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The immediate effects of deep breathing exercises on atelectasis and oxygenation after cardiac surgery

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Objective—To investigate the effects of deep breathing performed on the second postoperative day after coronary artery bypass graft surgery.
Design—The immediate effects of 30 deep breaths performed without a mechanical device ($n = 21$), with a blow bottle device ($n = 20$) and with an inspiratory resistance-positive expiratory pressure mask ($n = 20$) were studied. Spiral computed tomography and arterial blood gas analyses were performed immediately before and after the intervention.
Results—Deep breathing caused a significant decrease in atelectatic area from $12.3 \pm 7.3\%$ to $10.2 \pm 6.7\%$ ($p < 0.0001$) of total lung area 1 cm above the diaphragm and from $3.9 \pm 3.5\%$ to $3.3 \pm 3.1\%$ ($p < 0.05$) 5 cm above the diaphragm. No difference between the breathing techniques was found. The aerated lung area increased by 5% ($p < 0.001$). The PaO_2 increased by 0.2 kPa ($p < 0.05$), while $PaCO_2$ was unchanged in the three groups.
Conclusion—A significant decrease of atelectatic area, increase in aerated lung area and a small increase in PaO_2 were found after performance of 30 deep breaths. No difference between the three breathing techniques was found.

Postoperative atelectasis is common in patients after coronary artery bypass graft surgery (CABG) (1). The cause of atelectasis is complex and many factors may contribute, such as general anesthesia, diaphragmatic dysfunction, abdominal distension, chest wall alterations, pleural effusions and pain (2). The postoperative impairment is characterized by a restrictive ventilatory defect, shunt and arterial hypoxemia.

Different chest physiotherapy techniques with a variety of combinations are used to decrease the incidence and severity of pulmonary complications after cardiac surgery (3–8). There is an agreement that early mobilization after surgery is the most important therapy in the prevention and treatment of pulmonary impairment (9–11).

Deep breathing exercises with or without different mechanical devices, for example, positive expiratory pressure (PEP) are used in the postoperative care, with the aim of increasing lung volumes and ease the mobilization of secretions. Inspiratory resistance-positive expiratory pressure (IR-PEP) has been introduced in an attempt to enhance the function of the diaphragm after cardiac surgery (12). The techniques are used widely, but no obvious effect of these methods has been demonstrated in the prevention or treatment of atelectasis (4, 13). Several authors have strongly questioned the benefit of breathing exercises over early mobilization alone (9–11). Most investigators have focused on the prevention of pulmonary impairment, atelectasis and impaired oxygenation. The direct treatment effect of deep breathing on atelectasis and oxygenation has up to this date not been investigated in the cardiac surgery patient and computed tomography (CT) has not been used before in the evaluation of chest physiotherapy after cardiac surgery.

The present study was undertaken to investigate the immediate effects of one session of 30 voluntary deep breaths on atelectasis and oxygenation performed on the second postoperative day after CABG. Deep breathing performed with no mechanical device was compared with two deep breathing techniques assisted with PEP devices.

MATERIALS AND METHODS

Patients

The present study was conducted on 61 CABG patients (12 female, 49 male) at Örebro University Hospital. Another four patients were excluded

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Table I. *Demographic and surgical data*

	Deep breathing ($n = 21$)	Blow bottle ($n = 20$)	IR-PEP ($n = 20$)
Male/female, n	18/3	16/4	15/5
Age, years	66 ± 9	64 ± 8	64 ± 10
BMI, kg/m^2	27 ± 3	28 ± 4	27 ± 4
Never smoked/stopped/smoker, n	8/12/1	8/10/2	5/11/4
Left ventricular ejection fraction, %	55 ± 15	54 ± 16	61 ± 14
Operation time, h	4.1 ± 0.6	4.5 ± 1.0	3.8 ± 0.6
ECC time, min	102 ± 27	118 ± 36	97 ± 26
LIMA graft, n	17	18	16
Postoperative mechanical ventilation, h	6.7 ± 2.7	6.5 ± 4.0	5.0 ± 1.5

Data are presented as mean ($\pm$SD) or number of patients. No significant difference between groups.

BMI = body mass index; ECC = extracorporeal circulation; LIMA = left internal mammary artery; NYHA = New York Heart Association; n = number of patients.

because of impaired oxygenation (one), infirmity (two) and inexact CT scans (one). Patients who had unstable angina, previous cardiac surgery or serious renal dysfunction were not included. Informed consent was obtained from each patient and the study was approved by the Research Ethics Committee in Örebro.

Surgical and postoperative procedure

The surgical approach was through a median sternotomy and CABG was performed with saphenous vein grafts and in most cases the left internal mammary artery. Cold blood cardioplegia and for the most part pericardial cooling with ice was 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 h after surgery. Postoperatively the patients were artificially ventilated and a positive end-expiratory pressure of 5 cmH_2O was used. During anesthesia and after surgery the lungs were ventilated with 50–80% O_2. The patients were extubated when they had resumed normothermia, were hemodynamically stable and able to normoventilate without distress, according to standard procedures at the hospital. All patients received chest physiotherapy as conventionally used at the clinic, with early mobilization, active exercises of the upper limbs and thorax, breathing exercises and coughing techniques. All patients performed postoperative deep breathing exercises according to ordinary routines. Details of chest physiotherapy have been described previously (13).

Study groups

The 61 patients were randomly assigned to one of three study groups on the second postoperative day. The patients in the study groups were similar in terms of demographic and surgical data (Table I). In all three groups the patients performed three sets of 10 deep breaths (with or without mechanical devices) with a 30–60 s pause between each set (7–8 min in total), in the sitting position. The immediate effect of the deep breathing was investigated. The *Deep breathing group* was instructed to inspire as deep as possible through the nose or the mouth and expire normally through the mouth, with no mechanical device. Patients in the *Blow bottle group* also inspired deeply but exhaled through a PEP blow bottle device. A 50 cm plastic tube (1 cm internal diameter) in a bottle containing 10 cm of water, which causes a pressure of 10 cmH_2O during exhalation, was used. In the *Inspiratory resistance-positive expiratory pressure (IR-PEP) group* deep breathing was performed through a positive expiratory pressure/respiratory muscle training set (PEP/RMT; Astra Tech AB, Mölndal, Sweden). The system consists of a face mask and a valve connected to a T-tube where inspiratory and expiratory airflows are separated. The inspiratory and expiratory pressures were -5 and 15 cmH_2O, respectively. All patients in the three groups were instructed, by one physiotherapist (E.W.) to perform slow maximal inspirations, while expiration was ended approximately at functional residual capacity (FRC) to minimize unintentional airway closure and alveolar collapse.

Measurements

The measurements were conducted immediately before and after the deep breathing session in all three groups. One radiologist and one radiographer who were blinded to study group assignments made all measurements. Atelectasis and aeration of the lungs were assessed by CT (Tomoscan AV; Philips, the Netherlands) (14–16). The patient lay in the supine position with arms raised above the head and the examinations were made during apnea at FRC. First a frontal scout view covering the chest was obtained for positioning. The scan time was 9 s for a 12 cm volume scan at 225 mA and 120 kV. Slice thickness was 1.0 cm and a matrix of 512×512 elements was used. The total estimated effective dose was 1.5 mSv. Three of the transverse scans were used for subsequent analysis. A basal scan was positioned 1 cm, a middle scan 5 cm and an apical scan 9 cm above the top of the diaphragm. A 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 computer of the CT identified the border between inflated lung tissue and atelectasis. Aerated lung area was defined as volume elements (voxels) with attenuation values between -100 and -1000 Hounsfield units (HU) and atelectasis was defined as values between 100 and -100 HU (15, 17). The distance from the most cephalad point of the diaphragm and the carina was measured before and after intervention.

An arterial blood sample was drawn after each CT examination for blood-gas analysis (Radiometer ABL 505; Inter Bio-Lab, Orlando, FL). The patients had been transported to the Department of Radiology in a wheelchair and had been without supplementary oxygen for at least 15 min.

Statistical analysis

All data were collected and analyzed in a statistical computer program (StatView; Abacus Concepts, Inc., Berkeley, CA) and presented as mean values $\pm$ SD. The baseline data for the groups were compared by one-way analysis of variance (ANOVA) or χ^2-test. Repeated measurement ANOVA was used for comparisons before and after intervention and between the three treatment groups. All p-values refer to two-sided tests and statistical significance was accepted at the 0.05 level.

Table II. *Atelectasis before and after deep breathing intervention*

	Before intervention	After intervention	p-Value
Upper	$1.4 \pm 2.2\%$ (2.0 ± 3.0 cm^2)	$1.3 \pm 1.9\%$ (1.8 ± 2.6 cm^2)	0.23
Middle	$3.9 \pm 3.5\%$ (6.9 ± 5.7 cm^2)	$3.3 \pm 3.1\%$ (6.0 ± 5.1 cm^2)	<0.05
Base	$12.3 \pm 7.3\%$ (23.1 ± 13.1 cm^2)	$10.2 \pm 6.7\%$ (19.4 ± 12.3 cm^2)	<0.0001

Mean areas of bilateral atelectasis ($\pm$SD) in percentage of the total lung area and in absolute values.

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 performed before and after a deep breathing intervention ($n = 61$).

p-Values refer to the difference before and after intervention.

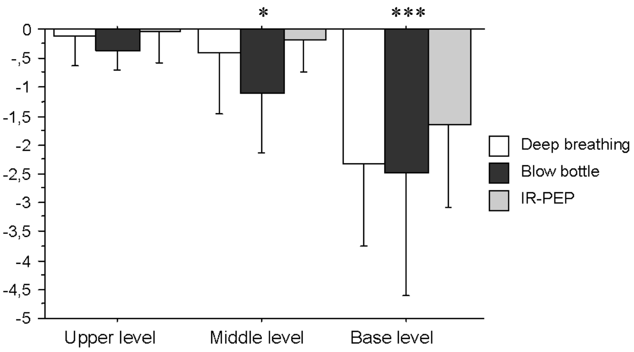

Fig. 1. Change of atelectatic area between measurements performed before and after deep breathing exercises in the three groups. The mean is atelectasis in percentage of the lung area at 1 cm above the top of the diaphragm (base level), 5 cm above (middle level) and 9 cm above the diaphragm (upper level). Data are expressed as means and 95% CIs. Statistical comparison before vs after intervention ($n = 61$). $^{*}p < 0.05$; $^{***}p < 0.001$. CI = confidence interval; IR-PEP = inspiratory resistance-positive expiratory pressure.

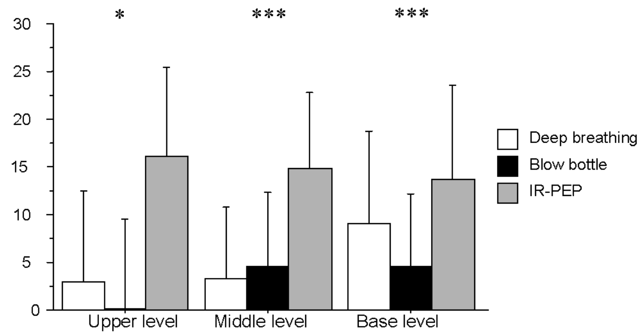

Fig. 2. Change of bilateral lung area (cm^2) between measurements performed before and after deep breathing exercises in the three groups ($n = 61$) at 1 cm above the top of the diaphragm (base level), 5 cm above (middle level) and 9 cm above the diaphragm (upper level). Data are expressed as means and 95% CIs. Statistical comparison before vs after intervention ($n = 61$). $^{*}p < 0.05$; $^{***}p < 0.001$. CI = confidence interval; IR-PEP = inspiratory resistance-positive expiratory pressure.

RESULTS

Atelectasis

Two days after CABG all patients had areas of atelectasis in one or both lungs (right sided in all but two patients, and left sided in all except one). 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. At the middle level it was 2.9 ± 2.5 and $5.6 \pm 7.6\%$ and at the apical level 1.1 ± 1.8 and $1.8 \pm 3.4\%$ in the respective lung. There was no significant difference between the groups in atelectatic area or aerated lung area before intervention.

After a series of three sets of 10 deep breaths a significant decrease in atelectatic area (both lungs, all three levels) was present in all three groups taken together from 32.0 ± 18.4 cm^2 ($6.2 \pm 3.9\%$ of total lung area) to 27.2 ± 16.9 cm^2 ($5.2 \pm 3.5\%$) ($p < 0.001$), with no significant difference between the patients in the deep breathing, blow bottle or IR-PEP group. Mean values for the study groups at the three CT levels are shown in Table II. The decrease was greatest at the basal level as shown in Fig. 1.

Aerated lung area

The total aerated lung area (both lungs, all three levels) increased significantly after intervention in the groups from 514 ± 119 to 537 ± 124 cm^2 ($p < 0.001$), with no significant difference between the three groups. The changes in aerated lung area were significant at all three CT levels as shown in Fig. 2. The distance between the diaphragm and the carina was unchanged after the deep breathing intervention, 7.4 ± 1.6 cm in the right and 8.8 ± 1.8 cm in the left lung.

Arterial blood gases

The patients showed moderate hypoxemia on the second postoperative day. The oxygenation showed a small improvement after deep breathing, while $PaCO_2$ was unchanged (Table III). There was no significant difference between the groups. A weak inverse correlation between the PaO_2 and atelectasis was found both before and after the intervention (Fig. 3).

DISCUSSION

On the second postoperative day after CABG all patients had atelectasis visible on CT. A large amount

Table III. *Arterial blood gases before and after deep breathing intervention*

	Before intervention			After intervention			
	Deep breathing	Blow bottle	IR-PEP	Deep breathing	Blow bottle	IR-PEP	*p*-Value
PaO_2 (kPa)	7.5 ± 0.8	7.8 ± 1.1	7.8 ± 0.8	7.6 ± 0.7	8.2 ± 1.6	8.0 ± 1.0	0.02
SaO_2 (%)	90.4 ± 2.5	90.6 ± 4.0	91.3 ± 2.0	90.5 ± 2.4	91.4 ± 4.4	91.7 ± 2.4	0.004
$PaCO_2$ (kPa)	5.1 ± 0.5	5.2 ± 0.6	5.1 ± 0.6	5.1 ± 0.5	5.2 ± 0.7	5.1 ± 0.6	0.26

Data are presented as mean ($\pm$SD). The measurements were performed before and after a deep breathing intervention ($n = 61$).
PaO_2 = arterial oxygen tension; SaO_2 = arterial oxygen saturation; $PaCO_2$ = arterial carbon dioxide tension.
p-Values refer to repeated measures ANOVA for the difference before and after intervention.
IR-PEP = inspiratory resistance-positive expiratory pressure.

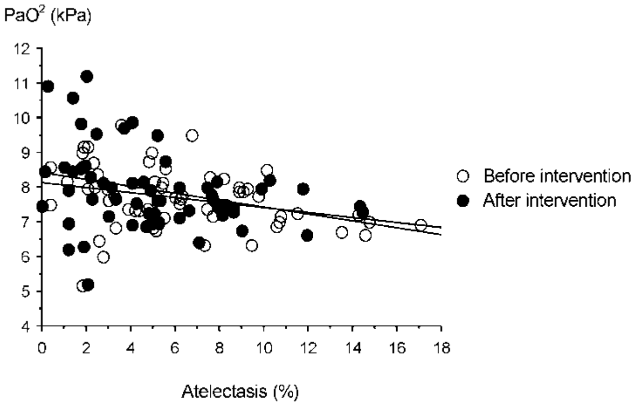

Fig. 3. Relationship between oxygenation and atelectasis. The *x*-axis shows atelectasis (total; bilateral, three levels) in percentage of the lung area and the *y*-axis shows the corresponding PaO_2 measured at the same time for each patient ($n = 61$) before ($r = -0.31$, $r^2 = 0.10$, $p < 0.05$) and after intervention ($r = -0.30$, $r^2 = 0.09$, $p < 0.05$). IR-PEP = inspiratory resistance-positive expiratory pressure.

of atelectasis in the basal parts was found. This is similar with previous findings immediately after and on the first postoperative day after cardiac surgery (1, 18). Thus, no or only minor resolution of the atelectasis seems to have occurred during the first two postoperative days. Similar with previous findings of lung collapse still present 5 days after abdominal surgery (19), a slow resolution of the much larger atelectasis seems to take place even in the postoperative period after CABG. It should also be emphasized that the atelectasis consists of pure lung tissue whereas the non-collapsed region consists mainly of air with, on average, 30–40% tissue. Thus, the amount of collapsed tissue is greater than the atelectatic area may suggest, and in this study it will easily exceed 20–25% of the total lung (1). Near the diaphragm, collapse may involve as much as half or more of the lung tissue.

The present results demonstrated a significant reduction of the atelectatic area and improvement in oxygenation after a series of three sets of 10 deep breaths on the second postoperative day. The relative decrease of atelectasis in the lungs was 16% at the basal level, 13% at the middle level and a non-significant decrease of 10% at the upper CT level after the intervention. The improvement in PaO_2 was minimal and seemingly of little clinical importance. Although modest, the effect on atelectasis and PaO_2 was achieved by just one series of breathing exercises. In clinical practice, the exercises are repeated every hour during daytime and for several days. It is not unlikely that repeated exercises will have a more substantial effect, but this requires further study.

No significant differences were found between patients performing the deep breathing with a blow bottle PEP device, an IR-PEP mask for both inspiratory and expiratory resistance or in patients who were without any mechanical device. No previous investigation has shown that voluntary deep breathing has an effect on postoperative atelectasis.

Moreover, the aerated lung area increased after deep breathing at all three scan levels. The increase was largest in the IR-PEP group, but this was not significantly different from the other two groups. The recruitment of collapsed lung tissue should result in increased lung volume and, most likely, in increased lung area. This was also seen. However, the distance from carina to diaphragm did not significantly differ by the measurements before and after the intervention. The breathing exercise may also have increased the inspiratory muscle tone, in particular in the IR-PEP group that had to inspire against a resistance.

Although chest physiotherapy with breathing exercises are used frequently in the postoperative care after cardiac surgery, studies of the effect on postoperative pulmonary complications have reported little or no benefit. Deep breathing in the prevention of pulmonary complications after CABG has accordingly been questioned (9–11, 20). However, the recording of body temperature, breath sounds and subjective symptoms, as is commonly done in postoperative studies, may not be sensitive enough to detect small or moderate pulmonary changes. Even with a chest x-ray small pulmonary changes may pass unnoticed. This could be one explanation why earlier studies have not been able to demonstrate an effect of breathing exercises.

CT makes it possible to detect atelectasis that cannot be seen on a conventional chest x-ray (14) and enables a more accurate quantification of the atelectasis. It should also be added that large atelectasis remained after the breathing exercise. More efficient recruitment of collapsed lung may improve the protective effect of physiotherapy.

A number of mechanical devices are used in the postoperative care to improve pulmonary function. To expire against a resistance, for example “pursed lips breathing”, is frequently used by patients to ease breathlessness. The expiratory resistance is thought to slow down expiration and to increase the lung volume. The PEP technique is used postoperatively with the aim of increasing lung volumes and ease the mobilization of secretions. The IR-PEP has been introduced in an attempt to enhance the function of the diaphragm after cardiac surgery (12). In this investigation deep breathing performed without a mechanical device was found to be as effective as with a blow bottle or an IR-PEP mask to reduce atelectasis and improve oxygenation. Nevertheless a mechanical device could possibly help the patient remember to perform breathing exercises, and patients may be of the opinion that the device is helpful and motivating.

In conclusion, this study showed extensive atelectasis, primarily in the basal parts of the lungs, on the second day after CABG. After one treatment session of 30 voluntary deep breaths a significant reduction of atelectatic lung area and a small improvement in oxygenation was found. Deep breathing without any mechanical device was as effective as deep breathing with a mechanical PEP device. Our data suggest that voluntary deep breathing exercises could be of benefit in the treatment of postoperative atelectasis after CABG.

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