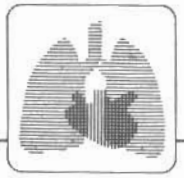

clinical investigations

Effects of Periodic Positive Airway Pressure by Mask on Postoperative Pulmonary Function*

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Postoperative pulmonary complications, alveolar-arteriolar oxygen difference ([A-a]O_2-diff), peak expiratory flow (PEF) and forced vital capacity (FVC) were compared in patients using continuous positive airway pressure (CPAP) and positive expiratory pressure (PEP) administered by face mask against those of a control group using a deep-breathing device (Triflo). Forty-three consecutive, randomized patients undergoing elective upper abdominal surgery were included. CPAP, PEP and Triflo were administered for 30 consecutive breaths in every waking hour for three days postoperatively. The (A-a)O_2-difference increased equally and significantly in the three groups after surgery, reaching a maximum on the first postoperative day. After this day, however, (A-a)O_2-diff decreased in the CPAP and PEP groups, being significantly lower in the PEP group compared to the control group, two days postoperatively ($p<0.05$) and significantly lower in both the PEP and CPAP groups three days postoperatively ($p<0.001$ and $p<0.05$, respectively.) PEF did not differ significantly between the groups before or after surgery, while FVC was significantly higher in the PEP and CPAP groups, compared to control, on the third postoperative day ($p<0.05$). Atelectatic consolidation was observed in six of 15 patients in the control group three days postoperatively, the incidence being significantly lower in both the PEP group (0 of 15, $p<0.001$) and the CPAP group (one of 13, $p<0.05$). We concluded that periodic face mask administration of CPAP and PEP are superior to deep breathing exercises with respect to gas exchange, preservation of lung volumes and development of atelectasis after upper abdominal surgery. We also conclude that the simple and commercially available PEP mask is as effective as the more complicated CPAP system.

There is controversy in the literature on how to prevent postoperative pulmonary complications in patients undergoing abdominal surgery. In addition to chest physiotherapy, with its proven beneficial effects,[1,2] various mechanical devices have been used to improve postoperative pulmonary function. Anderson et al,[3] in a non-randomized study, showed that treatment with intermittent positive pressure breathing (IPPB) three to four times daily after several forms of surgery significantly decreased the incidence of clinical and roentgenographic signs of pulmonary complications compared to untreated patients. This has not been confirmed in other studies, randomized[4] as well as nonrandomized,[5,6] in patients undergoing upper abdominal surgery. Moreover, in two recent controlled randomized studies, no positive effects of IPPB with regard to roentgenographic changes,[7,8] hypoxemia[8] and lung volumes[8] after upper[8] as well as lower abdominal surgery[7] were observed, compared to no treatment[7] or to chest physiotherapy without IPPB.[8] In one of the studies, vital capacity was even significantly depressed in the IPPB group.[8]

In randomized studies, deep breathing exercises with or without an incentive spirometric device (IS) have been reported to be more effective than no treatment,[1] conventional chest physiotherapy[9,10] and IPPB[11,12] as shown by abnormalities on chest x-ray film[1,9-12] and clinical signs of pulmonary complications after abdominal surgery.[9-11] However, Dohi and Gold[12] found that the effect of deep breathing exercise did not differ spirometrically from IPPB, and Jung and coworkers[13] showed that the incidence of postoperative pulmonary changes on chest x-ray film and clinical signs of pulmonary complications were the same, comparing IPPB, IS and resistance breathing ("blow gloves"). Celli and coworkers[7] recently showed in a randomized study that IPPB, IS and deep breathing exercises were equally effective in preventing postoperative clinical signs of pulmonary complications, compared to the untreated group.

Thus, based on the above, the value of IPPB in postoperative patients can be questioned,[14-17] espe-

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cially since an alarming number of complications associated with its use have been described, as reviewed by Gold.[17] The value of IS on preventing postoperative pulmonary complications is better documented, as outlined by Bartlett,[18] but its value has also been questioned by Bellman and Mittman.[19]

Andersen and coworkers[20] demonstrated, in a randomized study, that periodic continuous positive airway pressure (CPAP) adminstered by a face mask, in addition to chest physiotherapy, was highly effective in the treatment of surgical patients with atelectasis when compared to chest physiotherapy without CPAP. Stock et al[21] compared the effect on functional residual capacity (FRC) after upper abdominal surgery of intermittent CPAP by face mask for three postoperative days with IS and deep breathing exercises. A more rapid increase in FRC occurred in patients who received CPAP. Roentgenographic evidence of atelectasis did not differ significantly between the groups, and arterial Po_2 was not measured postoperatively.

The aim of this study was to analyze the prophylactic effect of periodic administration of CPAP by mask on postoperative radiologic complications, hypoxemia and vital capacity after upper abdominal surgery. Secondly, we wanted to test the prophylactic effect of intermittent administration of positive expiratory pressure (PEP) using a simple, commercially available device (PEP-mask, Astra-Meditec) on postoperative pulmonary function.

Materials and Methods

Fifty consecutive patients admitted for elective upper abdominal surgery participated in this study. The protocol was approved by the Ethical Committee for Human Studies of the University of Gothenburg and all patients gave their consent. Preoperatively, forced vital capacity (FVC) and peak expiratory flow (PEF) were determined using a wedge spirometer and a peak flow meter. In order to match the groups, patients were stratified according to pulmonary function, age (more or less than 60 yrs), body weight, smoking habits and sex. A preoperative value of FVC and/or PEF <30 percent of the predicted value was considered abnormal. Body weight more than 30 percent above normal value (according to height and age) was considered overweight. Patients who had not smoked for one year before surgery were defined as nonsmokers. After stratification, the patients were randomized to one of three groups: control group, CPAP group and PEP group (described below). The patients received a general balanced anesthesia with tracheal intubation and all patients underwent laparotomy through an upper abdominal vertical incision. In all patients, postoperative pain was controlled with epidural morphine analgesia for at least two days postoperatively using a lumbar epidural catheter (2 to 4 mg morphine in 8 to 10 ml saline solution, two to three times a day). Spirometry was performed preoperatively and on the third day postoperatively. Chest x-ray examinations were made preoperatively and on the first and third postoperative day. The radiologist who read all radiographs was unaware of the kind of device used for treatment. The registered chest x-ray findings were classified as normal, minor abnormal (plate-like atelectasis) or major abnormal findings (atelectatic consolidation with an air bronchogram). Arterial blood gas samples were taken preoperatively within one hour after surgery, six hours after surgery and in the evening of the first, second and third postoperative days. Alveolar-arteriolar oxygen difference ([A-a] O_2-diff) was calculated and blood gas samples were taken after 20 min breathing oxygen with $FIo_2 = 0.5$.

Treatment Protocol

The patients received basic postoperative chest physiotherapy, including deep breathing exercises, forced expiration maneuvers and active mobilization for 30 to 40 min twice daily on the day of surgery and on the three following days. These procedures were performed by trained chest physiotherapists.

The control group carried out deep breathing exercises taking 30 sustained maximal inspirations every waking hour with the aid of a deep breathing exerciser (Triflo, Chesebrough-Pond's Inc). The CPAP group received periodic continuous positive airway pressure by face mask for 30 breaths every waking hour with a positive end-expiratory pressure between 10 to 15 cm H_2O. The CPAP system employed was described by Andersen and coworkers.[20] The PEP group intermittently received positive expiratory pressure (PEP), also for 30 breaths every waking hour, using the device shown in Figure 1. This consists of a face mask and a one-way valve, upon which expiratory resistances were mounted with internal diameters ranging from 2.5 to 3.5 mm. A manometer was also inserted between the valve and the resistance to measure the actual value of PEP. The patients were trained preoperatively with individually chosen expiratory resistances to create a peak PEP of 10 to 15 cm H_2O, which was checked postoperatively. With this device, peak PEP was rapidly reached at the start of expiration and was held almost constant throughout the expiratory phase. The patients received instruction and exercised with the assigned device on the day before surgery.

Treatment was started one hour after surgery and was continued for three postoperative days. Each hourly treatment was noted on a special record sheet by a nurse or the patient himself.

Exclusion Criteria

Patients were excluded from the study if they had postoperative clinical and radiographic signs of pulmonary congestion resulting from overhydration or left ventricular failure peri- or postoperatively. Patients were also excluded if they did not wish to continue in the study or had treatment complications.

Data Analysis

Values are reported as mean values ± SEM. The differences between the groups were analyzed using the nonpaired Student's *t*-test and the chi-square test, and within the groups using a paired

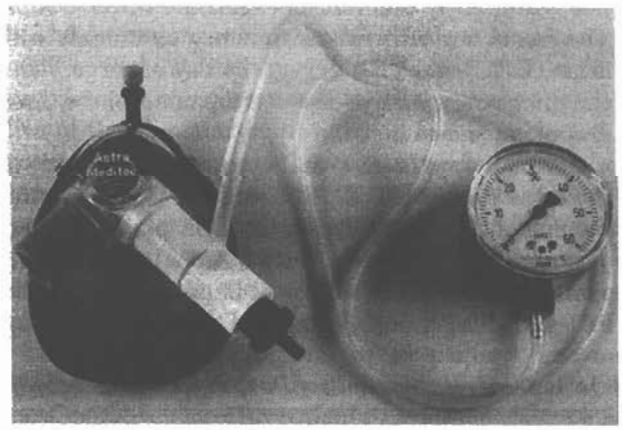

Figure 1. Astra-Meditec's so called PEP mask which consists of a face mask coupled to a one-way valve, upon which expiratory (as well as inspiratory) resistances can be mounted with different internal diameters. A manometer also may be inserted between the valve and the resistance to measure the value of positive expiratory pressure (PEP).

Table 1—*Characteristics of Patients*

	Control	CPAP	PEP
Total	15	13	15
Sex (M/F)	6/9	7/6	8/7
Age (years)	51.7±4.7	52.5±3.5	56.9±3.8
>60 years of age	7	4	7
Body weight (kg)	90.4±7.4	93.4±6.3	89.0±7.0
Obese	6	6	4
Smoking history	7	6	8
Duration of anesthesia, h	4.6±0.4	3.9±0.2	4.3±0.3
(A-a)O_2-diff. preop	12.4±1.0	14.6±1.3	13.8±0.9
FVC, l preop	3.4±0.2	3.9±0.3	3.5±0.2
PEF l/min preop	476±26	513±29	481±23

Student's *t*-test. Probability values less than 0.05 were considered significant.

Results

Seven of the 50 consecutive patients entering the study were excluded. One patient in the control group and three in the CPAP group were excluded because of pulmonary congestion. In the PEP group, one patient was excluded due to pulmonary edema and another due to severe postoperative headache resulting from puncture of the dura mater while inserting the epidural catheter. The third patient discontinued because of severe nausea and postoperative gastric tube irritation.

The characteristics of the remaining 43 patients are given in Table 1. There were no significant differences between the three groups according to sex distribution, age, number of patients more than 60 years of age, mean body weight, number of obese patients, smokers, and patients with abnormal PEF and/or FVC levels preoperatively. In the CPAP group, only four patients aged more than 60 years were included since two of the three patients excluded for pulmonary congestion in this group were older than 60 years. The preoperative values of (A-a)O_2-diff, PEF and FVC were not significantly different between the three groups. The frequency of hourly respiratory treatments with Triflo, CPAP and PEP during the day of surgery and the three postoperative days was the same for the three groups, as shown in Table 2.

After surgery, (A-a)O_2-diff increased significantly in the three groups (Fig 2), reaching a maximum in the evening of the day of surgery (control) and on the first postoperative day (CPAP, PEP). After the first postoperative day, gas exchange was improved in both the PEP and CPAP groups, compared to the control group

Table 2—*Mean Frequency of Daily Respiratory Therapy*

	Control (Triflo)	CPAP	PEP
Day of surgery	5.3±0.5	5.6±0.4	5.3±0.4
First postop day	11.4±0.6	10.8±0.4	11.8±0.5
Second postop day	11.0±0.7	10.4±0.6	11.7±0.6
Third postop day	8.6±0.9	7.0±0.8	9.0±0.8

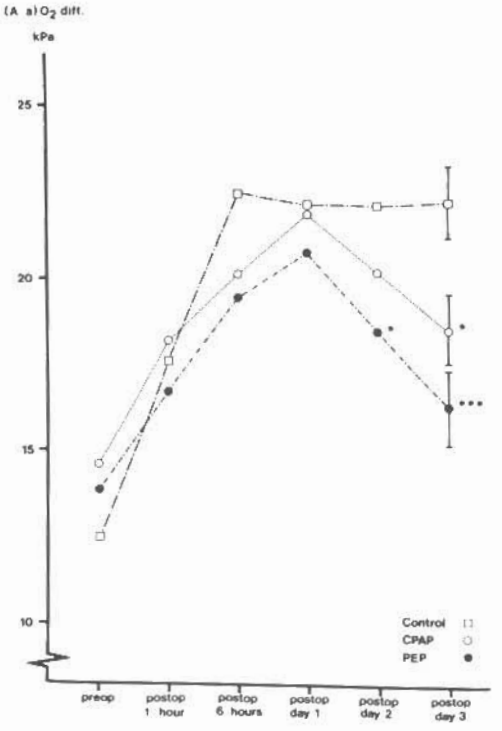

FIGURE 2. The pre- and postoperative values of (A-a) O_2-difference for the control, CPAP and PEP groups. The (A-a) O_2-diff increased significantly after surgery in all groups. After the first postoperative day, gas exchange improved gradually in the CPAP and PEP groups compared to the control group. Bars are omitted for clarity except at the third postoperative day. Significance levels are shown as *$p<0.05$, ***$p<0.001$, in comparing PEP and CPAP with control. There were no significant differences between PEP and CPAP at any of the postoperative days.

where no decrease of the (A-a)O_2-diff was apparent. On the second postoperative day, (A-a)O_2-diff was significantly lower in the PEP group ($p<0.05$) but not in the CPAP group, as compared to the control group. On the third postoperative day, (A-a)O_2-diff was significantly lower in both the PEP group ($p<0.001$) and the CPAP group ($p<0.05$). There were no statistically significant postoperative differences between the PEP and CPAP groups. The actual PaO_2 values while breathing 50 percent oxygen are shown in Figure 3. On the second postoperative day, PaO_2 was significantly higher in the PEP group ($p<0.05$) but not in the CPAP groups, as compared to control patients. On the third postoperative day, PaO_2 was significantly higher in both the PEP group ($p<0.01$) and the CPAP group ($p<0.05$), as compared to control, while there was no significant difference between the PEP and CPAP groups postoperatively.

PEF was recorded preoperatively and on the third postoperative day (Fig 4), and was decreased significantly ($p<0.001$) in all groups. There were no differences between the groups preoperatively or postoperatively. FVC was also recorded preoperatively and on the third postoperative day (Fig 5). As expected, FVC decreased significantly for the control group

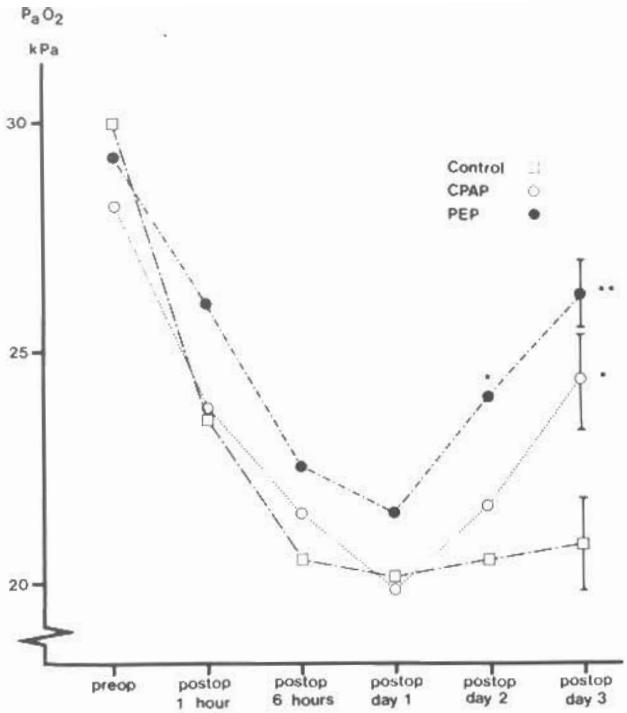

FIGURE 3. The pre- and postoperative values of arterial P_{O_2} for the control, CPAP and PEP groups. On the second postoperative day, PaO_2 was significantly higher in PEP group, compared to control patients. On the third postoperative day, PaO_2 was significantly higher in both PEP and CPAP groups compared to control. There were no significant differences between PEP and CPAP at any of the postoperative days.

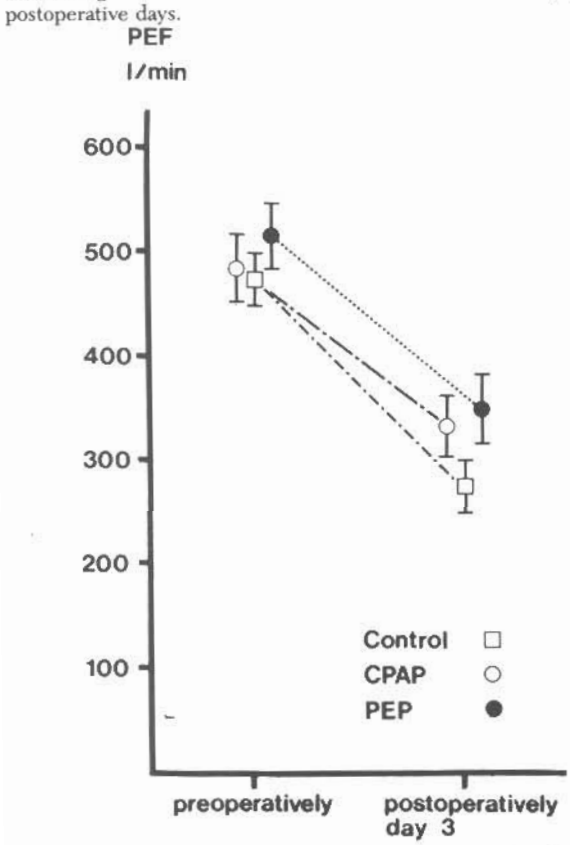

FIGURE 4. Peak expiratory flow (PEF) decreased significantly in all groups after surgery. There were no significant differences between the groups either preoperatively or on the third postoperative day.

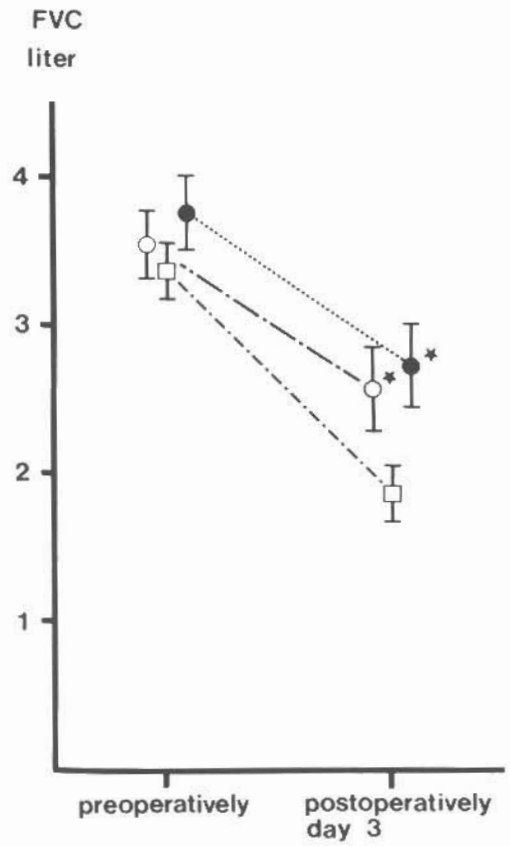

FIGURE 5. Forced vital capacity (FVC) decreased significantly in all groups. On the third postoperative day, FVC was significantly higher in both the CPAP and the PEP group, compared to the control group. *$p<0.05$, comparing PEP and CPAP with control. There was no significant difference between PEP and CPAP groups on the third postoperative day.

($p<0.001$), CPAP group ($p<0.01$) and the PEP group ($p<0.01$). On the third postoperative day, FVC was significantly higher in both the CPAP and the PEP groups, as compared to control ($p<0.05$), while there was no significant difference between the two treatment groups.

The development of postoperative chest x-ray abnormalities is shown in Figure 6. All patients had normal preoperative chest x-ray results. In the control group, five of the 15 patients (33 percent) had an atelectatic consolidation on the first postoperative day; this figure increasing to six of 15 on the third postoperative day (40 percent). In the CPAP group, two of 13 patients (15 percent) had an atelectatic consolidation. The corresponding value on the third post-operative day was one of 13 (8 percent).

In the PEP group, one of 15 patients had an atelectatic consolidation (7 percent) on the first postoperative day. This patient had normal chest x-ray results on the third postoperative day. Thus, no patient had an atelectatic consolidation in the PEP group on the third postoperative day. In the control group, there was no radiologic improvement in any patient, but four patients with normal chest x-ray results on the first

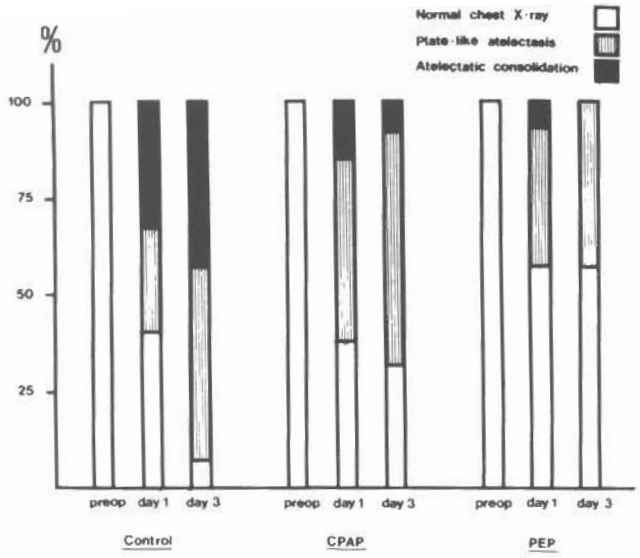

FIGURE 6. Shows the development of postoperative chest x-ray abnormalities for the three groups. Preoperatively, all patients had normal chest X-ray films. The incidence of atelectatic consolidation on the third postoperative day was significantly lower in both the PEP ($p<0.001$) and the CPAP groups ($p<0.05$), compared to the control group (0, 8 and 40 percent respectively).

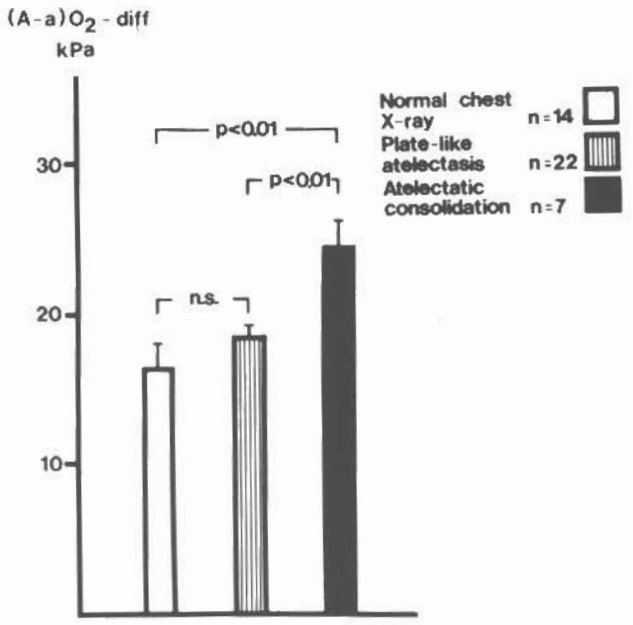

FIGURE 7. The (A-a) O_2-diff was significantly higher in the group with atelectatic consolidations compared to the group with plate-like atelectasis ($p<0.001$) and the group with normal chest x-ray film ($p<0.01$).

postoperative day deteriorated and developed plate-like atelectasis ($n=3$) and an atelectatic consolidation ($n=1$) on the third postoperative day. In the CPAP group, one patient improved from the first to the third day (atelectatic consolidation to plate-like atelectasis) and one deteriorated (normal to plate-like atelectasis). Finally, in the PEP group, one patient improved from atelectatic consolidation on the first day to normal chest x-ray results on the third postoperative day, while another patient deteriorated from normal chest x-ray results to plate-like atelectasis on the third day. In all other patients, the registered chest x-ray findings were unchanged from the first to the third day. The incidence of atelectatic consolidation was significantly lower in both the CPAP ($p<0.05$) and PEP ($p<0.01$) groups on the third postoperative day, while statistical significance was not achieved on the first postoperative day.

Thus, of the 43 patients included in this study, seven had major abnormal chest x-ray findings with atelectatic consolidations, 22 had minor abnormalities with plate-like atelectasis and 14 had normal chest x-ray results on the third postoperative day. The (A-a) O_2-diff was significantly higher in the group of patients with atelectatic consolidations compared to both the group with plate-like atelectasis ($p<0.001$) and the group with normal chest x-ray results ($p<0.01$). The latter two groups did not differ significantly (Fig 7). FVC was significantly higher in the group of patients with normal chest x-ray results as compared to both the group with atelectatic consolidations ($p<0.05$) and the group with plate-like atelectasis ($p<0.05$). The latter two groups did not differ significantly (Fig 8).

DISCUSSION

Controversy in the literature concerning beneficial prophylactic effects of mechanical devices on postoper-

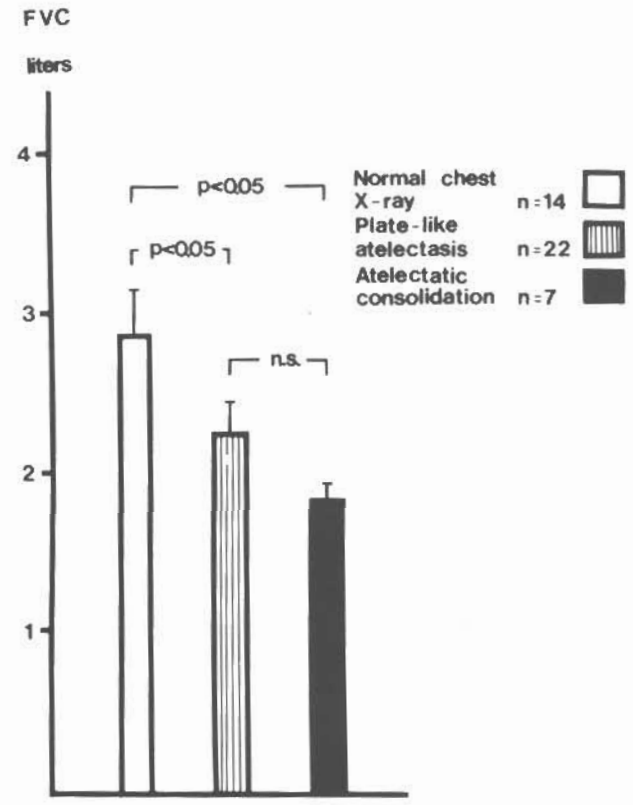

FIGURE 8. Forced vital capacity was significantly higher in the group with normal chest x-ray film compared to the group with plate-like atelectasis ($p<0.05$) and the group with atelectatic consolidations ($p<0.05$).

ative pulmonary function is probably due to the heterogeneous nature of the studied treatment groups and the tremendous variation in how treatment is delivered to patients. It is well known that the incidence of postoperative pulmonary complications varies considerably depending on the types of surgery and abdominal incision.[22-28] Despite this, treatment groups consist of patients subjected to various forms of surgery (abdominal, orthopedic, thoracic, etc[2,3]), as well as of patients with both upper and lower abdominal incisions.[7,9,11-13] Studies on patients undergoing upper abdominal surgery include laparatomized patients with both subcostal and vertical incisions.[4-6] No efforts have been made to match groups before randomization, according to the known risk factors of high age, obesity, poor preoperative pulmonary function and smoking habits.[26,29] It is also striking that the very important parameter of pulmonary function, arterial Po_2, has been measured and followed postoperatively in only one report. Moreover, lung volumes have been recorded spirometrically pre- and postoperatively in only four studies.[5,8,12,21] Thus, it cannot be deduced with any certainty from earlier studies that patients with radiologic (atelectasis) or "clinical signs" (cough, fever, phlegm, dyspnea, etc) of pulmonary complications also developed hypoxemia or alveolar collapse, as measured by vital or functional residual capacity.

Our aim, therefore, was to analyze in a prospectively randomized study the effects of periodic mask CPAP, PEP and deep breathing exercises. Consecutive patients undergoing upper abdominal surgery through a vertical incision were included and were stratified before randomization according to known risk factors. All patients were subjected to the same regimen of postoperative pain management. The degree of patient compliance with the three different modes of treatment did not vary between the groups (Table 2).

The reasons why our so-called control group was an "active control" with a generally established prophylactic treatment were twofold. First, it could be argued that if periodic treatment with CPAP or PEP (ten to 12 times a day) was superior to basic chest physiotherapy (two times a day), this effect could be due simply to a more frequent unspecific "lung expansion training" and not necessarily to a specific effect of the periodic application of continuous or expiratory positive airway pressure. This argument can be applied to the work by Andersen et al,[20] where conventional chest physiotherapy plus periodic CPAP was more effective than conventional chest physiotherapy alone in the treatment of postoperative atelectasis. Second, we wondered if basic chest physiotherapy plus periodic CPAP or PEP by face mask for 30 breaths ten times a day was significantly better than treatment with basic chest physiotherapy plus deep breathing exercises with 30 maximal inspirations ten times a day. Currently, frequent deep breathing exercises are the best documented, if not most convincing, propylactic treatment and also the one most commonly used. A national survey found that deep breathing exercises with an incentive spirometric device were used in 95 percent of hospitals for the prevention and treatment of postoperative atelectasis, compared to 30 to 50 percent using IPPB.[30] Whether deep breathing exercises are carried out with a Triflo deep breathing exerciser, a Bartlett-Edwards or a Spirocare incentive spirometer or no device at all is probably of minor importance. Lederer et al[3] compared the use of these three deep breathing devices in patients undergoing upper abdominal surgery. All patients were instructed to take as deep an inspiration as possible and to hold the inspiration for two to three seconds. They were also advised to repeat this maneuver ten times per hour, while awake, for five postoperative days. There were no statistically significant differences among the three groups with respect to postoperative mean values of FVC, FEV_1 or PEF, changes in heart rate or breathing frequency, the incidence of postoperative atelectasis or pneumonia, and the mean length of postoperative stay. They concluded that all three devices were equally effective and that the Triflo device had a greater degree of acceptability. Celli et al[7] found that incentive spirometry (IS) and deep breathing exercises without a device (DBE) were equally effective in preventing pulmonary complications after upper and lower abdominal surgery. Stock and coworkers[21] demonstrated that the use of IS with documented maximal volume inhalations was not superior to DBE in preventing postoperative pulmonary complications after upper abdominal surgery. Mean values for FVC, FRC and FEV_1 were not significantly different between the two groups. The incidence of atelectasis on the third postoperative day was approximately 40 percent for both the IS- and the DBE-group. In the present study, the incidence of atelectasis on the third postoperative day was also 40 percent in the control group using the Triflo deep breathing device, although care must be taken in comparing groups from different studies.

Those patients who developed major pulmonary roentgenographic complications also developed impaired pulmonary gas exchange and had a lower FVC, compared to those with normal chest x-ray results postoperatively (Fig 7, 8). These findings, although not surprising, are poorly documented;[8] however, since the vast majority of reports have radiologically defined pulmonary complications without measuring PaO_2 and/or lung volumes. Our definition of major chest x-ray abnormalities (described in methods) is therefore of probable clinical significance, as the patients with atelectatic consolidations had a significantly higher (A-a) O_2-diff and significantly lower FVC, as compared to the groups with plate-like atelectasis and normal

chest x-ray films, respectively.

Anderes et al[32] showed that venous admixture was significantly lower postoperatively, compared to control values, if patients were ventilated with PEEP during operation and were spontaneously breathing with CPAP 5 cm H_2O for three postoperative hours before extubation. However, Carlsson et al[33] and Lotz et al[34] could not prevent hypoxemia or reduced vital capacity by treating patients for two[34] or four[33] hours postoperatively with CPAP by a face mask. Andersen et al[35] studied the propylactic effect of periodic CPAP by face mask on patients operated upon in the renal angle and found no difference compared to the control group with respect to development of atelectasis. However, in their report, treatment was interrupted after the first postoperative day. One can thus conclude from our study, together with the above-mentioned, that postoperative treatment with CPAP by face mask must continue for two to three days after surgery before beneficial effects on pulmonary function can be detected. This conclusion is also supported by the results by Stock et al.[21] They found that FRC, relative to the four hour postoperative value, was significantly higher on the second and third postoperative days in the CPAP-group, as compared to the incentive spirometry group and the deep breathing exercise group. However, in their study, the incidence of atelectasis reported on chest x-ray film was not significantly lower in the CPAP group as compared to the other groups, and arterial Po_2 was not measured.

It is well-known that FRC decreases after surgery.[8,21] If it becomes lower than closing capacity, airway closure may ensue. It is also known that CPAP increases FRC and improves oxygenation.[36] It is likely that the prophylactic intermittent increase of FRC, as performed with periodic CPAP, may explain the beneficial effects, described in our work and by Stock et al,[21] by preventing postoperative closure of small airways and alveolar collapse. Andersen et al[20] have suggested and demonstrated experimentally[37] that CPAP can effectively reopen collapsed alveoli through collateral channels, a mechanism of great probable importance in this aspect. One could argue that intermittent treatment with CPAP, PEP or deep breathing exercises were equally ineffective in preventing deterioration in gas exchange since (A-a) O_2-diff increased postoperatively to the same extent in the three groups and reached a maximum at approximately the first postoperative day. Perhaps, therefore, the beneficial effects of CPAP and PEP are not mainly preventive, but an effective way to treat and reexpand collapsed parts of the lungs postoperatively by the above-described mechanism. However, it is likely that the clear distinction between prevention and treatment of atelectasis and impairment of gas exchange in this study is difficult.

Of interest was the finding that periodic PEP with the simple device (Fig 1) employing an expiratory resistance with a peak PEP of 10-15 mm H_2 seemed to be as effective as the more complicated CPAP system. Can periodic administration of mask PEP reopen collapsed alveoli via collateral channels and increase FRC as effectively as mask CPAP? It has been reported that intubated anesthetized patients[38,39] and dogs[40,41] increase their PaO_2 with the imposition of expiratory resistance, probably due to reversal of alveolar collapse.[38] Based on the results of the present study, we suggest that expiratory positive airway pressure may be as effective as continuous positive airway pressure and definitely better than deep breathing exercises in preventing atelectasis development and in treating alveolar collapse postoperatively. It can be speculated that the crucial point for the recruitment of collapsed alveoli via collateral channels is the application of a positive airway pressure during the expiratory phase, and not necessarily during inspiration. The PEP-mask also has some major advantages over the CPAP-system since it is easily portable and not restricted to intensive care units. After careful information, the patient can treat himself postoperatively without constant supervision. Finally, the device does not harm the patient.

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