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CHEST PHYSIOTHERAPY AFTER CORONARY ARTERY BYPASS GRAFT SURGERY—A COMPARISON OF THREE DIFFERENT DEEP BREATHING TECHNIQUES

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The effectiveness of three deep breathing techniques was evaluated in 98 male patients after coronary artery bypass graft surgery in a randomized trial. The techniques examined were deep breathing with a blow bottle-device, an inspiratory resistance-positive expiratory pressure mask (IR-PEP) and performed with no mechanical device. Pulmonary function and roentgenological changes were evaluated. Four days post-operatively there were significantly decreased vital capacity, inspiratory capacity, forced expiratory volume in 1 second, functional residual capacity, total lung capacity and single-breath carbon monoxide diffusing capacity in all three groups ($p < 0.0001$). No major differences between the treatment groups were found, but the impairment in pulmonary function tended to be less marked using the blow bottle technique. The Blow bottle group had significantly less reduction in total lung capacity ($p = 0.01$) compared to the Deep breathing group, while the IR-PEP group did not significantly differ from the other two groups.

Key words: physical therapy, thoracic surgery, coronary artery bypass, post-operative complications, positive-pressure respiration, respiratory function tests.

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INTRODUCTION

A decrease in pulmonary function is well known after open heart surgery. Roentgenological signs of atelectasis are common and various studies have documented reduced lung volumes and oxygenation in the post-operative period. Chest physiotherapy is routinely used in order to prevent or reduce pulmonary complications after surgery. Post-operative treatment includes early mobilization, change of position, breathing exercises and coughing techniques. Various mechanical devices have also been used in order to improve post-operative pulmonary function, for example incentive spirometry, continuous positive airway pressure and intermittent positive pressure breathing. Little or no evidence documenting the efficacy of these techniques have been found though (1–6).

Resistive breathing such as positive expiratory pressure (PEP) has been incorporated in routine post-operative care after open heart surgery in many medical centres. The technique was developed in Denmark in the 1970s and was primarily used with the aim of mobilizing secretions (7). Inspiratory resistance-positive expiratory pressure (IR-PEP) has also been introduced in an attempt to enhance the function of the diaphragm after open heart surgery (4). The blow bottle is another technique to produce expiratory resistance and the initial rationale for the technique was to expand the lungs (8). The early investigation by Iverson et al. (9) in 1978 appears to be the only investigation dealing with the efficacy of resistive breathing with blow bottles after open heart surgery. The evaluation and comparison of different PEP devices, in recent years seem to be scarce (4, 10). Different techniques are used in different countries and there is no absolute consensus to the most effective chest physiotherapy regime after open heart surgery.

The purpose of this study was to evaluate the efficacy of two mechanically assisted deep breathing techniques used after coronary artery bypass grafting (CABG), compared with deep breathing performed with no mechanical device. Pulmonary function and roentgenological changes were assessed.

METHODS

One hundred and thirteen male patients scheduled for CABG at a Medical centre hospital were considered for the study. Patients who had unstable angina, previous open heart surgery or renal dysfunction requiring dialysis were not included. The study was approved by the Ethics Committee at Örebro medical centre hospital and informed consent was obtained from each patient.

The surgical approach was through a median sternotomy and CABG was performed with saphenous vein grafts and/or the left and/or right internal mammary artery. Cold blood cardioplegia and pericardial cooling with ice were used. An insulation pad was used to protect the phrenic nerve. The patient's lungs were kept deflated during the aortic occlusion. The pericardium, the mediastinum and one or both pleura were drained, usually less than 24 hours after surgery. Post-operatively the patients were artificially ventilated and a positive end-expiratory pressure of 5 cm H_2O was used. Following surgery, inspired oxygen fraction in nitrogen was 0.6–0.8. The patients were tracheally extubated, when hemodynamically stable and able to normoventilate without distress.

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Chest physiotherapy

All patients received basic post-operative chest physiotherapy as conventionally used at the clinic by two physiotherapists once or twice daily. The therapy consisted of mobilization and active exercises of the upper limbs and thorax, breathing exercises and instructions in coughing techniques. Patients were mobilized as early as possible by the nursing staff and physiotherapists according to the ordinary routines. The patients were instructed to sit out of bed and stand up on the first post-operative day, walk in the room or a short distance in the corridor on the second day, and walk freely in the corridor on the third post-operative day.

Before surgery the patients were randomly assigned, with sealed envelopes, to one of three treatment groups. The patients in the Blow bottle group were instructed to do deep breathing exercises with a blow bottle device. A bottle with 10 cm of water and a 40 cm plastic tube (1 cm diameter) were used. The manoeuvre gives a resisted exhalation with an expiratory peak pressure of +10 (±1) cm H_2O.

In the IR-PEP group the deep breathing was performed through an PEP/RMT set by Astra Tech AB, Mölndal, Sweden. The system consisted of a face mask/ventil connected to a T-tube where inspiratory and expiratory airflows are separated by a valve. Various resistance nipples were applied to receive wanted pressure, measured by a manometer. The expiratory pressure used was +10 cm H_2O and the inspiratory pressure −5 cm H_2O. The nipples used for expiratory pressure were 2.5 mm, 3.0 mm or 3.5 mm and for inspiratory pressure; 4.0 mm, 4.5 mm or 5.0 mm. In the deep breathing group the patients were instructed to inspire deeply through the nose and expire through the mouth without any mechanical device. In all three groups the patients were instructed to perform a maximal inspiration, while expiration was ended at approximately functional residual capacity (FRC) to avoid airway closure.

Pre-operatively the patients practiced the different breathing techniques and received general information about post-operative routines, early mobilization and efficient coughing. All groups were instructed to perform 30 deep breaths with or without the mechanical device once an hour at daytime. The breathing exercises were, if possible, done in a sitting position and three sessions of 10 deep breaths each were performed, interrupted by a pause and coughing or huffing, if needed. Exercises were started 1 hour after extubation and continued until the fourth post-operative day. The patients were actively encouraged to use the suggested treatments by the staff during the 4 days of the investigation.

Measurements

Pulmonary function measurements were performed pre-operatively and on the fourth post-operative day with a Medical Graphics PF/Dx Pulmonary Function System (Spiropharma A/S, Denmark) with proprietary software. The equipment was calibrated every morning prior to measurements. Four medical laboratory technicians who were unaware of the patient's randomization performed the tests. The patients were in a sitting position and a nose-clip was used. Predicted values for pulmonary function were related to age, sex, length and weight according to the values reported by Grimby & Söderholm (11). The results of the post-operative pulmonary function were expressed in percentage of the individual pre-operative values, and the relative decrease in pulmonary function was compared between the treatment groups.

Three slow inspiratory vital capacities were obtained and the largest used for measurement of vital capacity (VC) and inspiratory capacity (IC). For the measurement of forced expiratory volume in 1 second (FEV1), the highest value of two or three technically satisfactory manoeuvres was retained. FRC and residual volume (RV) were measured with the single breath nitrogen washout technique. Total lung capacity (TLC) was calculated as VC + RV.

The pulmonary diffusing capacity for carbon monoxide (DLCO) was measured according to the method of Ogilvie et al. (12). The gas mixture used for the measurement was 0.5% neon, 0.3% carbon monoxide, 21% oxygen, balance nitrogen. The gas sample was aspirated automatically into the chromatograph for analysis. The patients were instructed to exhale slowly and maximally to RV, and then rapidly inhale the gas mixture to TLC. The DLCO measurement was considered acceptable if the inspired volume was greater than 90% of the patients' VC. Two or three repeated tests were performed and the highest accepted value was retained. Repeated tests were separated by a washout period of at least 5 minutes DLCO was expressed both in absolute values and per litre of alveolar volume (DLCO/VA), measured by neon dilution during the breath holding manoeuvre. The DLCO values were corrected for the patient's current haemoglobin concentration using the equation of Cotes et al. (13).

At the time of the pulmonary function test the patients were asked to quantify the pain from the median sternotomy incision while taking a deep breath. A continuous visual analogue scale (VAS) from 0 (no pain) to 10 (the worst imaginable pain) was used.

An anteroposterior chest roentgenogram was taken in the standing position before the operation and on the fourth post-operative day. Presence or absence of atelectasis and/or pleural effusion was recorded. Evaluation was performed by a radiologist who was unaware of the patient's randomization. The size of atelectasis seen on the chest radiograph was scored in the right and left lung separately. An arbitrary scale was used for scoring of atelectasis: 0, no abnormality; 1, minimal abnormality (plate atelectasis); 2, moderate abnormality (segmental atelectasis); 3, major abnormality (lobar atelectasis). The left hemi-diaphragm was described as raised if the highest point was at the same horizontal level or higher than that on the right.

Statistical analysis

The pre-operative, demographic and operative variables for the groups were compared by one-way analysis of variance or chi-square test. The pre- and post-operative pulmonary function values were compared by a paired *t*-test for each variable. The relative decrease of the pulmonary function variables after the operation was calculated for each patient and the mean value for the three groups were analysed with one-way analysis of variance. If a difference was found between the groups, the means were compared by Scheffe's test.

Chest roentgenological scores were examined and analysed separately in the left and the right lung, and differences between the treatment groups were analysed with a chi-square test. All results refer to two-sided tests and a probability value less than 0.05 was considered significant.

RESULTS

Fifteen patients were excluded from the study after surgery, the main cause for each patient is reported in Table I. In total, 98 men were included, their ages ranging from 46 to 81 years. Demographic and operative variables are presented in Table II. No significant differences between the three groups were found except for a longer duration of anaesthesia in the IR-PEP group than the deep breathing group. Pain from the sternotomy measured by VAS while the patient took a deep breath showed no significant difference between the Blow bottle (2.7 ± 1.9), IR-PEP (2.9 ± 2.2) and Deep breathing (2.4 ± 2.2) groups.

Pulmonary function

Because of unsatisfactory calibration of the equipment or

Table I. *Cause of exclusion from the study*

	Blow bottle	IR-PEP	Deep breathing
Circulatory instability	0	3	2
Reoperation	1	0	1
Pneumothorax	0	0	1
Poor oxygenation	0	0	1
Sternal pain	1	1	0
Confusion	0	1	1
Failure to cooperate	2	0	0

IR-PEP = inspiratory resistance-positive expiratory pressure.

Table II. *Demographic and operative variables (mean ± SD)*

	Blow bottle ($n = 36$)	IR-PEP ($n = 30$)	Deep breathing) ($n = 32$)	p-value
Age (years)	66.1 ± 9.4	65.9 ± 8.8	63.5 ± 9.2	0.45
Body mass index (kg/m^2)	27.1 ± 3.5	27.0 ± 3.6	26.9 ± 3.1	0.95
NYHA classification	3.0 ± 0.8	3.3 ± 0.8	2.9 ± 0.9	0.11
Smokers/non-smokers (n)	5/31	7/23	8/24	0.86
Operation time (hours)	4.2 ± 0.7	3.9 ± 0.8	3.9 ± 0.8	0.15
AoO (minutes)	63 ± 15	57 ± 21	55 ± 17	0.18
IMA grafts (n)	28	22	27	0.56
Pleural space entered (n)	28	24	29	0.34
Duration of anaesthesia	11.8 ± 2.2	13.1 ± 2.9	11.4 ± 2.0	0.02

IR-PEP = inspiratory resistance-positive expiratory pressure; NYHA = New York Heart Association; AoO = aortic occlusion time; IMA = internal mammary artery.

inability of the patient to perform the manoeuvre properly measurements of FRC and TLC was completed in 87 patients and DLCO in 82. Pulmonary function values before surgery and on the fourth post-operative day are given in Table III. The pre-operative lung function did not differ between treatment groups in any of the measured variables. The measured variables were normal as related to predicted values (11) with VC 88 ± 14% of predicted and FEV1 93 ± 19% of predicted.

Four days post-operatively all pulmonary function variables were significantly decreased in the three groups ($p < 0.0001$) compared to pre-operative values. Figure 1 shows the post-operative pulmonary function in percentage of the pre-operative value, in each of the three treatment groups. The post-operative mean VC for all patients was 63 % of the pre-operative value, and FEV1 was reduced to 66%.

The relative decrease in pulmonary function variables, on the fourth post-operative day, displayed a small difference between the three treatment groups, when analysed with one-way analysis of variance. *Post hoc* analysis showed that 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 fell in between and did not significantly differ from the other two groups. DLCO on the fourth post-operative day was decreased to 67% ($p < 0.0001$) of pre-operative values. No significant difference between treatment groups was found.

Chest roentgenological changes

No patient showed signs of atelectasis before the operation. On the fourth post-operative day atelectasis was found in 66 of the patients (67%). The incidence and severity of chest roentgenological signs of atelectasis in the left and right lung are presented in Table IV. Atelectasis was present only in the left lung in 43 patients, only in the right lung in five patients and in both lungs in 18 patients on the fourth post-operative day. There were no significant differences among the three groups in the occurrence of atelectasis in the left lung ($p = 0.47$) or in the right lung ($p = 0.73$).

Twenty-eight patients (29%) had signs of elevated left hemidiaphragm; they were nine in the Blow bottle group, seven in the IR-PEP group and 12 in the Deep breathing group. Two patients had signs of elevated right hemidiapragm and they were both in the IR-PEP group.

Pleural effusions were found in 62 patients (63%). In 55 patients the effusion was left sided and in the remaining seven patients it was bilateral. Of the patients with left sided pleural effusion 19 were in the Blow bottle group, 16 in the IR-PEP group and 27 in the Deep breathing group. The incidence of left

Table III. *Pulmonary function data before and on the fourth post-operative day following coronary artery bypass surgery (mean ± SD)*

	Pre-operative				Post-operative			
	Blow bottle	IR-PEP	Deep breathing	p-value*	Blow bottle	IR-PEP	Deep breathing	p-value†
VC (l)	4.0 ± 0.7	4.2 ± 0.8	4.1 ± 0.6	0.41	2.6 ± 0.6	2.6 ± 0.6	2.4 ± 0.5	0.10
IC (l)	3.2 ± 0.6	3.3 ± 0.8	3.2 ± 0.7	0.40	2.1 ± 0.5	2.1 ± 0.5	1.9 ± 0.5	0.61
FEV1 (l)	2.8 ± 0.6	3.0 ± 0.8	2.8 ± 0.5	0.26	1.9 ± 0.4	1.9 ± 0.5	1.8 ± 0.4	0.07
FRC (l)	3.1 ± 0.8	3.3 ± 0.9	3.2 ± 0.6	0.38	2.3 ± 0.5	2.6 ± 0.8	2.3 ± 0.5	0.07
TLC (l)	6.1 ± 1.0	6.6 ± 1.1	6.3 ± 0.8	0.12	4.3 ± 0.7	4.5 ± 1.1	4.0 ± 0.7	0.01
DLCO (ml/min/mmHg)	21.6 ± 5.4	25.1 ± 7.4	25.3 ± 5.2	0.06	14.5 ± 3.2	17.0 ± 5.5	16.3 ± 4.4	0.36
DLCO/VA (ml/min/mmHg/l)	3.7 ± 1.0	3.9 ± 0.8	4.0 ± 0.8	0.42	3.5 ± 0.9	3.9 ± 1.0	4.0 ± 0.9	0.43

* The difference between the means of the treatment groups.
† The difference between the means of the relative decrease in pulmonary function from before the operation.
IR-PEP = inspiratory resistance-positive expiratory pressure; VC = vital capacity; IC = inspiratory capacity; FEV1 = forced expiratory volume in 1 second; FRC = functional residual capacity; TLC = total lung capacity; DLCO = single breath diffusing capacity for carbon monoxide; DLCO/VA = DLCO per unit alveolar volume.

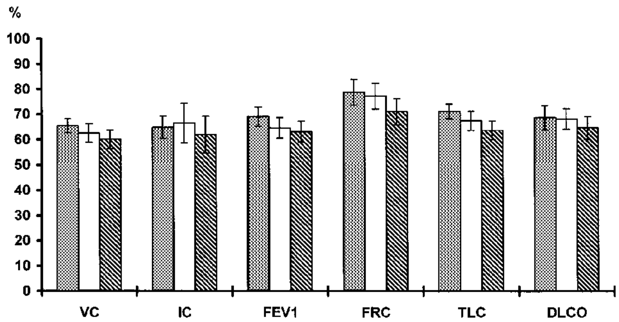

Fig. 1. The pulmonary function values on the fourth post-operative day in percentage of pre-operative values for the three treatment groups. Error lines indicate the 95% confidence interval. IR-PEP = inspiratory resistance-positive expiratory pressure; VC = vital capacity; IC = inspiratory capacity; FEV1 = forced expiratory volume in 1 second; FRC = functional residual capacity; TLC = total lung capacity; DLCO = single-breath carbon monoxide diffusing capacity. ▩ Blow bottle. □ IR-PEP. ▧ Deep breathing.

pleural effusions did not significantly differ between treatment groups. The incidence of right sided pleural effusion was three, two and two, respectively.

DISCUSSION

The pulmonary function after CABG were severely reduced in all treatment groups on the fourth post-operative day, with a mean 60–75% of the pre-operative values. The reduction is similar to what have been shown in several previous studies on the fourth post-operative day after open heart surgery (3, 4, 14). The reasons for the restrictive impairment and atelectasis are multiple and include, besides the effects of anaesthesia (15), intra-operative events such as internal mammary artery harvesting (16), changes caused by mechanical alteration of the thoracic cavity (17), immobilization and pain. The reduction in lung volumes and expiratory flow rates impairs cough and clearance of secretions, and pain may reduce the ability to cough even more. In the present study the scoring of post-operative pain by VAS on the fourth post-operative day was similar in the three treatment groups.

The best technique for lung expansion is claimed to be a maximal inspiration. A study by Rothen et al. (18) showed that during general anaesthesia an inflation to VC was needed to re-expand virtually all atelectatic lung tissue. Unfortunately, after surgery, many patients are unable or unwilling to breathe deeply.

There is some evidence that regular chest physiotherapy significantly decreases the incidence of pulmonary complications after major abdominal and thoracic surgery (19). Mechanical aids to lung expansion in the post-surgical patient have attracted considerable interest in Scandinavia. The blow bottle is a cheap and simple method of producing a positive expiratory pressure. The use of the blow bottle in post-operative care is aimed at increasing the pulmonary volume and facilitating the release of pulmonary secretions, but documentation of efficacy in patients after heart surgery has been scarce. Iverson et al. (9) compared 87 cardiac surgery patients treated with blow bottles, intermittent positive pressure breathing (IPPB) and incentive spirometry. The incidence of pulmonary complications was 30% in the IPPB group, 15% in the spirometry group but only 8% in the Blow bottle group. The result was not statistically significant and the equipment and technique of the blow bottle was not in full detail described. It is therefore difficult to know if our results support these findings.

The IR-PEP system is used to create an active inspiration in addition to PEP. The inspiratory resistance is believed to increase demands on the diaphragm and improve recovery of its function, but this has not been clearly established. In this study the blow bottle was found to be at least as effective as the IR-PEP mask in preventing pulmonary function decrease on the fourth post-operative day.

Airway closure is a normal physiological phenomenon during deep expiration, which may occur already at normal FRC in the elderly. Thus, the reduction in FRC post-operatively will promote airway closure (20) which may eventually lead to resorbtion atelectasis, when breathing exercises are made. It is therefore important to start from a high lung volume and to finish expiration before closing volume is reached.

Improper performance of deep breathing exercise may decrease, rather than increase end-expiratory lung volume if a patient exhales forcefully toward residual volume (21). It is important to halt the expiration at or near FRC so that airway closure is prevented or limited as much as possible.

The optimal frequency and duration of the treatment are important factors to consider. In the present study the patients were encouraged to perform 30 deep breaths once per hour except during the night, and the frequency and duration of the exercises were chosen according to the ordinary routines at the clinic. Deep breathing therapy is suggested to be provided at least every 1–2 hours, but the optimal frequency is not yet known. Jenkins et al. (22) compared three physiotherapy regimes in 110 men undergoing CABG and concluded that the addition of breathing exercises or incentive spirometry to a regimen of early mobilization and coughing confers no extra benefit after uncomplicated CABG. The patients in the two treatment groups were instructed to take at least 10 deep breaths or use the incentive spirometer at least 10 times in each waking

Table IV. *The incidence of chest roentgenological signs of atelectasis in the left/right lung on the fourth post-operative day after coronary artery bypass graft surgery*

	Blow bottle (n = 36)	IR-PEP (n = 30)	Deep breathing (n = 32)
No abnormality	11/28	13/22	13/25
Plate atelectasis	12/4	4/3	8/5
Segmental atelectasis	11/4	12/5	8/2
Lobar atelectasis	2/0	1/0	3/0

IR-PEP = inspiratory resistance-positive expiratory pressure.

hour. Perhaps are 10 deep breaths per hour, or even 30, not enough to give a clinical important improvement.

Atelectasis were present in 67% of the patients on the fourth post-operative day, which is equal to what have been found in earlier studies after CABG (10, 23). The occurrence of atelectasis showed no statistical difference between the groups in the present study. Right-sided abnormalities were equally rare, as was found in a previous study by Jain et al. (23).

Few data are available concerning post-operative diffusion capacity abnormalities in patients after CABG. A decrease in DLCO by 27%, and a decrease in DLCO/VA by 18%, has been reported 2 hours post-operatively in 10 patients undergoing cardiac surgery requiring cardiopulmonary bypass (24). The single-breath test, used in the present study, is the most common method to measure pulmonary diffusing capacity. The transfer of carbon monoxide is a complex phenomenon and there is a large inter-laboratory variability in the results for the measurement of DLCO (25), which necessitates the use of the same equipment pre- and post-operatively. Our results showed a reduction in DLCO to 67% of the pre-operative value on the fourth post-operative day, while corrected for lung volume, DLCO/VA remained almost unchanged. It is therefore possible that the reduction in DLCO could be due solely to the reduction in lung volume.

To avoid errors caused by large variances within experimental groups, we focused on the differences between the pre- and post-operative pulmonary function values of each individual patient. A slow VC and not forced VC, which has been investigated in other studies (4, 22), was chosen to compare the different chest physiotherapy regimes. We considered the slow VC manoeuvre to be more efficient than forced VC in estimating the lung volume, as pain due to the sternal split may hinder forceful expiration.

It is possible that the way chest physiotherapy and deep breathing manoeuvres are performed are of importance for the result. Thus, the deeper the inspiration is, the more likely it is that an atelectasis resolves. Assistance from the physiotherapist is important to help the patients to perform their very best. Patient collaboration and motivation are essential factors in any treatment. Lack of control of the deep breathing exercises renders the techniques a degree of uncertainty that may call for new modalities or at least better control of the execution of the exercise.

CONCLUSION

There were no major differences between the three treatment groups on the fourth post-operative day. The relative decrease in pulmonary function tended to be less marked by chest physiotherapy using the Blow bottle technique than by Deep breathing without any mechanical device and the technique was at least as good as the IR-PEP technique. The Blow bottle is furthermore an inexpensive method that will be well accepted and easily learned by patients, and works as well as more complex techniques. However, a technique that offers even better supervision and the assistance of a deep inspiration with optimal continuance may prevent further lung function deterioration.

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