to improve ventilation by removing secretions from the airways. In an effort to increase lung volume following surgery, various deep breathing manoeuvres have been implemented as a main component in the care of the postoperative patient (8).

Today, various chest physiotherapy techniques are used to increase lung volumes, improve oxygenation and decrease the incidence and severity of pulmonary complications after cardiac surgery (9-14). Deep breathing is a major part of the therapy, but several authors have questioned the benefit of breathing exercises over early mobilisation alone (15-17). Despite the common use of breathing exercises in the management of CABG patients in many countries, scientific evidence for the efficacy is lacking (14, 17-20). The physiotherapy treatment has even been considered to cause adverse effects and costs only (21).

Pulmonary function after cardiac surgery

Patients undergoing cardiac surgery develop postoperatively restrictive respiratory abnormalities with severely reduced lung volumes (4, 6), impaired ventilatory mechanics (22, 23), decreased lung compliance and increased

breathing effort (24). The significantly reduced lung volumes contribute to impaired gas exchange. Various studies have documented arterial hypoxemia (3, 25) and decreased diffusion capacity (6, 26) in the early postoperative period. The pulmonary function gradually recovers, but decrements in pulmonary function still 3-4 months after cardiac surgery have been reported (5, 6, 27).

Patients with a lung disease, smoking history, advanced age or obesity have increased risk of complications following surgery (28-31). Site of surgery, duration of anaesthesia and postoperative riskfactors, such as immobilisation, analgesia, sedation, emergency surgery and inadequate preoperative education are also reported to contribute to an increased risk (32, 33).

Roentgenological changes

Atelectasis and pleural effusion is common in the early postoperative period after cardiac surgery (3, 34). It is concluded that atelectasis assessed by computed tomography (CT) in dependent lung areas is a contributory cause to impaired gas exchange after cardiac surgery (35). The cause of atelectasis is complex and many factors may contribute, for example compression of the lungs during surgery, abdominal distension, chest wall alterations, surfactant deficiency, diaphragmatic dysfunction, pleural effusion, pain and impaired mucociliary transport (36-38). The presence of pleural effusion has been reported to be associated with larger decreases in pulmonary function (34, 39).

Postoperative atelectasis is a condition for which chest physiotherapy is frequently recommended, even if a spontaneous resolution over days occurs. Repeated attempts have been made to reduce, or even prevent atelectasis, for example by perioperative management (40), postoperative mobilisation and breathing exercises, but no documentation of its efficacy has been found. (12-14, 17, 41).

Postoperative pulmonary complications

Cardiac surgery presents a high risk of postoperative complications (2, 38). The definition of a pulmonary complication seems to be unclear, though. Atelectasis, pleural effusion, pulmonary oedema, bronchospasm, dyspnea, cough, pneumonia, diaphragmatic dysfunction, respiratory failure and exacerbation of lung disease have all been reported as complications (2, 32, 42). In some studies definition of postoperative pulmonary complications are based only on chest radiographic changes (43), while others use a combination of variables for the definition (17, 20). Atelectasis, pulmonary oedema, lower respiratory tract infection, and ventilatory insufficiency, are considered the leading causes of postoperative morbidity (38).

Causes of the pulmonary impairment

Patients undergoing CABG are subject to the combined effects of anaesthesia (44, 45), thoracic surgery and cardiopulmonary bypass on pulmonary function (25, 46, 47).

The opening of the thorax has an effect on respiratory muscles and pulmonary mechanics (23). A reduced and uncoordinated rib cage expansion has been reported to arise (22). In addition the development of pleural effusions and extravascular lung water causes reduced lung compliance (48).

Application of cold cardioplegic solution for cardiac protection intraoperatively is associated with phrenic nerve paralysis and diaphragmatic dysfunction after surgery (37). The incidence of phrenic nerve injury is also increased when IMA is harvested (49). Additional surgical trauma, pain and a more pronounced decrease in pulmonary function has been found using IMA grafting as compared to saphenous vein grafting (6, 25, 50).

Mucociliary clearance is adversely affected after surgery by the effects of general anaesthesia, intubation and analgesia. Expiratory flow rates are directly related to lung volume and therefore when lung volumes are decreased, as in the postoperative period, coughing will be less effective (46, 51). Insufficient breathing as well as the absence of a normal sigh mechanism and coughing technique, immobilisation and inadequate patient cooperation may moreover affect the pulmonary function (46, 52, 53). The absence of sighs has been suggested to lead to alveolar collapse within one hour (54, 55). Pain, discomfort and fear contribute as well to the pulmonary impairment (4, 56, 57).

Postoperative pain

Cardiac surgery can be associated with intense postoperative pain during the first postoperative days (57) and a high incidence of chronic sternotomy pain has been reported (58). Pain from the sternotomy incision can keep patients from action that prevents postoperative complications. Coughing, moving or turning in bed and deep breathing have been given especially high pain scores (57). The patients may be unable to deep breathe and the reduced inspiratory capacity also limits the patient's ability to cough effectively and results in ineffective airway clearance. Pain-relief from thoracic epidural analgesia after CABG has been reported to improve expiratory muscle strength, which may improve cough and expectoration (59).

Adequate analgesia is therefore of particular importance for the prevention of pulmonary complications (60, 61). Gust et al. (56) conclude that treatment with patient controlled analgesia may reduce respiratory complications after CABG.

Postoperative chest physiotherapy

Chest physiotherapy has long been a standard component of postoperative care, with the aim of preventing or reducing complications such as impaired pulmonary function, atelectasis, pneumonia, sputum retention and gas exchange impairments (19, 21, 62). Techniques used include early mobilisation (15), positioning (9, 63), exercises of the shoulder girdle and upper back (64) and a variety of breathing exercises with (10, 12, 14, 16, 41, 65) or without mechanical devices (13, 17, 20). Manual techniques such as percussion and vibration may be hazardous in the cardiac surgery patient, because of the risk of sternum instability and no positive effects have been found (16, 66, 67).

Various regimens are used in different countries and there is no agreement about the most effective treatment after CABG. Deep breathing exercises have been widely used, but in recent years the routine use of breathing exercises after cardiac surgery has been strongly questioned (17, 20, 21, 68).

In the late 1960s, patients would spend at least three weeks resting in bed after cardiac surgery. Since then the practice of chest physiotherapy has changed in response to medical and surgical advances (62). Nowadays there is an agreement as to the value of early mobilisation and positioning after major surgery (9, 63). Shoulder range of motion exercises is today a common form of therapy intended to improve ventilation, preserve thorax mobility and ease sternal circulation and healing (64).

Deep breathing exercises

Postoperative deep breathing exercises is used to restore lung volume and avert the restrictive postoperative ventilatory pattern. The theoretical basis of encouraging patients to inspire deeply is that deep breathing opens collapsed alveoli and prevents atelectasis and pulmonary function decrease (69). Physiotherapists also use breathing exercises to promote secretion removal, increase thorax mobility, enhance relaxation and control breathlessness (69, 70).

The technique for teaching patients how to perform the breathing exercises varies in the literature (17, 20, 71) and differs depending on the purpose. A slow inspiration improves basal ventilation as a result of a preferential distribution of air to dependent regions (72).

Thorén et al. (73) presented the first major study showing benefits of postoperative maximal inspirations in abdominal surgery patients. There is evidence that regular chest physiotherapy and deep breathing exercises after major abdominal surgery significantly decreases the incidence of pulmonary complications (74, 75). In contrast, breathing exercises combined with chest physiotherapy after cardiac surgery have been reported to be no more effective than mobilisation alone in reducing atelectasis (14), pneumonia or other postoperative pulmonary complications (14, 16, 20).

Mechanical devices

There are several mechanical devices in current use to help the spontaneously breathing patient to improve pulmonary function after cardiac surgery. The aim of the techniques is to increase pulmonary volume, prevent or diminish atelectasis, assist in sputum clearance and subsequently increase arterial hypoxemia (46, 76, 77).

Most investigations involving mechanical devices after cardiac surgery have examined incentive spirometry (IS), frequently used in the United States (14, 41, 43, 78, 79) and intermittent positive pressure breathing (IPPB) (80-82). Scientific evidence does not support the use of these techniques, though (14, 15, 19, 41, 79) and IPPB may even in some circumstances be inferior to other techniques (81, 82).

Continuous positive airway pressure (CPAP) have in some studies been demonstrated to improve oxygenation and decrease shunt fraction and venous admixture during and immediately after treatment (11, 41, 83, 84), but other authors have found no such effects (10, 83, 85).

PEP

To expire against a resistance, for example against half closed lips (pursed lips breathing) is frequently used by patients with chronic obstructive disease. The expiratory resistance is thought to slow down expiration and increase lung volume, and may prevent or reduce airway collapse (86). The positive expiratory pressure (PEP) technique was developed in Denmark in the 1970s for the primary purpose of mobilising secretions. Various PEP devices have been developed, for example the PEP/respiratory muscle training (PEP-RMT) mask (Astra Tech, Denmark). In an early study by Falk et al. (87) it was shown that use of the PEP-mask technique increased mucus expectoration in patients with cystic fibrosis. Since then, various PEP devices have been developed and physiotherapists have used the PEP system for different purposes.

The use of PEP in postoperative care is mostly intended to increase pulmonary volume and facilitate the release of pulmonary secretions (86). The physiological explanation of how the technique is supposed to improve pulmonary function is unknown, although PEP is believed to increase transpulmonary pressures resulting in an increased functional residual capacity (FRC). In healthy subjects, PEP increases tidal volume by activity of both expiratory and inspiratory muscles, while FRC remains unchanged (88). The pressure during breathing is measured with a manometer (89). The required pressure is dependent on the patients' expiratory flow through the device and the instructions vary with the intended purpose.

Another simple PEP system is the blow bottle. The device consists of a plastic tube and a bottle of water. An expiration through the system leads to

a resisted exhalation. The initial rationale for use of blow bottles was to expand the lungs in patients with empyema, as related by Bartlett et al. (90).

In the postoperative cardiac surgery patient different PEP devices have been used, but no obvious effect of these methods have been distinguished in the prevention of pulmonary complications (10, 12, 80).

IR-PEP

Inspiratory muscle training is indicated for patients who exhibit signs of decreased strength or endurance of the diaphragm and intercostal muscles (70). Patient's undergoing cardiac surgery may have diaphragmatic dysfunction (91, 92). Inspiratory resistance- positive expiratory pressure (IR-PEP) has been introduced in an attempt to enhance the function of the diaphragm after cardiac surgery (10). Richter Larsen et al. (12) found a tendency towards decreased risk of postoperative complications in groups using PEP and IR-PEP compared to a control group using no mechanical device. The inspiratory resistance is believed to increase demands on the diaphragm and improve recovery of its function.

Is postoperative deep breathing exercises necessary?

Chest physiotherapy when provided routinely for patients following CABG has not been proven to diminish pulmonary complications (15-17, 68) and the value of mechanical devices in postoperative care is controversial. There is little conclusive evidence that these techniques are effective means to decrease the negative effects of surgery on pulmonary function (41, 83, 93, 94). In a recent systematic review Pasquina et al. (21) conclude that evidence is lacking on benefit from any method of prophylactic chest physiotherapy after cardiac surgery.

Aims of the study

The overall aim was to study pulmonary function and to evaluate the effectiveness of deep breathing exercises performed by patients after CABG.

The specific aims were:

1. to describe pulmonary function, roentgenological changes and sternotomy pain four days and four months after surgery.
2. to evaluate the efficacy of two mechanically assisted deep breathing techniques, compared to deep breathing performed with no mechanical device on the fourth postoperative day.
3. to investigate the immediate effects of one session of 30 voluntary deep breaths performed with or without a mechanical device on the second postoperative day.
4. to evaluate the effectiveness of deep breathing exercises performed with a blow bottle device during the first four postoperative days compared to a control group who performed no breathing exercises.

Material and Methods

Patients

A total of 315 patients undergoing CABG alone (not associated with valve replacement or other procedures) at the Department of Cardiothoracic Surgery, Örebro University Hospital, Sweden gave their informed consent for participation in the studies. Patients who had an emergency operation, previous cardiac surgery, haemodynamic complications, renal dysfunction requiring dialysis, difficulties to co-operate or who were unable to communicate in Swedish were not included. The measurements were performed from February 1996 to January 2003.

In **study I** a sample of 113 men was included during a seven-month period. The results from another 24 women have already been presented as an advanced-level paper completed as part of a Masters programme.

In **study II** the patients were selected on the basis of having previously participated in **study I**. The first 25 patients, living within 50 km from the hospital, were enrolled in the study to undergo a pulmonary function test four months after surgery. The 65 patients participating in **study III** were included between September 1998 and December 1999. A separate control group (n = 12), is also presented in the thesis. In **study IV** 112 patients were included from May 2002 to January 2003.

The studies were approved by the local Research Ethics Committee. Patients were given both verbal and written information before considering participation in the studies. It was made clear that participation was voluntary and could be terminated at any time.

Surgical and postoperative procedure

All patients received premedication and general anaesthesia. In **study I and II** the lungs were ventilated with an inspired oxygen concentration of 40-60% and in **study III and IV** 40-80%. CABG was performed with cardiopulmonary bypass through a median sternotomy. Saphenous veins and generally the left or right IMA were used in grafting. Cold blood cardioplegia and topical cardiac cooling with ice were used in most cases in **study I, II and III** and occasionally in **study IV**. An insulation pad was used to protect the phrenic nerve. The patient's lungs were either kept deflated (**I, II**) or

ventilated mechanically at a rate of 120 breaths per minute (**III, IV**) during aortic occlusion (AoO). The pericardium, mediastinum, and occasionally one or both pleura were drained, usually less than 24 hours after surgery.

Postoperatively the patients were artificially ventilated and a positive end-expiratory pressure of 5 cmH₂O (**I, II**) or 5-10 cmH₂O (**III, IV**) was used. The patients were extubated when they had resumed normothermia, were haemodynamically stable, and could normoventilate without distress, in accordance with ordinary clinical routines.

All patients received pain relief with ketobemidone and paracetamol according to their needs. Additional analgesia was given if pain on a visual analogue scale (VAS) was ≥ 4 cm. The patients were mobilised as soon as possible by the nursing staff and otherwise treated according to ordinary postoperative routines.

Chest physiotherapy

The patients received postoperative care and chest physiotherapy as conventionally administered at Örebro University Hospital, by one of the physiotherapists at the Department of Cardiothoracic Surgery, once or twice daily for at least the first four postoperative days. The therapy consisted of early mobilisation, instructions in efficient coughing techniques, deep breathing exercises and daily range of motion exercises of the shoulder girdle and upper back. Preoperatively all patients received a written education sheet about chest physiotherapy and verbal information about postoperative routines.

All patients, except for the Control group patients in **study IV** were instructed to perform 30 deep breaths with or without the assistance of a mechanical device once an hour during daytime for the first four postoperative days. Other than the breathing exercises, patient management was similar between groups in terms of assessment, positioning and mobility. The patients were mobilised as early as possible. They were instructed to sit out of bed and/or stand up on the first postoperative day, walk in the room or for a short distance in the corridor, on the second day, and walk freely for a longer distance in the corridor on the third postoperative day. The patients participated in a sitting group exercise program on the third and fourth postoperative day (**III, IV**).

Study groups

Study I

Preoperatively the 113 patients in **study I** were randomly assigned, by sealed envelopes, to one of three treatment groups performing different deep breathing techniques hourly during the first four postoperative days. The

examined techniques were deep breathing with no device for assistance, deep breathing performed with a blow bottle device (expiratory pressure +10 cmH₂O) and deep breathing performed with an IR-PEP mask (inspiratory pressure -5 cmH₂O and expiratory pressure +10 cmH₂O). The patients were informed by a physiotherapist about the deep breathing and practised the techniques preoperatively.

Study III

The 65 patients in **study III** were randomised to one of three deep breathing groups, before the measurements on the second postoperative day. The same physiotherapist instructed and verbally encouraged all patients during the deep breathing intervention. The effects of exercises were investigated immediately after the intervention. The examined techniques were deep breathing, deep breathing with the blow bottle device (expiratory pressure +10 cmH₂O) and deep breathing performed with the IR-PEP-mask (inspiratory pressure -5 cmH₂O and expiratory pressure +15 cmH₂O). The patients performed postoperatively deep breathing exercises according to ordinary routines, but were randomised to either of the three study groups just before measurements.

Study IV

The 112 patients in **study IV** were preoperatively randomly assigned to a Treatment group performing deep breathing exercises with a blow bottle device or a Control group. The patients in the Control group were not instructed to do any breathing exercises during the first four postoperative days.

The deep breathing techniques

The exercises were started approximately one hour after extubation and continued for the first four postoperative days. The patients were encouraged to perform 30 deep breaths once per hour while awake (daytime). The exercises included three sets of 10 deep breaths (with or without mechanical devices) with a 30-60 s pause between each set (7-8 minutes in total). If needed, the patients were asked to cough during the pause to mobilise secretions. Exercises were, if possible, done in the sitting position. The exercises were administered once or twice per day by the physiotherapist in the ward, and in between the patients were encouraged by other members of the health team to use the suggested treatments. Compliance with treatment was documented in patient records until the morning of the second postoperative day, and after that it was self-reported.

Deep breathing technique

The patients in the Deep breathing group were instructed to slowly inspire deeply through the nose or the mouth and expire normally through the mouth, using no mechanical device.

Blow bottle technique

Patients in the Blow bottle group also were instructed to inspire deeply, but expire through a PEP blow bottle device (Figure 1). A bottle filled with 10 cm of water and a 40-50 cm plastic tube (1 cm internal diameter) was used to give an expiratory pressure of +10 cm H₂O, measured by a manometer. The patients were asked to perform slow maximal inspirations, while expiration was aimed to end approximately at FRC to minimize airway closure and avoid alveolar collapse.

IR-PEP technique

In the IR-PEP group deep breathing was performed with a PEP/RMT mask (Figure 1). The system consists of a face-mask connected to a T-tube in which inspiratory and expiratory airflow are separated by a valve. Various resistance nipples can be applied to exert the desired pressure, as measured with a manometer. The nipples used for the inspiratory pressure were 4, 4.5 or 5 mm and were for the expiratory pressure 2.5, 3 or 3.5 mm.



Figure 1. A blow bottle device and a positive expiratory pressure/respiratory muscle training (PEP/RMT) mask (Astra Tech AB, Mölndal, Sweden).

Measurements

Spirometry

Pulmonary function measurements in **studies I and II** were performed using a portable pulmonary function lab (Medical Graphics PF/Dx Pulmonary Function 1085 D System, Spiropharma A/S, Denmark) with Breeze version 1.9F software (Figure 2). The measurements were performed at the Department of Cardiothoracic Surgery, by four experienced medical laboratory technicians. In **study IV**, a Jaeger MasterScreen PFT/Bodybox (Spiropharma Cardiopulmonary Diagnostics A/S, Denmark) was used, and the measurements were performed at the Department of Clinical Physiology, by six medical laboratory technicians.

The pulmonary function tests were performed with the patient wearing a noseclip, in the sitting position preoperatively, on the fourth postoperative day (**I, IV**) and four months postoperatively (**II**). The medical laboratory technicians were unaware of the patient's randomisation. The equipments were calibrated every morning prior to the measurements. Updating of room temperature and barometric pressure were made during calibration.

In **studies I and II**, the largest of three inspiratory slow vital capacities was obtained for vital capacity (VC) and inspiratory capacity (IC). The highest value of two or three technically correct attempts was retained for the measurement of forced expiratory volume in 1 second (FEV1). FEV% was calculated as FEV1 in percentage of VC. The single breath nitrogen washout technique was used to measure FRC, residual volume (RV) and total lung capacity (TLC). After measurement of FRC the patient made a slow VC. The IC from this was added to the FRC to determine TLC. RV was calculated as TLC minus VC from the same manoeuvre.

In **study IV** the highest value of three technically satisfactory attempts was retained for VC, IC, FEV1, forced vital capacity (FVC) and FRC. TLC was calculated as FRC + IC.

Predicted values for pulmonary function tests in **studies I and II** were related to age, sex, height and weight according to the normal values reported by Grimby & Söderholm (95). In **study IV**, the values were related to age, sex and height according to the reference values reported by Quanjer et al. (96). The pulmonary function values on the fourth postoperative day are expressed as a percentage of the preoperative values (**I and IV**).



Figure 2. Portable Medical Graphics PF/Dx Pulmonary Function 1085 D System, (Spiropharma A/S, Denmark) used in **studies I and II**.

Diffusion capacity

The measurements of diffusion capacity in **studies I and II** were made with the equipment presented in Figure 2. The Single breath diffusing capacity for carbon monoxide (DLCO) test was performed according to the method of Krogh et al. (97), as modified by Forster et al. (98) and Ogilvie et al. (99). The patients were instructed to exhale slowly and maximally to RV and then rapidly inhale maximally to TLC to fill the lungs with diffusion gas (neon, carbon monoxide, oxygen and nitrogen). Helium was used as a carrier gas. The gas sample was then aspirated into the chromatograph for analysis. The measurements were considered valid if the results differed by less than 10 percent. If the first two attempts were not reproducible, a third attempt was made. The tests were separated by a washout period of at least 5 minutes. DLCO was expressed in absolute values (ml/min/mmHg) and also calculated per litre of alveolar volume measured during the breath holding manoeuvre (DLCO/VA). The predicted values for DLCO were those of Crapo et al. (100). The values were corrected for the patient's preoperative or postoperative haemoglobin concentrations using the equation of Cotes et al. (101).

Chest roentgenogram

In **study I**, a chest roentgenogram was taken in the standing position before the operation and on the fourth postoperative day. Presence or absence of atelectasis and/or pleural effusion was recorded. A radiologist who was un-

aware of the patient's randomisation performed the evaluation. An arbitrary scale was used for scoring of atelectasis: 0 = no abnormality, 1 = minimal abnormality (plate atelectasis), 2 = moderate abnormality (segmental atelectasis), and 3 = major abnormality (lobar atelectasis). The right and left lungs were scored separately. The left hemidiaphragm was described as raised if its highest point was at the same horizontal level or higher than that of the right lung.

Computed tomography

In **study III**, CT measurements were made immediately prior to and after the deep breathing session (10-20 min between measurements). In **study IV**, CT measurements were made on the fourth postoperative day. All patients participating in **study III and IV** were transported by wheel-chair to the Department of Radiology. They had been in a sitting position and had been without supplementary O₂ for at least 15 minutes, before the measurements.

One radiologist and one radiographer who were blinded to study group assignment made all the measurements in both studies. In **study III** atelectasis and aeration of the lungs were assessed by spiral CT (Tomoscan AV; Philips, the Netherlands) presented in Figure 3. In **study IV** spiral CT (Philips CT Secura, Philips Medical Systems, the Netherlands) was used. The patient was in the supine position on the table with the arms raised above the head. Examinations were made during apnoea at resting expiratory lung volume. First a frontal scanogram covering the chest was obtained for positioning. The scan time was 9 s for a 12 cm volume scan at 225 mA (**III**) or 280 mA (**IV**), and 120 kV. Slice thickness was 1.0 cm and a matrix of 512 x 512 elements was used. The total estimated dose equivalent was 1.5 mSv. Three of the transverse CT scans were used for subsequent analysis, positioned 1 cm (basal), 5 cm (middle) and 9 cm (upper) above the top of the right diaphragm. The radiologist delineated the lung area manually from the inner margins of the thoracic cage, excluding pleural fluid, tissue between the ribs, mediastinum or any part of the diaphragm. The CT computer identified the border between aerated lung tissue and atelectasis. Aerated lung was defined as volume elements (voxels) with attenuation values between -100 and -1000 Hounsfield units (HU), while atelectasis was defined by values between +100 and -100 HU (102, 103). In **study III** the most cephalad point of the diaphragm was determined in relation to the carina before and after intervention. Atelectatic and aerated lung areas were measured in both lungs separately. The atelectatic areas as a percentage of the total lung area were calculated.



Figure 3. Computed tomography (CT) of a patient in **study III**.

Arterial blood gas analysis

An arterial blood gas (ABG) sample was drawn from an arterial catheter after each CT examination for blood gas analysis (Radiometer ABL 505; Inter Bio-Lab; Orlando) in **study III**. In **study IV**, an arterial blood sample was drawn immediately before induction of anaesthesia and on the fourth postoperative day. A heparinised 2-ml plastic syringe was used and the sample was stored at room temperature before analysis. The arterial oxygen tension (PaO_2), arterial oxygen saturation (SaO_2) and arterial carbon dioxide tension (PaCO_2), were measured. The patients had been without supplementary oxygen for at least 15 minutes before measurements.

Pain and subjective experiences

All patients were given pain relief according to standard routines at the hospital. At the time of the pulmonary function test on the fourth postoperative day (**I, II, IV**) and four months postoperatively (**II**), the patients were asked to quantify their sternotomy wound pain at rest, while taking a deep breath, while coughing and while performing the pulmonary function test. An unmarked, continuous, 10-cm horizontal visual analogue scale, (VAS), ranging from 0 (no pain) to 10 (the worst imaginable pain) was used (104). In addi-

tion, patients in **study II** retrospectively assessed their postoperative pain during the 4 months period, on an arbitrary scale (severe, moderate, little or no pain).

On the fourth postoperative day, the patients in the Deep breathing groups (**I, IV**) were asked to score their subjective impressions of the benefit and/or discomfort of the breathing exercises performed on the four first postoperative days. Answers were recorded on an arbitrary scale from 0 (not at all) to 3 (very much). Four months after surgery, patients in **study II** subjectively described their experience of breathing compared to the preoperative status (improved, unaltered or impaired) and whether range of motion in shoulders and thorax had been affected after surgery.

Statistical analysis

Required sample sizes were determined before the studies were started (**I, III, IV**). A significance level of 0.05 and a power of 0.80 were accepted. Differences between study groups of 10-20% in VC (**I**) and 30% (**III**) or 15-20% (**IV**) in atelectatic area were considered of clinical interest.

Data were collected and analysed using the statistical computer program SPSS (SPSS Inc. Chicago, Illinois) in **studies I and II** and StatView (Abacus Concepts, Inc. Berkeley, California) in **studies III and IV**. Baseline data for the groups were compared using one-way analysis of variance (ANOVA) (**I, III**), Student's unpaired t-test (**IV**) or chi-square test (**I, III, IV**). In **study I** chest roentgenological scores for the left and the right lungs were analysed separately, and differences between the treatment groups were analysed with a chi-square test.

Postoperative pulmonary function values in **study I, II, IV** were compared with preoperative values using a Student's paired t-test. To ascertain whether there were significant differences between the groups, ANOVA was used in **study I**, and an unpaired t-test was used in **study IV**. The postoperative values as percentages of the preoperative values served as the dependent variables. A repeated measurement ANOVA was used in **study III** for comparisons before and after intervention and between the three treatment groups. If a difference was found between the groups, the means were compared using Scheffe's post hoc test. The Pearson correlation was used to analyse relationships between variables. All results refer to two-sided tests and probability values less than 0.05 were considered significant.

Results

Of the 315 patients included and randomised in the studies, a total of 41 were excluded (Table 1) because of reoperation, failure to co-operate, confusion, reluctance, pneumothorax, pleural effusions, cardiac, neurological, respiratory or sternal complications. In total 274 patients were investigated.

Table 1. *Patients included in studies I-IV*

	Study I	Study II	Study III	Study IV
Considered for the studies	115	30	66	115
Declined participation	2	5	1	3
Excluded	15	-	4 (0/4) ¹	22 (5/17) ¹
Investigated	98	25	61 (12/49) ¹	90 (23/67) ¹

Number of patients

¹ (females/males)

There were no significant differences in terms of the preoperative demographic or surgical data (Table 2) in the randomised studies (**I**, **III**, **IV**), except for a longer duration of anaesthesia in the IR-PEP group than in the Deep breathing group ($p = 0.02$) in **study I**. In **study IV** no significant difference in length of ICU stay or postoperative hospital stay was noticed between the Treatment and Control group.

Pain from the sternotomy as measured by VAS (Table 3) did not significantly differ between any of the groups (**I**, **IV**). Four months after surgery the pain was mild (Table 3). In answer to the question about experienced pain during the four months since the operation, one of the patients reported severe pain, 7 moderate, 12 little and 5 patients reported no pain (**II**).

Table 2. Demographic and surgical data

	Study I, n = 98	Study II, n = 25	Study III, n = 61	Study IV, n = 90
Male/female, n	98/0	25/0	49/12	67/23
Age, years (range)	65 ± 9 (46-81)	66 ± 10 (46-79)	65 ± 9 (42-80)	66 ± 9 (45-83)
BMI, kg/m ²	27 ± 3	26 ± 3	27 ± 4	27 ± 4
NYHA I-II/IIIA-IIIB/IV, n	16/79/3	6/19/0	15/32/14	30/57/3
Preoperative EF, %	60 ± 14	63 ± 13	57 ± 15	55 ± 14
Never smoked/stopped/smoker, n	37/42/19	9/10/6	21/32/8	37/34/19
Operation time, h	4.0 ± 0.7	4.2 ± 0.8	4.1 ± 0.8	2.7 ± 0.8
ECC time, min	109 ± 29	111 ± 21	106 ± 30	81 ± 22.7
AoO, min	59 ± 17	58 ± 13	58 ± 19	48 ± 15
Total number of anastomoses	6.2 ± 1.2	6.2 ± 1.2	6.2 ± 1.3	5.6 ± 1.4
LIMA/RIMA/epigastrica graft, n	77/0/0	21/1/1	51/1/0	86/0/0
Pleural space entered, n	81	16	51	76
Postoperative mechanical ventilation, h	6.7 ± 2.2	7.2 ± 3.6	6.1 ± 3.0	5.0 ± 1.9

BMI = body mass index, NYHA = New York Heart Association functional capacity classification, EF = ejection fraction, ECC = extracorporeal circulation, AoO = aortic occlusion, LIMA =Left internal mammary artery, RIMA = right internal mammary artery

Table 3. Postoperative sternotomy incision pain measured by a visual analogue scale (VAS)

	Study I	Study II	Study IV	Study II 4 months
Pain at rest	1.4 ± 1.4 (1.0)	1.3 ± 1.1 (1.0)	1.4 ± 1.6 (0.9)	0.0 ± 0.5 (0.1)
Pain while taking a deep breath	2.7 ± 2.1 (2.4)	3.1 ± 2.4 (2.4)	2.5 ± 2.1 (2.1)	0.4 ± 0.5 (0.2)
Pain while coughing	4.4 ± 2.5 (4.2)	4.2 ± 2.6 (4.2)	4.3 ± 2.8 (4.4)	1.0 ± 1.5 (0.3)
Pain at pulmonary function test	2.2 ± 2.1 (1.6)	2.4 ± 2.3 (1.6)	2.4 ± 2.2 (1.9)	0.2 ± 0.2 (0.1)

Pain measured on the 4th postoperative day in **study I, II and IV** and after 4 months in **study II**. Mean (± SD) and median values within parenthesis (cm).

Spirometry

The pulmonary function values measured before surgery were normal as related to the predicted values in **studies I, II and IV**. Preoperative lung function did not differ between treatment groups for any of the measured variables (**I, IV**). Postoperative measurements of FRC and TLC could not be completed in 11 patients in **study I** and two patients in **study II**, because of unsatisfactory equipment calibration or that the patients could not perform the test acceptably.

Four days postoperatively all pulmonary function variables were significantly decreased ($p < 0.0001$) compared to preoperative values in **studies I and IV** (Figure 4 and 5). In **study I**, there were no major differences between the Blow bottle, IR-PEP and Deep breathing group, but the Blow bottle group had significantly less reduction in TLC ($p = 0.01$) and a tendency to less reduction in FRC ($p = 0.07$) and FEV1 ($p = 0.07$) than the Deep breathing group. The IR-PEP group did not significantly differ from the other two groups. In **study IV** the reduction in FVC ($p = 0.01$) and FEV1 ($p = 0.01$) was more pronounced in the patients in the Control group, who did no breathing exercises, than in the Deep breathing group (Figure 5).

Four months after surgery, the patients in **study II** still had pulmonary function values that were significantly reduced between 6 % ($p < 0.05$) and 13 % ($p < 0.001$), while no significant abnormalities were found in FEV% and RV.

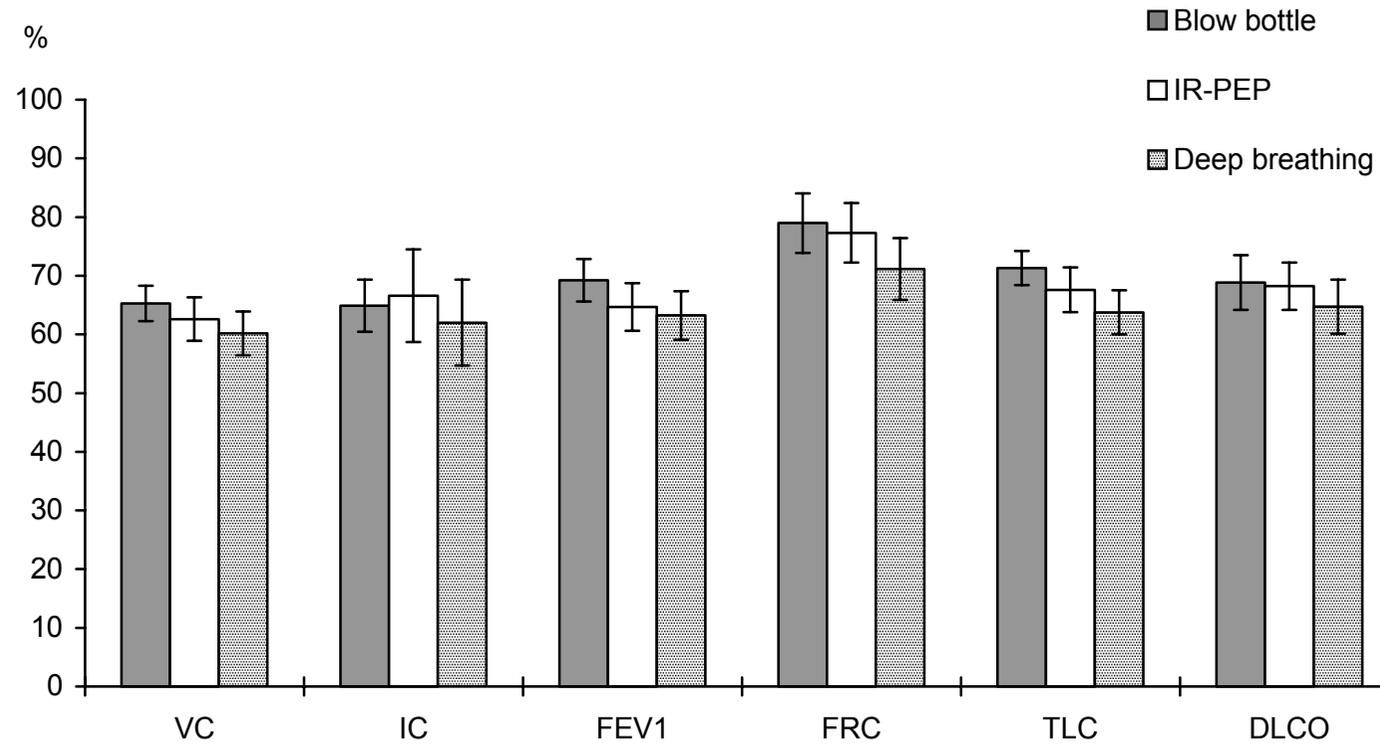


Figure 4. The pulmonary function in the three treatment groups in **study I** on the fourth postoperative day, expressed as percentages of preoperative values. Blow bottle group $n = 36$, IR-PEP- group $n = 30$, Deep breathing group $n = 32$. Error lines indicate the 95 % confidence interval.

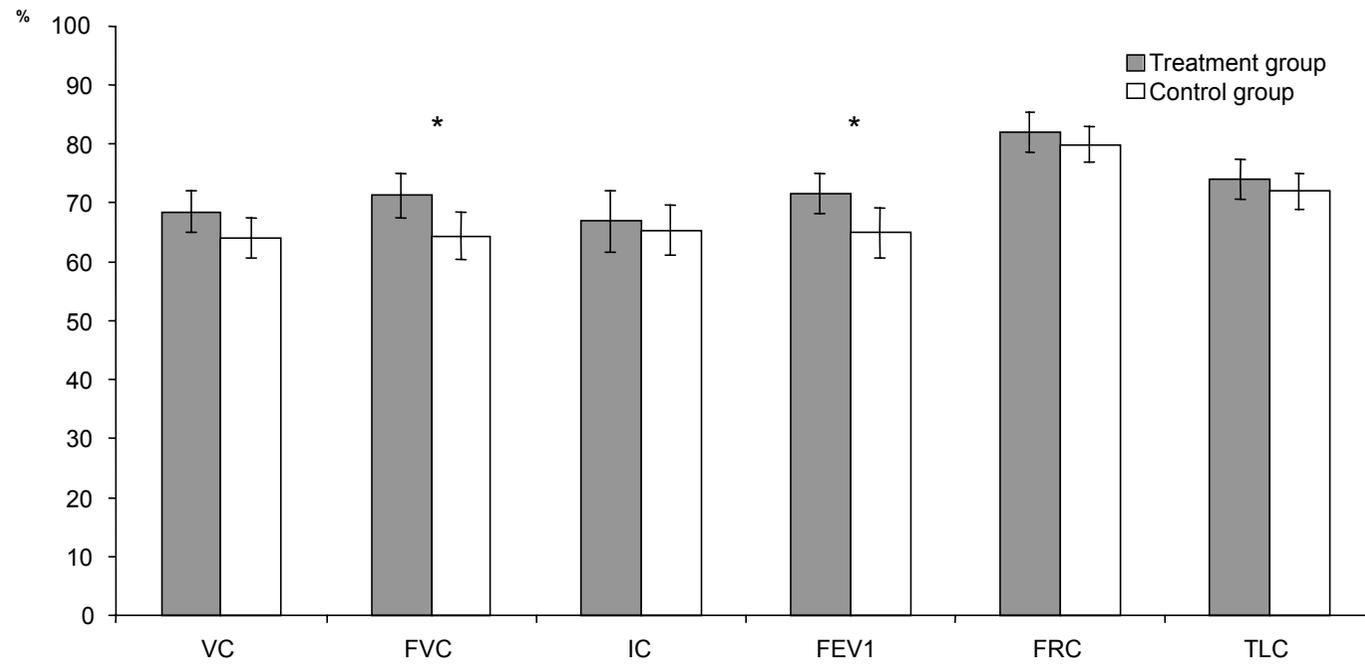


Figure 5. The pulmonary function in the Treatment and Control group in **study IV** on the fourth postoperative day, expressed as percentages of preoperative values. Treatment group $n = 48$, Control group $n = 42$. Error lines indicate the 95 % confidence interval. * $p < 0.05$

Diffusion capacity

DLCO could not be completed in 16 of the patients in **study I**, and 6 patients in **study II** because of unsatisfactory calibration or because the patients did not manage to perform the manoeuvre properly. Four days postoperatively, DLCO was significantly decreased ($p < 0.0001$) compared to the preoperative values (Figure 4, Table 4). There were no significant differences between the three groups using different postoperative breathing techniques (**I**). A correlation between the relative decrease in DLCO and the relative decrease in VC ($r = 0.70$, $r^2 = 0.49$; $p < 0.0001$) and FEV1 ($r = 0.65$, $r^2 = 0.42$ ($p < 0.0001$)) on the fourth postoperative day was found in **study I**.

Four months after surgery DLCO was still significantly impaired to $90\% \pm 12\%$ ($p < 0.01$) of the preoperative value, while DLCO/VA had returned to $99\% \pm 12\%$ (**II**) (Table 4).

Table 4. DLCO and DLCO/VA

	Preoperative	4 th postop day	4 months postop
DLCO	24.0 ± 6.3	16.0 ± 4.6	21.9 ± 5.8
Percentage of predicted	109%	67%	104%
DLCO/VA	3.9 ± 0.9	3.8 ± 0.9	3.8 ± 0.9

The values are expressed as means \pm 1 SD and as percentages of predicted values. Measured DLCO were corrected for the patients haemoglobin concentration using the equation of Cotes et al. $DLCO \times (10.22 + Hb) / (1.7 \times Hb)$.

Preoperatively and 4th postoperative day $n = 82$ (**I**), 4 months postoperatively $n = 25$ (**II**).

DLCO = Single breath diffusing capacity for carbon monoxide ($ml/min/mmHg$)

DLCO/VA = DLCO per unit alveolar volume ($ml/min/mmHg/L$)

Roentgenological measurements

Chest roentgenogram

On the fourth postoperative day, signs of atelectasis were found in 67% of the 98 patients in **study I** on an ordinary chest roentgenogram. There were no significant differences between the Blow bottle, IR-PEP or Deep breathing groups. Twenty-eight patients (29%) showed signs of elevated left hemidiaphragm, and pleural effusions were found in 62 patients (63%). The effusion was left sided in 55 patients and bilateral in the remaining 7. The incidence of pleural effusions did not significantly differ between treatment groups. Atelectasis was more common in patients with pleural effusion (67%) than in those without (33%).

Computed tomography

Two days after surgery, all 61 patients in **study III** had areas of atelectasis in one or both lungs. The atelectatic area was largest at the basal scan level, $8.2 \pm 7.5\%$ of the total lung area in the right lung and $23.1 \pm 20.6\%$ in the left lung (difference between right and left lung, $p = 0.03$). At the middle level it was $2.9 \pm 2.5\%$ and $5.6 \pm 7.6\%$ (n.s.) and at the apical level $1.1 \pm 1.8\%$ and $1.8 \pm 3.4\%$ (n.s.) respectively. There were no significant differences between the Deep breathing, Blow bottle or IR-PEP group in atelectatic area or aerated lung area before intervention. After 30 deep breaths, atelectatic area decreased in all patients, taken together, as follows; at the upper level, atelectatic area decreased from $1.4 \pm 2.2\%$ to $1.3 \pm 1.9\%$ ($p = 0.23$); at the middle level from $3.9 \pm 3.5\%$ to $3.3 \pm 3.1\%$ ($p < 0.05$); and at the basal level from $12.3 \pm 7.3\%$ to $10.2 \pm 6.7\%$ ($p < 0.0001$). The calculated total atelectatic area decreased from $6.2 \pm 3.9\%$ to $5.2 \pm 3.5\%$ ($p < 0.001$). No significant difference was found between the groups (Table 5). A representative patient is illustrated in Figure 6.

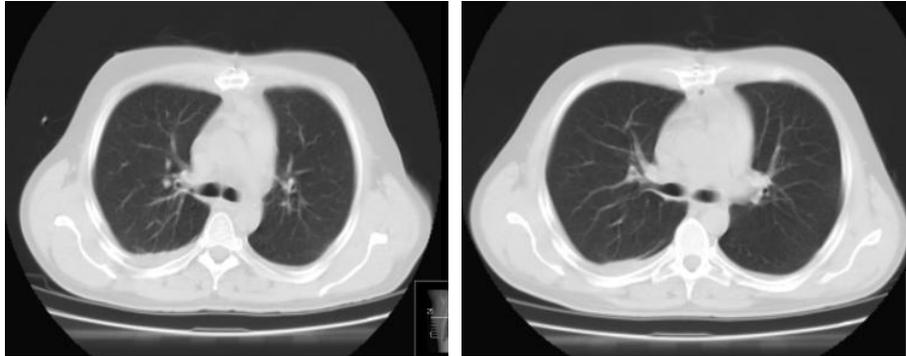
Total aerated lung area increased significantly at all three CT levels, in all patients taken together, after deep breathing exercises, from $514 \pm 119 \text{ cm}^2$ to $537 \pm 124 \text{ cm}^2$ ($p < 0.001$), with no significant difference between the three groups. The distance between the diaphragm and the carina was unchanged after the breathing intervention.

In order to investigate whether the time interval between the two CT examinations could affect atelectasis or oxygenation, 12 patients who performed no intervention (normal breathing) were investigated. No significant change in atelectatic area, aerated lung area or PaO_2 was found by the time of the second measurement, and no further patients were included.

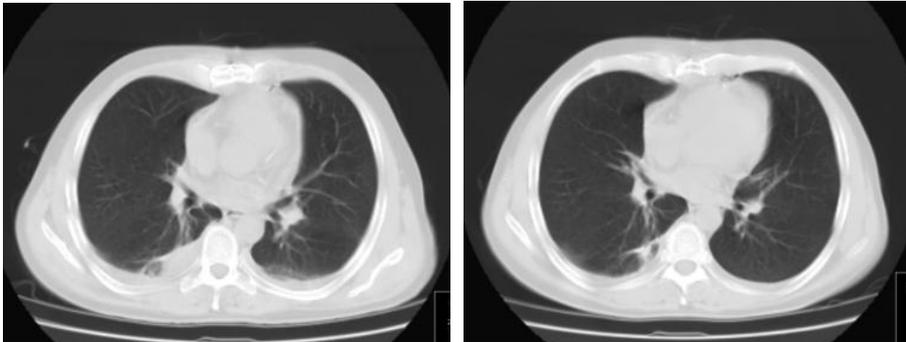
Table 5. Atelectasis before and after deep breathing

	Before			After			p Value
	Deep breathing	Blow bottle	IR-PEP	Deep breathing	Blow bottle	IR-PEP	
Upper level	1.4 ± 2.1% (2.1 ± 3.0 cm ²)	1.8 ± 2.6% (2.6 ± 3.4 cm ²)	1.0 ± 1.9% (1.4 ± 2.7 cm ²)	1.3 ± 1.5% (2.0 ± 2.1 cm ²)	1.5 ± 2.5% (2.1 ± 3.4 cm ²)	1.0 ± 1.7% (1.4 ± 2.4 cm ²)	n.s.
Middle level	4.6 ± 3.9% (7.7 ± 5.9 cm ²)	4.2 ± 3.7% (7.7 ± 6.4 cm ²)	2.7 ± 2.4% (5.2 ± 4.4 cm ²)	4.3 ± 3.6% (7.2 ± 5.4 cm ²)	3.1 ± 2.9% (5.8 ± 5.3 cm ²)	2.5 ± 2.6% (4.9 ± 4.5 cm ²)	<.05
Basal level	13.7 ± 6.0% (25.1 ± 12.0 cm ²)	12.9 ± 8.9% (24.7 ± 16.0 cm ²)	10.3 ± 6.7% (19.5 ± 10.6 cm ²)	11.4 ± 6.0% (21.7 ± 12.8 cm ²)	10.4 ± 7.6% (19.9 ± 13.5 cm ²)	8.7 ± 6.3% (16.6 ± 10.6 cm ²)	<.0001

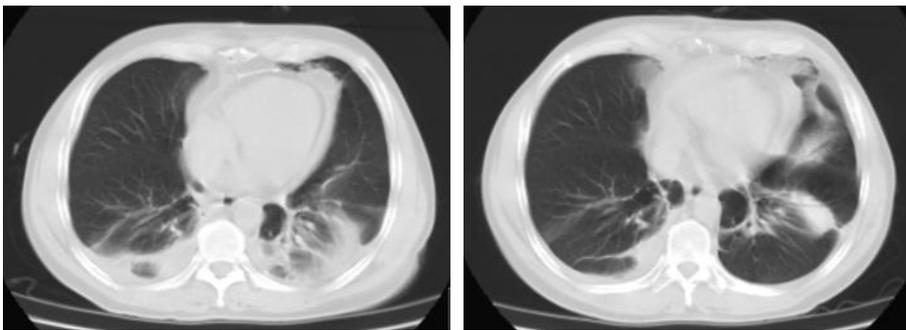
Mean areas of bilateral atelectasis (± SD) as percentages of total lung area and in absolute values (within parenthesis). The basal level is 1 cm above the top of the diaphragm, the middle level 5 cm, and the upper level 9 cm above. The measurements were made before and after a deep breathing intervention in **study III**. P values refer to the difference before and after intervention in the three groups taken together ($n = 61$).



a)



b)



c)

Before intervention

After intervention

Figure 6. Computed tomography (CT) of the lungs in patient 43 immediately before and after 30 deep breaths performed with an IR-PEP-mask. The CT levels were positioned a) 9 cm (0% vs. 0%), b) 5 cm (4% vs. 1%), and 1 cm (11% vs. 2%) above the diaphragm (atelectatic area as % of total lung area before vs. after intervention).

In **study IV** all 90 patients showed signs of atelectasis on the fourth postoperative day. The atelectatic area at the basal level was $2.4 \pm 4.2\%$ in the right lung and $7.6 \pm 11.9\%$ in the left lung, as a percentage of the total lung area. There was no significant difference between the right and left lung at any CT level. Because of technical and scheduling difficulties, missing data are apparent in the Deep breathing ($n = 11$) and Control groups ($n = 6$).

Less atelectasis was found in the group that had performed deep breathing exercises during the first few postoperative days than in the control patients. Bilateral atelectasis in the Deep breathing group was half of that in the Control group, in total $1.2 \pm 0.8\%$ vs. $2.2 \pm 2.8\%$ of the lung area (upper scan: $0.1 \pm 0.2\%$ vs. $0.3 \pm 0.5\%$, $p = 0.01$; middle scan: $0.7 \pm 0.6\%$ vs. $1.3 \pm 2.2\%$, $p = 0.09$; and basal scan: $2.6 \pm 2.2\%$ vs. $4.7 \pm 5.7\%$, $p = 0.04$). A weak inverse correlation between the amount of atelectasis at the basal level and FEV1 was found on the fourth postoperative day ($r = -0.32$, $r^2 = 0.10$, $p < 0.01$).

Arterial blood gases

In **study III** ABG were measured immediately before and after the deep breathing intervention on the second postoperative day. The patients showed moderate hypoxemia. Oxygenation showed a small improvement after the deep breathing intervention in all three groups. PaO₂ increased from 7.7 ± 0.9 kPa to 7.9 ± 1.1 kPa ($p = 0.02$) and SaO₂ from $90.7 \pm 2.9\%$ to $91.2 \pm 3.1\%$ ($p = 0.004$), while PaCO₂ remained unchanged at 5.2 ± 0.6 kPa. There was no significant difference between the three techniques. A weak inverse correlation between PaO₂ and atelectasis was found in **study III** ($r = -0.31$, $r^2 = 0.10$, $p < 0.05$) and in **study IV** ($r = -0.24$, $r^2 = 0.06$, $p < 0.05$). On the fourth postoperative day no significant differences in PaO₂, SaO₂ or PaCO₂ were found between the Deep breathing and Control groups in **study IV**.

Subjective experiences

In **study IV** the 90 patients in the Deep breathing group self-reported that they had performed the breathing exercises 7 ± 2 (range 2-12) times a day and that each session had consisted of 25 ± 8 (range 8-30) breaths. All patients (two missing data) answered that the deep breathing technique was easy to perform. In total, 33 patients experienced subjective benefits from the breathing exercises, 2 experienced no benefits and 11 had no opinion. Five patients had experienced discomfort from the deep breathing exercises

and 8 of the patients would have preferred to perform the deep breathing without the blow bottle device.

In **study II**, 11 of the 25 patients felt that their subjective breathing capacity was improved, 2 felt it was impaired, and 12 reported that it was unchanged four months after surgery compared to their preoperative status. Six patients experienced deteriorated range of motion in shoulders and thorax four months after surgery.

Discussion

A marked reduction in lung volumes was present on the fourth postoperative day, which was of the same extent as found in other investigations after CABG (10, 14, 20). Four months after surgery the pulmonary function was still significantly reduced, although to a minor extent.

On the second postoperative day all patients had atelectasis visible on CT. One session of deep breathing exercises performed with or without a PEP device caused an immediate significant reduction in atelectatic area and an improvement in oxygenation. No differences between deep breathing performed with or without a blow bottle or PEP-device was found, except for a less marked decrease in TLC in the Blow bottle group on the fourth postoperative day in **study I**.

It was found that chest physiotherapy including deep breathing exercises performed with a blow bottle device during the first four postoperative days was superior to a chest physiotherapy treatment without breathing instructions. In patients who had performed breathing exercises atelectasis was decreased by half and a slightly better preservation of spirometric variables was found.

Despite the common use of breathing exercises in the management of CABG patients in many countries, scientific evidence for the efficacy of the treatment has been lacking. Atelectasis may promote pulmonary infection and it thus seems a reasonable aim to reduce the amount. CT has not previously been used in the evaluation of chest physiotherapy after cardiac surgery and no study has ever before shown an effect of deep breathing exercises in the prevention or treatment of pulmonary impairments or atelectasis (16, 17, 21).

Postoperative pulmonary function

A pronounced decrease in pulmonary function was present postoperatively to 60-75% of preoperative values on the fourth postoperative day. Several authors have previously found greater decreases of approximately 50% of the preoperative values on the fourth postoperative day after CABG (10, 14, 20, 82). Management in perioperative care, adequate pain relief and early mobilisation routines could possibly explain the better preserved pulmonary function in this study, compared to that found by previous authors.

Patients with pulmonary atelectasis in the postoperative period have a greater decrease in pulmonary function than those with normal chest radiographs (4, 105). This was supported in **study IV** by the significant correlation between the amount of atelectasis and FEV1.

DLCO was decreased to the same extent as the spirometry values. When corrected for lung volume, DLCO/VA was almost unchanged compared to preoperative values. The reduction in DLCO could, in other words, be explained by the reduction in lung volume. A similar decrease in DLCO and DLCO/VA 2 hours postoperatively have been reported in patients undergoing cardiac surgery requiring ECC (26). Shapira et al. (6) reported that DLCO improved to a level higher than the preoperative level 3 months postoperatively. In our study DLCO was still significantly impaired to 90% of the preoperative value four months postoperatively.

Four months after CABG we found that lung volumes except RV, were still significantly reduced compared to preoperative values. This finding supports the work of Braun et al. (5), Shapira et al. (6) and Shenkman et al. (27), who described an even more pronounced decrease in pulmonary function in patients after cardiac surgery. Several factors that may influence the pulmonary function have been suggested, for example impaired pulmonary mechanics, pleural changes, atelectasis, inflammatory reactions due to cardiopulmonary bypass, various hemodynamic variables and cardiac function (23, 25, 48, 106).

Pain after cardiac surgery can lead to poor inspiratory effort in the spontaneously breathing patient, which may contribute to postoperative pulmonary dysfunction (56). Optimal pain relief is essential to enable the patient to perform maximal inspiration (42). Four months postoperatively pain was rated low in this study and could thus not explain the pulmonary impairment.

Recovery of pulmonary function can be delayed for months after surgery, but if it is permanent is not yet known. The crucial question is whether the reduced pulmonary function is of a clinically significant degree. A reduction in FRC of 5-10% is maybe not a relevant problem for most patients, except for those with serious pulmonary disease.

Roentgenological changes

All patients had atelectasis visible on CT two days after CABG. This is similar to previous findings after cardiac surgery (3, 35). Atelectasis was greatest near the diaphragm in the supine patients, and decreased in size towards the apex, as previously reported (107, 108). Since atelectasis constitutes non-expanded lung tissues, their inflation by air should result in much larger volume.

Several investigators, including us, have used ordinary chest roentgenograms in evaluating postoperative atelectasis (10, 12, 13, 16, 17, 41, 82).

Arbitrary scales have been used for quantification, and some authors have just stated whether atelectasis was present or not, without providing any description of its extent (11, 14, 20). In our study atelectasis as revealed by ordinary chest roentgenograms was present in 67% of the patients on the fourth postoperative day, equivalent to what has been found in earlier studies after CABG (12, 109).

Bartlett et al. (54) proposed in the 1970s that the best technique to reverse alveolar collapse is voluntary deep breathing or sustained maximal inspiration, such as a sigh or yawn. Several other authors have stated that the pressure required to reopen closed lung units is very high and is unlikely to be achieved in normal breathing (110-112).

In **study IV** all patients had visible atelectasis on CT on the fourth postoperative day. The patients performing deep breathing exercises postoperatively had significantly smaller atelectatic areas, by an average half the size of those of the Control group. Scientific documentation of efficacy of deep breathing exercises with regard to decreased atelectasis in the cardiac surgery patient has so far never been presented. In contrast, numerous authors have concluded that breathing exercises have no effect at all in the postoperative cardiac surgery patient (17, 21, 68, 118, 120).

Relationship between atelectasis and oxygenation

One consequence of atelectasis is intrapulmonary shunting and hypoxemia (107, 113-115). A moderate hypoxemia was found on the second postoperative day. Since baseline ABG was taken before induction of anesthesia it is possible that PaO₂ was lower than the day before surgery, because of the effects of premedication and the supine body position (116). The oxygenation had slightly improved by the fourth postoperative day. Hachenberg et al. (35) found that atelectasis amounted to 24% of the lung area near the diaphragm 2 hours after cardiac surgery, and that pulmonary shunt correlated with the amount of atelectasis. We found a weak inverse correlation between atelectatic area and PaO₂, and this is in agreement with Tenling et al. (3). Postoperatively reduction in PaO₂ is not a reliable indicator of the extent of atelectasis though, because compensatory hypoxic vasoconstriction occurs in the atelectatic areas (117).

Pulmonary complications

Atelectasis, impaired pulmonary function and gas exchange are almost universal findings after cardiac surgery and do not necessarily reflect clinically significant pulmonary complications. The criteria used for diagnosing a

”pulmonary complication” differ widely between various studies (10, 12, 15, 80, 118). Atelectasis and arterial desaturation may be of particular concern in critically ill and older patients, in whom relatively small reductions in PaO₂ may precipitate acute cardiac dysrhythmias and vital organ dysfunction. Atelectasis is also a risk factor for pneumonia, which has significant morbidity and mortality in this patient population (38). The consequences are variable and largely depend on the underlying condition of the patient, particularly with regard to pulmonary dysfunction (32). Patient symptoms may range in severity from an asymptomatic radiographic abnormality to a severe dysfunction, requiring mechanical ventilation.

Methodological considerations

In this study of CABG patients we have focused on lung volumes, atelectasis and gas exchange, as have many authors previously (10, 12, 14, 17, 41, 82, 83). Fever, auscultation, subjective symptoms and chest x-rays are often imprecise for the detection of small changes in pulmonary function, and may be one explanation why earlier studies have not demonstrated an effect of breathing exercises (10, 17, 20). Evaluation of the efficacy of chest physiotherapy techniques has been limited methodologically, because benefits can be explained by several confounding factors, such as the effect of mobilisation and positioning (119).

For practical reasons emergency surgery patients did participate in the study. It is thus possible that the most unwell patients were not included, but considering that the breathing techniques are primarily suitable for the uncomplicated patient, the selection can be considered appropriate. If emergency patients as well had been included, it may have been even larger differences between the study groups, since these patients are at a higher risk of developing complications (33).

The spirometric data were analysed in terms of percentage change from preoperative values, to control for variability between subjects. The spirometry was performed using a portable measurement system in the first studies and using a body box in the last study. The measurements using the portable system were more extensive and took longer time, compared to the last study. This could explain the difficulties some patients had in completing the tests acceptably, and could account for the internal exclusion in **study I**. The single-breath test using carbon monoxide, used in the present study, is the most widely used method for measuring of pulmonary diffusing capacity and is the only non-invasive means of determining the functional integrity of the alveolar-capillary membrane (101). The diffusion test was performed before the nitrogen washout, because inhaling 100% oxygen during a nitrogen washout test may saturate the haemoglobin and decrease the patients’ diffusion capacity values.

Pulmonary function measurements depend on patient co-operation, and the ability to take deep breaths could have been altered depending on the type and timing of the last dose of analgesics. Thus patients were asked to score their sternotomy pain immediately after the spirometry, to control for any differences that could influence outcome. No differences in the scoring of pain were found between any of the groups.

CT has not previously been used in the evaluation of postoperative chest physiotherapy. To diminish atelectasis is a main focus after CABG, but no earlier studies have shown any treatment effects. Small changes in atelectasis are not reliably measured by ordinary chest roentgenograms, and could be an explanation why no previously effects have been demonstrated. The atelectatic areas defined at a given scan level were expressed as percentages of the total lung area at that level, to take into account individual differences in lung size.

Compliance with treatment was documented on an observation chart for the first postoperative day and after that self-reported by the patients in **study IV**. An arbitrary scale was used in the questionnaire to briefly to assess the patients' subjective experiences. The frequency of mobilisation was not, however, documented.

Immediate effects of deep breathing exercises

In **study III** we focused on the treatment effect of deep breathing on the resolution of existing atelectasis. A significant decrease in atelectatic area after the breathing session was present in the three treatment groups taken together. The Blow bottle, IR-PEP and Deep breathing techniques were similar in their ability to diminish atelectasis. Because of the small number of patients investigated in each group and the brief duration of the period investigated, the finding require further clinical verification.

Deep breathing also significantly increased the aerated total lung area especially in the IR-PEP group, but the increase did not significantly differ from the other two groups. One explanation for the increase could be that the recruited atelectatic areas resulted in increased lung volume and an expected change in the lung area. A difference in the positioning of the CT scan levels before and after the deep breathing intervention because of changed diaphragm position could also explain a changed rib cage configuration and a larger area. However the distance between the carina and the diaphragm did not significantly change after deep breathing.

Furthermore, PaO₂ increased significantly after the deep breathing session, while PaCO₂ remained unchanged. An immediate improvement in oxygenation after deep breathing has earlier been described by Jenkins et al. (93), who found small but significant rises in transcutaneous measured oxygenation (tc-pO₂) but no changes in carbon dioxide (tc-pCO₂) immediately

after voluntary deep breathing. In our study we were able to confirm the immediate effect of breathing exercises, with a significant decrease in atelectatic area, an increase in aerated lung area, and a small increase in PaO₂ after the performance of 30 deep breaths. Though the effect could be considered relatively small, the accumulated effect may be larger because standard physiotherapy often consists of repeated treatments over an extended period of time. The effect was measured immediately after the intervention and no more measurements were made. It is possible that collapse of the re-expanded atelectatic lung tissue may occur after some time, but our study does not permit us to estimate how long lasting this effect might be. There could still be a clinically important effect if the deep breathing sessions are performed regularly. This was studied in **paper IV**.

Effects of deep breathing exercises performed regularly

Postoperative chest physiotherapy is aimed at both preventing and reducing pulmonary function impairments, incidence and severity of atelectasis, chest infections and postoperative complications. In **study IV** comparison between patients performing deep breathing and control patients showed that the Deep breathing group had half as much atelectasis on the fourth postoperative day. Postoperative management and chest physiotherapy was otherwise identical. Thus we have for the first time demonstrated that the addition of deep breathing exercises to a routine postoperative chest physiotherapy regimen was effective in preventing and treating atelectasis, and in improving pulmonary function. The patients reported that they had completed the exercises 7 times a day. This is a higher frequency than reported in the study by Brasher et al. (20). Ingwersen et al. (10) found a PEP treatment regime to be preferred by patients, over two other regimes and consequently patients tended to use the mask more frequently.

It is important to combine several treatment techniques in postoperative care to achieve optimal treatment results, but this makes it difficult to identify the most efficient therapeutic modes. The natural history of postoperative pulmonary complications is usually recovery, so it is not possible to determine the true benefits of treatment without control patients.

The study by Stiller et al. (17) is the only investigation that includes a control group of patients who received no physiotherapy at all. It was concluded that the incidence or severity of fever, hypoxemia, chest roentgenological abnormalities or clinically significant postoperative pulmonary complications was not different between patients who received prophylactic chest physiotherapy compared to patients who received no treatment. The overall incidence of pulmonary complications was high though, since 9 of the 120 patients developed a clinically significant pulmonary complication.

Comparison of deep breathing techniques

Throughout the world there are differences in usage of mechanical devices, and several published studies have compared various techniques used postoperatively (10, 12, 80, 82). No method of postoperative pulmonary therapy has been distinguished to be superior at preventing or treating atelectasis or pulmonary impairments (9-12, 85, 112). PEP, IR-PEP and blow bottles are used in many Western European countries for several reasons (86). In our study we found no major differences between patients performing deep breathing with or without a mechanical device. However, the Blow bottle group had a small, but significantly better preserved TLC and a tendency to less reduction in FRC and FEV1 than the Deep breathing group on the fourth postoperative day.

The blow bottle device has been used as part of the routine care of the cardiac surgery patient since the 1980s at Örebro University Hospital. The blow bottle system has previously been found useful in postoperative care after abdominal surgery (121, 122). However, the device has not been subjected to adequate trials concerning its effectiveness regarding postoperative pulmonary function after CABG. The study by Iverson et al. (80) appears to be the only one dealing with the efficacy of blow bottles after cardiac surgery. However, the equipment and technique for using the blow bottle system were not well described and no statistical significance values were given.

The blow bottle technique is obviously an expiratory and not an inspiratory manoeuvre. However, when properly performed, the patient is obliged to take a deep breath prior to expiration through the system. If the PEP device is used to increase pulmonary function, slow, deep inspirations should be emphasized. The possible efficiency of the technique may depend on the combination of the deep inspiration and the positive expiratory airway pressure, and this combination may promote expansion and maintenance of alveolar and airway integrity. Perhaps the only benefit of an expiratory focused device is the deep inspiration that precedes the expiratory manoeuvre. It is important to finish expiration before closing volume is reached though. Improper use of blow bottles may decrease rather than increase end-expiratory lung volume if a patient exhales forcefully toward RV (76).

The cross-sectional aerated lung area was mostly increased in the IR-PEP-group, but was not significantly different from the other two groups. Thus, no obvious effect of IR-PEP was found in this thesis.

The frequency and duration of treatment vary between studies, but several authors have suggested performance of hourly exercises (10, 12-14, 17, 20). In our studies we matched the studied frequency of treatment to those prevalent in ordinary routines, and we made 30 deep breaths in all treatment groups. It has been suggested that regardless of the modality chosen, therapy should be provided as frequently as possible for the first four days post-

operatively (42). At least every 1-2 hour in order to correct atelectasis (123) and a minimum of 10 consecutive breaths per hour have been suggested as the minimum therapeutic intervention. Clinical studies to date have not defined an optimal frequency, but it is reasonable to expect that the breathing exercises should be performed at least hourly. Performing deep breathing more frequently (every 30 minutes) may be optimal, but considering that it requires a very well motivated and tolerant patient, to keep up this frequency, it might not be feasible in standard postoperative care.

Physiotherapists actively instruct the patient in independent performance of the technique. Discontinuation of an intervention may be indicated because of lack of motivation. If the suggested treatments or exercises are proven to be effective, it should be easier for the physiotherapist to motivate patients to perform them.

Clinical implications

We have in this thesis shown an immediate treatment effect of voluntary deep breathing on atelectasis and oxygenation, and that breathing exercises performed regularly may prevent or reduce postoperative atelectasis and lung impairment after CABG.

Our suggestion is that deep breathing exercises should continue to be assigned to CABG patients in the clinical practice. Repeated, slow maximal deep breaths performed with or without a PEP device may prevent or reduce postoperative impairment. Since the differences between deep breathing, blow bottle or IR-PEP technique seem to be small, individual preferences may be acceptable in the choice of a mechanical device. A specific technique might be more suitable for some patients than others.

Despite the fact that deep breathing is a major part of chest physiotherapy, no earlier study has confirmed its effectiveness in CABG patients. Deep breathing exercises can easily be accomplished hourly and at low cost. However, a technique that offers even better supervision and assistance of a deep inspiration with optimal continuance may prevent more of the lung function deterioration.

Conclusions

- A significant restrictive decrease in pulmonary function was present on the fourth postoperative day after CABG. The pulmonary function was still impaired four months after surgery. Pain from the sternotomy was low and could not explain the impairment. Extensive atelectasis was demonstrated on the second and fourth postoperative days, accompanied by an impaired oxygenation.
- No major differences were found between patients performing deep breathing with or without a blow bottle or an IR-PEP-mask during the first four postoperative days.
- One treatment session of deep breathing exercises performed with or without a blow bottle or an IR-PEP mask significantly reduced atelectasis and improved oxygenation.
- Patients who performed deep breathing exercises with a blow bottle device postoperatively showed a significantly smaller amount of atelectasis and had less reduction in FVC and FEV1 on the fourth postoperative day compared to control patients.

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