Continuous Positive Airway Pressure Effect on Functional Residual Capacity, Vital Capacity and Its Subdivisions*

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Thirty-four otherwise healthy patients having to undergo elective upper abdominal surgery were randomly assigned to two equal groups. In the treatment group, constant positive airway pressure (CPAP) with an expiratory pressure of 12 cm H₂O was applied at one hour following extubation, and at daily intervals for the first five days following surgery for a continuous period of three hours. The control group received no CPAP treatment. All patients were given postoperative physiotherapy. In patients who received postoperative CPAP with an end-expiratory pressure of 12 cm H₂O, marked normalization of pulmonary function was noted.

Even healthy patients usually develop a clinically relevant restriction of pulmonary function following upper abdominal surgery. This restriction is characterized by a marked fall in vital capacity (VC) and a less marked but more far-reaching decrease in functional residual capacity (FRC), which is associated with a reduction in lung compliance and in the arterial partial pressure of oxygen. In patients recovering from acute respiratory failure, continuous positive airway pressure (CPAP) at an appropriate level not only improves oxygenation and carbon dioxide elimination, but lung mechanics as well.

Controversy exists, however, whether CPAP, when administered at regular intervals following extubation, promotes recovery of pulmonary function and prevents pulmonary complications after upper abdominal operations.

This study assesses the effect of intermittent continuous positive airway pressure (CPAP) via a mouthpiece during spontaneous respiration on the postoperative changes in functional residual capacity, and on vital capacity and its subdivisions in order to establish whether this form of treatment is of value in improving lung function and decreasing the incidence of respiratory complications.

METHOD

Thirty-four adults having to undergo elective major upper abdominal surgery (cholecystectomy together with bile duct surgery, gastropasty, or gastric bypass) who were otherwise healthy, consented to partake in the investigation. These patients were randomized into two groups of equal size. Their physical characteristics, the duration of anesthesia, and the type of operation performed are shown in Table 1. Apart from there being 11 women in the control and five in the CPAP group, there were no significant differences between the groups (analysis of variance). All the patients were nonsmokers. Preoperative chest disease was excluded by a thorough history and examination, chest x-ray, spirometry, and measurement of the functional residual capacity.

Preoperatively, both the control and CPAP group patients were given instruction in the physiotherapy techniques which were applied postoperatively. In addition, the patients of the CPAP group were instructed in, but not treated with, the CPAP system.

In all patients, the same anesthetic procedure was chosen, ie, general endotracheal anesthesia with a balanced technique, N₂O/O₂ (FIO₂ 0.3), and mechanical ventilation with zero-end-expiratory pressure.

All patients were extubated immediately postoperatively. Postoperative pain was controlled with 5 to 7.5 mg piritramide given intravenously at intervals of at least four hours. Analgesic requirements during the first 72 hours following surgery were practically the same in both groups (8.6 ± 2.7 injections in the control as compared to 9.2 ± 1.8 in the CPAP group).

In both groups, standard physiotherapy, ie, deep breathing and coughing, was performed at least at hourly intervals during the daytime for the subsequent 48 hours. The 17 patients of the CPAP group breathed through a continuous flow CPAP system at an FIO₂ of 0.35 for three hours per day for the first five postoperative days beginning one hour after extubation. In this continuous flow CPAP system, the fresh gas flow passes to the patient via a reservoir partly filled with heated water which also serves as a fresh gas reservoir. The patient breathes out via a water lock, the depth of which is adjustable. No rebreathing is possible when the fresh gas

| Table 1—Composition of Groups with Respect to Physical Status and Duration of Anesthesia |
|---------------------------------------------|---------|---------|
|                                             | Control Group | CPAP Group |
| Age (yr)                                   | 65 (52-77)   | 66 (50-77) |
| Sex (F/M)                                  | 11/6       | 5/12     |
| Height (cm)                                | 166 (155-177) | 171 (154-185) |
| Weight (kg)                                | 65 (47-85) | 66 (50-95) |
| Duration of anesthesia (min)               | 185 (105-275) | 179 (95-265) |
| Operation: cholecystectomy                 | 11        | 10       |
| gastropasty/                               |           |          |
| gastric bypass                             | 6         | 7        |

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flow is set to 1.5 times the respiratory minute volume. An airway pressure of 12 cm H$_2$O was applied using a specially developed mouthpiece, while nose breathing was blocked by means of a soft nasal clamp.

In order to be able to measure respiratory function at the bedside, we constructed a mobile set consisting of an electronic spirometer, pneumotachograph, and a density oscillimeter for the measurement of function residual capacity by means of the helium dilution method. The precision of this method had previously been tested on a lung function model and found to be accurate to within 5 percent. All volumes were recorded with a two-channel recorder. At each point of measurement, the functional residual capacity and the vital capacity were measured twice.

The first postoperative pulmonary function measurements were taken one hour after extubation and were followed in the treatment group by three hours of CPAP-breathing, the efficacy of which was tested by renewed measurements 15 minutes after the end of CPAP use. Pulmonary function was again measured on the first, third, and fifth postoperative day before and 15 minutes following CPAP application, and once on each of these days in the control group.

Pulmonary function measurements were performed by a researcher who was not aware of which group the patients were in.

All measurements were carried out with the patient lying supine and with the head-end of the bed tilted to 30°. At least one hour was allowed to elapse after piroramidine had been given before measurements were taken.

A radiologist interpreted an upright chest x-ray film of each patient both preoperatively and on the fourth postoperative day without knowledge of whether the patient was receiving CPAP or not.

A pulmonary complication was considered to be present when the patient's temperature rose above 38.5 °C, physical findings during percussion and auscultation were abnormal, and the chest x-ray film denoted a pathologic condition as reported by the radiologist. When a complication was suspected or diagnosed, daily chest x-ray films were carried out.

Differences in intergroup measurements of the first, third, and fifth postoperative days were tested for significance using the Wilcoxon-Mann-Whitney-test. The pulmonary function data of the control group were only compared with pre-CPAP pulmonary function measurements. In order to avoid the influence of factors present prior to the investigation, the differences between initial and postoperative values were compared. Differences in functional residual capacity and vital capacity between those patients with complications and those without were also tested with the Wilcoxon-Mann-Whitney-test. A probability of 0.05 on two-tailed testing was regarded as being significant in all tests. Median values and 95 percent confidence limits are shown in the figures.

**RESULTS**

Figure 1 shows the vital capacity measurements. The preoperative median vital capacity of the control group was 3,150 ml. This value fell to 990 ml one hour after extubation and gradually rose to 1,880 ml on the fifth postoperative day. We found a similar initial fall in the vital capacity of the CPAP group from 3,560 ml to 870 ml, but a more rapid tendency to return to normal values. Immediately after the first three hours of CPAP application, the vital capacity rose from a median value of 871 ml to 2,083 ml. On the first postoperative day, 2,039 ml was measured, which increased to 2,713 ml after CPAP. On the third postoperative day, a decreased vital capacity to 2,647 ml before CPAP application was measured. These vital capacity values on the third postoperative day were significantly higher than those of the control group, however. A further increase to 3,033 ml was registered following CPAP on the third postoperative day. On the fifth postoperative day, the median vital capacity before CPAP use was at 3,101 ml, significantly higher than the values of the control group. On this last day of observation, the median vital capacity rose by 498 ml to 3,599 ml after CPAP application.

In the CPAP group, the inspiratory reserve volume fell from a preoperative median value of 1,928 ml to 329 ml immediately postoperatively, and in the control group, from 2,163 ml to 358 ml. On days 3 and 5, the median inspiratory reserve volume of the CPAP group was significantly higher, even prior to CPAP application, than in the control group. On day 5, the median value of this volume had risen to only 940 ml in the control group as compared to 2,220 ml in CPAP group before CPAP application (Fig. 2).
The postoperative median expiratory reserve volume of both groups was zero (Fig 3). On the third and fifth day following surgery, the values of the CPAP group before CPAP application were significantly higher (390 ml on day 3 and 630 ml on day 5) than those of the control group (170 ml on day 3 and 220 ml on day 5).

Immediately after operation, the functional residual capacity of the control group fell from a preoperative median value of 2,760 ml to 2,030 ml, and that of the CPAP group from 2,420 ml to 1,880 ml (Fig 4). The lowest recorded median of 1,340 ml was found in the control group on the first postoperative day. An increase to 1,550 ml was found on the third day following surgery, but even by the fifth postoperative day, the functional residual capacity had not yet returned to normal. Fifteen minutes after the first three-hour period of CPAP treatment, the median functional residual capacity rose from 2,030 ml to 2,410 ml. On the first, third, and fifth postoperative days, the functional residual capacity of the CPAP group, prior to CPAP, was significantly higher than in the control group. Immediately following this treatment, an additional rise in functional residual capacity was registered at each point of measurement. The median functional residual capacity values of the CPAP group had returned to normal by the fifth postoperative day when measured after CPAP application.

Pulmonary complications developed in five of the control group patients as compared to one patient in the CPAP group. The incidence of pulmonary complications between the two groups was not statistically significant (chi square test, probability of 0.05). Of the control group patients, four were diagnosed as having macroatelectasis and one a bronchopulmonary consolidation. One CPAP group patient developed bronchopulmonary consolidation, but no atelectasis, on the third postoperative day. None of these complications was of such a degree that specific treatment (intubation, ventilation) was necessary or that inpatient care had to be prolonged. The vital capacity of these six patients was compared with that of the remaining 28 patients who were free of respiratory complications (Fig 5). The vital capacity of those patients who developed pulmonary complications was significantly lower. The functional residual capacity of those patients who developed complications was also significantly lower on the first, third, and fifth days (Fig 6).

**Discussion**

Extrathoracic factors which restrict diaphragmatic movement, such as surgical trauma to the abdominal wall, pain-induced reflexes, and a rise in intraabdominal pressure, are primarily responsible for the postoperative restriction of pulmonary function. The postoperative fall in vital capacity and functional

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*Figure 3. Expiratory reserve volume results. Control group, one measurement per day; CPAP group, two measurements per day, one before and one after CPAP application. Significantly lower expiratory reserve volume in the control group on day 3 and day 5 (p<0.05).*

*Figure 4. Functional residual capacity results. Control group, one measurement per day; CPAP group, two measurements per day, one before and one after CPAP application. Significantly lower functional residual capacity in the control group on day 1, day 3, and day 5 (p<0.05).*

*Figure 5. Comparison of vital capacity between the six patients who developed a pulmonary complication and the 28 who did not. Significantly lower vital capacity in the complication group on day 1, day 3, and day 5 (p<0.05).*
residual capacity found in this study supports previous observations that pulmonary function deteriorates after upper abdominal surgery.\(^\text{10,12}\) Immediately following surgery, the vital capacity of both groups fell to 30 percent of the preoperative value. By the fifth postoperative day, the values of the untreated control group had reached 60 percent of the preoperative volume. Because our observations were limited to five days, we do not know when the vital capacity of this group returned to normal. The functional residual capacity, which can be regarded as a measure of the alveolar volume available for pulmonary gas exchange, is the most important of the measurements made. This value fell to a minimum in both groups at 24 hours following surgery. Similar observations have been reported by other authors.\(^\text{8,3,13}\)

The changes in lung volume, in particular the fall in expiratory reserve volume to zero at one hour after extubation, indicate a restriction of diaphragmatic function, partly as a result of the surgical trauma. A further explanation afforded for the restriction in diaphragmatic motility is a reflex inhibition of the motor efferents in the phrenic nerve by visceral and/or somatic afferents.\(^\text{14}\) It has been shown in studies both on animals and in patients that the fall in diaphragmatic motility is greatest immediately postoperatively, and that this function returns to normal on the first postoperative day.\(^\text{5,14}\)

The high level of the diaphragm and the extrapulmonary factors discussed above lead to a shallow, monotonous, uniform type of respiration with a markedly reduced inspiratory reserve volume. This, in turn, leads to difficulty in coughing up mucous secretions and to a tendency for microatelectasis and areas with a low ventilation-perfusion quotient to develop secondary to partial or complete closure of the terminal airways. The delay in the decrease in functional residual capacity is presumably the result of these alterations in pulmonary mechanics.

Various therapeutic concepts have been suggested and tried in an attempt to avoid postoperative respiratory changes and the associated hypoxemia. The blockade of inhibitory pain reflexes by epidural or intercostal blocks, intensive physiotherapy, and the postoperative once-only application of CPAP with an airway pressure of 5 cm H\(_2\)O have been shown to reduce pulmonary complications somewhat, but lung function parameters are not significantly altered by these methods.\(^\text{3,12,13,18}\) There can be no doubt, however, that CPAP via a mask or mouthpiece is an effective means of support for mild to moderate posttraumatic and postoperative respiratory insufficiency.\(^\text{19,20}\)

The use of continuous positive airway pressure at 12 cm H\(_2\)O avoids lower lobe pulmonary hypoventilation. After the first three-hour period of CPAP application in this study, lung volumes already showed a tendency to normalize, but we found that they had decreased again slightly by the next point of observation. When compared to our own previous observations and those of other authors,\(^\text{10,21}\) the more rapid normalization of respiratory function under CPAP treatment found in this study can be explained by the higher CPAP pressure and the longer and the more frequent application thereof.

It should be noted that the patients participating in this study were older than those previously studied. Furthermore, the results do not allow any conclusions as to whether this pressure and the periods of treatment are optimal. The 15 minute-application of CPAP at an airway pressure of 7.5 cm H\(_2\)O at two hourly intervals during the daytime during the first three days following upper abdominal surgery has also been shown to lead to a more rapid normalization of the functional residual capacity and to a reduction in the incidence of atelectasis.\(^\text{18}\) In a recent study by Ricksten et al,\(^\text{22}\) CPAP (10 to 15 cm H\(_2\)O) applied by a face mask for 30 breaths every waking hour, for three postoperative days (beginning one hour after upper abdominal surgery), was more effective than deep breathing exercises (incentive spirometry), in terms of improving pulmonary function and gas exchange and reducing atelectasis. The prevention of pulmonary complication could not be statistically proven in our study.

We consider the application of CPAP immediately following, or at least during the first hour after surgery to be important, because Wolff and co-workers\(^\text{24}\) have shown that directly following surgery, the biomechanics of the alveoli are unstable, and that spontaneous respiration at this point in time can lead to a rapid deterioration in gas exchange which then remains below normal levels for a number of days. Both this study and that of Ricksten indicate that if CPAP is to produce important benefits for the postoperative patient, it should be applied early (ie, during the first postoperative hour), at a pressure greater than 10 cm H\(_2\)O.
and intermittently for several days.

The number of patients undergoing either cholecystectomy or gastric surgery, the duration of surgery, and of anesthesia were practically the same in both groups (Table 1). The changes in lung function parameters were the same in both groups at the first postoperative measurement. In the CPAP group, two lung volume measurements were carried out on each day of observation, as opposed to only one measurement in the control group. Because vigorous physiotherapy with deep breathing exercises was given to both groups at intervals of at least three hours, the effect of this one further vital capacity maneuver was considered to be negligible.

Constant positive airway breathing via a mouthpiece was well tolerated by the majority of our patients. No severe complications, such as the aspiration of gastric contents, occurred, nor was gastric dilatation ever observed, despite the fact that all patients had a nasogastric tube. The use of a nose clamp, which can be unpleasant when such a tube is in place, is not mandatory in routine clinical use because the pressure loss so incurred is minimal.

Conclusions

These findings imply that the postoperative prophylactic use of CPAP is, indeed, effective not only in reducing pulmonary complications but in effecting an earlier return to normal pulmonary function. Comparison with previous results indicates that not only should an adequate pressure be applied (>10 cm H₂O), but also that the timing of application should be early (ie, during the first postoperative hour), the period of use about three hours per day, and that CPAP treatment should continue for several postoperative days.

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