Prevention of Postoperative Pulmonary Complications with CPAP, Incentive Spirometry, and Conservative Therapy*

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Continuous positive airway pressure (CPAP) administered at intervals with a mask and incentive spirometry (IS) were compared with a regimen of coughing and deep breathing (CDB) to determine which promoted the most rapid recovery of pulmonary function after upper abdominal operations in 65 adults. Postoperatively, FRC of patients in all groups was similar relative to preoperative values. However, mean FRC of patients who received CPAP increased more rapidly than did mean FRC of those receiving CDB when compared to the values obtained following operation ($p<0.05$). Incentive spirometry did not increase FRC to a greater extent than did CDB. Roentgenographic evidence of atelectasis 72 hours postoperatively was observed in 23 percent of CPAP patients (five of 22) and 42 percent and 41 percent of patients who received CDB (eight of 19) and IS (nine of 22). Two patients (3 percent) developed pneumonia. The low incidence of pneumonia regardless of the type of therapy may be attributable to vigorous, vigilant respiratory care in a population at high risk for developing pneumonia. Frequency and supervision of respiratory therapy may be more important than the type of therapy delivered after upper abdominal operations. Mask CPAP offers advantages because it requires no effort from the patient, and therapy is not painful.

Upper abdominal operations frequently are accompanied by postoperative pulmonary complications.[1] Most agree that, after abdominal operations, a restrictive pulmonary defect occurs.[1-3] This defect is characterized by a 55 percent decrease in forced vital capacity (FVC) concomitant with a 30 percent reduction in functional residual capacity (FRC), but no change in the percentage of the FVC that is expired during the first second (FEV_1).[2] The diminished FRC appears to be related to postoperative pulmonary morbidity.[1,3-5] Controversy exists, however, concerning which is the best mode of respiratory therapy for prophylaxis.[6,7] Comparison of results from previous investigations is complicated by a lack of uniformly defined postoperative pulmonary complications. Most agree that pneumonia occurs in 12 percent to 20 percent of patients after upper abdominal operations.[8-10]

This study tested which of three types of respiratory therapy promoted better recovery of pulmonary function after upper abdominal operations. The three methods examined were a conservative regimen of coughing and deep breathing (CDB), incentive spirometry (IS), and continuous positive airway pressure (CPAP) delivered at intervals with a face mask.

Materials and Methods

This project was approved by the Mercy Hospital Drug/Research Review Committee and was conducted during a continuous six-month period. The night before operation, 65 adults scheduled for elective upper abdominal operations gave informed consent to participate in this study. The patient's age, sex, body surface area, smoking history, and any history of pulmonary disease were recorded (Table 1).

A computer random number generator was used to assign each patient to one of three treatment groups for postoperative respiratory therapy: CDB, IS, and CPAP delivered with a mask. All patients performed a multiple breath nitrogen washout to determine FRC and spirometry using a portable pulmonary function testing device. Physical and roentgenographic examinations of the chest also were performed, and oral temperature was recorded. The evening before operation, patients received instruction in and practiced the postoperative respiratory therapy assigned. All patients received general anesthesia with tracheal intubation. Anesthesia was maintained with an inhalational agent or by using a balanced technique with fentanyl, N_2O, O_2, and pancuronium bromide. The surgical procedure and duration of anesthesia were recorded.

Extubation in the operating room followed termination of general anesthesia and four hours later, the respiratory treatment regimen began after spirometry and nitrogen washout were performed. Postoperatively, all patients breathed room air. All treatments were administered by a physician or trained respiratory therapist, lasted 15 minutes, and were delivered every two hours during waking hours from the fourth to the 72nd hour after operation. Incentive spirometry was delivered with a volumetric spirometer. The incentive

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Table 1—*Composition of Treatment Groups with Respect to Physical Status and Operation*

	CDB	IS	CPAP
No. in Group	20	22	23
Males	9	8	8
Females	11	14	15
ASA Physical Status:[15]			
I	6	7	11
II	12	14	10
III	2	1	1
IV	0	0	1
Smoking history:			
Never smoked	10	10	8
Quit smoking >6 mos	5	3	4
Smoke	4	8	11
Smoke pipe or cigars	1	1	0
History pulmonary disease*	4	6	6
Mean age ± SEM (years)	48 ± 4	54 ± 4	49 ± 5
Mean body surface area ± SEM (m^2)	1.84 ± 0.06	1.84 ± 0.06	1.90 ± 0.07
Operation:			
Cholecystectomy	12	15	18
Gastroplasty/Gastric bypass	1	1	2
Other bowel surgery	5	5	3
Major vascular	2	1	0
Mean duration of anesthesia ± SEM (min)	155 ± 19	135 ± 12	132 ± 11

*Those having had one or more: chronic cough, chronic sputum production, emphysema, bronchitis, or asthma.

spirometer had a piston which was adjusted to contain from 200 to 2,000 ml (Fig 1). When patients inhaled through the spirometer, the floor of the piston rose and lit a bulb when the preset volume had been withdrawn from the spirometer. A continuous leak in the piston insured that patients would have to continue to inspire at a minimum rate of 100 ml/sec to keep the bulb lit, once the preset volume was inspired from the spirometer. This forced the patient to keep the glottis open. The maximum volume at which patients were able to keep the bulb lit for 3 seconds was used to deliver each treatment. If inspiratory effort improved during the 15-minute treatment, the volume was increased. The total number of times patients kept the bulb lit for three seconds and the corresponding volume were recorded. During the CDB regimen, the therapist and patient splinted the patient's wound with their hands. Patients were instructed to take four to five maximal inspirations and then to cough heartily by using a "huffing" technique every three to five minutes.[11]

Continuous positive airway pressure was delivered with a soft, self-sealing mask. A compressed gas-powered Venturi device delivered a continuous flow of gas greater than 90 L/minute through a threshold resistor valve which generated 7.5 cm H_2O pressure. While patients wore the masks, they were asked to take two or three maximal inspirations every three to five minutes. An adequate seal of the mask against the patient's face was attained by ensuring that the expiratory valve remained open throughout the entire respiratory cycle. The time and duration of all treatments were recorded for every patient.

Spirometry and FRC determinations were performed at the bedside four hours postoperatively to obtain a clinical baseline, and 24, 48, and 72 hours postoperatively to evaluate respiratory status and effect of therapy. Lung volumes were measured 24, 48, and 72 hours postoperatively ten minutes after a treatment was completed. Functional residual capacity was always measured before the forced expiratory maneuvers. Patients reclined at 30° from horizontal to perform lung volume measurements four hours postoperatively. For the remainder of spirometry and nitrogen washout maneuvers, patients sat on the edge of the bed or in a chair. Upright anterior-posterior chest roentgenograms were taken at the bedside 24 and 72 hours postoperatively and were interpreted by staff radiologists who knew that the patients were participating in this study but were unaware of the patients' respiratory therapy. Oral temperatures were

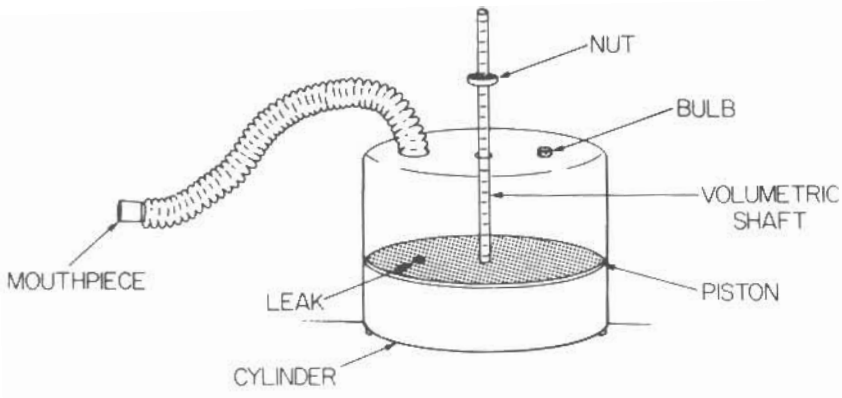

FIGURE 1. Cross-section of the volumetric incentive spirometer. Inspiration through the mouthpiece moves the spirometer piston upward. When the piston contacts the ceiling of the spirometer, a bulb lights. A 100 ml/minute leak is built into the piston which requires continual inspiratory flow to maintain a lit bulb. The spirometer volume is changed by moving the nut along the shaft of the piston.

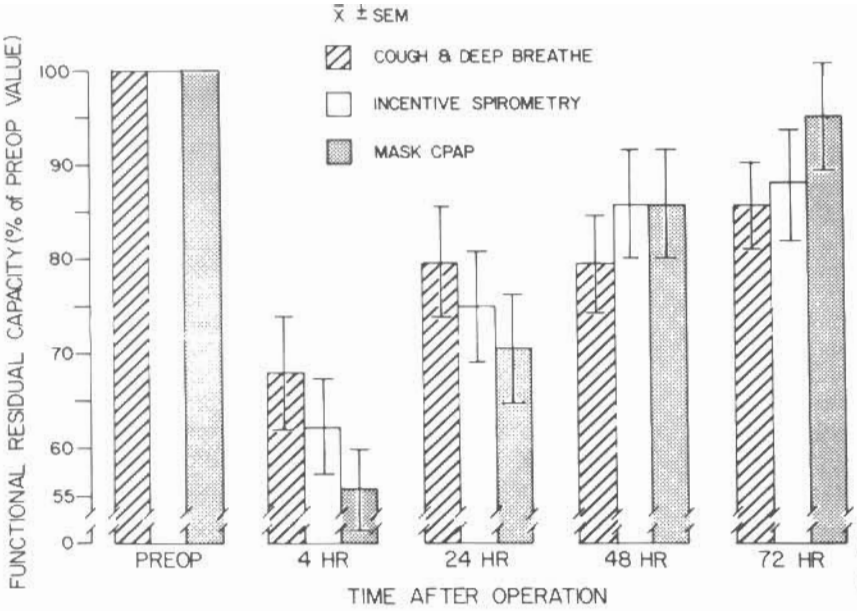

FIGURE 2. Functional residual capacity relative to preoperative values at 4, 24, 48, and 72 hours postoperatively for patients treated with CDB, IS, and CPAP.

recorded every six hours for the first 72 hours after operation. Rales, rhonchi, wheezes, and decreased breath sounds heard on auscultation of the chest and respiratory rate were recorded before and after each treatment throughout the study period.

A diagnosis of pneumonia was made when patients met two of the following three criteria: a change in the color or quantity of sputum, an oral temperature of >38.5°C for at least two days, and an infiltrate on chest roentgenogram. Sputum then was cultured for isolation of a predominant organism.

The Statistical Analysis System[12] was used to randomize subjects and computerize, edit, and analyze data. Functional residual capacity, FVC, and FEV_1 were analyzed as functions of body surface area and as a percentage of preoperative values to compare similarity of treatment groups preoperatively and to assess the effect of operation on lung volumes four hours postoperatively. Respiratory therapy treatments were started immediately after the four-hour postoperative lung volumes were determined, and thereby reflect the condition of the lungs at the time respiratory therapy was instituted. Therefore, the four-hour lung volumes are the best point of reference from which to determine the efficacy of pulmonary therapy. All FRC, FVC, and FEV_1 values obtained subsequent to the day of operation were also analyzed as functions of the four-hour postoperative values. Two-sided paired Student's *t*-tests were used to determine statistical significance of trends within a single group over time. Since possible differences between each pair of treatment were of independent interest, and variability appeared to differ from group to group, each pair of treatments was separately contrasted using two-sided independent sample Student's *t*-tests for groups with unequal variances.[13] Since the underlying observed distribution of FRC appeared positively skewed, high values were reexamined and their clinical validity confirmed. To evaluate the dependence of results on these data points, nonparametric (Wilcoxon) tests were performed as this procedure is valid for asymmetric distributions and is robust to statistical outliers. Proportions of patients with roentgenographic evidence of atelectasis or infiltrate, with recorded temperatures above 38.5°C, and with decreased breath sounds were compared across groups using the standard differences of proportions Z-test.[13] McNemar's test[14] was used to compare such proportions within the same group at different times.

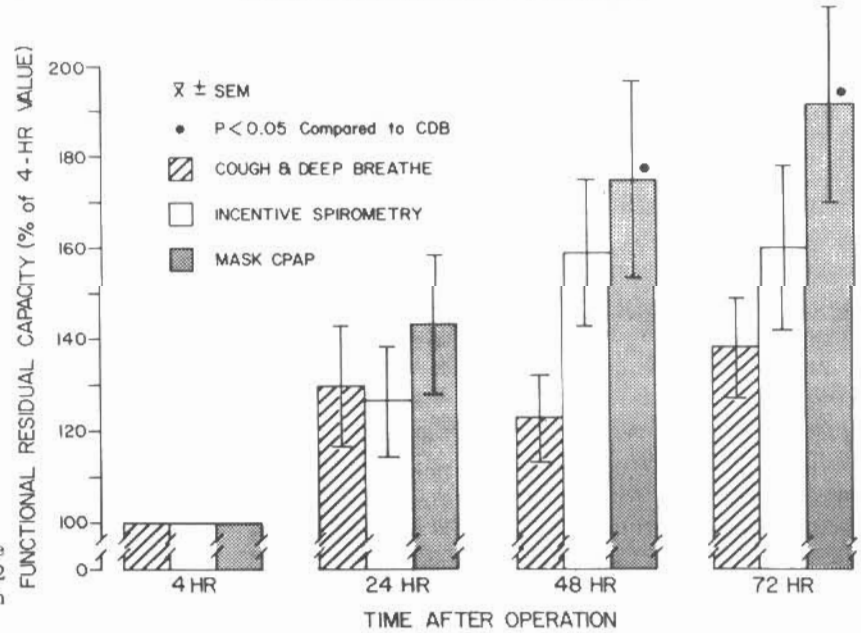

FIGURE 3. Functional residual capacity relative to 4-hours postoperative values at 24, 48, and 72 hours postoperatively for patients treated with CDB, IS, and CPAP.

Table 2—*Functional Residual Capacity Throughout Study Period (mean ± SEM)*

	CDB	IS	CPAP
A. Indexed to body surface area (ml/m²).			
Preoperative	1310 ± 100	1170 ± 90	1190 ± 100
4 hr postoperative	920 ± 120*	680 ± 60*	620 ± 70*
24 hr postoperative	990 ± 90	770 ± 50	810 ± 100
48 hr postoperative	1030 ± 100	960 ± 70	930 ± 70
72 hr postoperative	1090 ± 80	970 ± 60	1040 ± 70
B. As percentage of preoperative value (%).			
4 hr postoperative	68 ± 6	62 ± 5	56 ± 4
24 hr postoperative	79 ± 6	75 ± 6	71 ± 6
48 hr postoperative	79 ± 5	86 ± 6	86 ± 6
72 hr postoperative	86 ± 4	88 ± 6	95 ± 6
C. As percentage of four-hour postoperative clinical baseline (%).			
24 hr postoperative	130 ± 14	127 ± 12	143 ± 15
48 hr postoperative	123 ± 9	158 ± 16	175 ± 22†
72 hr postoperative	138 ± 11	160 ± 18	192 ± 21†

*Four-hour postoperative values differed significantly from preoperative values ($p<0.001$).

†Values significantly greater compared to CDB group ($p<0.05$).

Results

Table 1 displays composition of the treatment groups with respect to sex, age, and characteristics of history, physical status, and operation. Both preoperatively, and at four hours postoperatively, mean FRC, FVC, FEV_1, and FEV_1/FVC were similar for patients in the three treatment groups (Tables 2 through 5). Statistically significant postoperative declines in FRC, FVC, and FEV_1 were seen in each treatment group ($p<0.001$). These averaged 39 percent, 60 percent, and 59 percent, respectively. Although the average declines of FVC and FEV_1 were similar, mean FEV_1/FVC ratio in the entire subject group nevertheless increased 5 percent when analyzed subject by subject ($p<0.05$).

The change in FRC with respect to time is displayed in Figures 2 and 3 and Table 2. The FVC and FEV_1 data are summarized in Tables 3 through 5. Twenty-four hours after operation, the relative increases in FRC were similar for all groups. When examining FRC results as raw data or when expressed as a percentage of the preoperative value, there are no significant differences between the groups (Fig 2). However, when examined relative to the point at which treatment was instituted, four hours postoperatively, FRC was significantly higher in the CPAP than in the CDB group ($p<0.05$ by both parametric and nonparametric analyses) with the IS group intermediate, 48 and 72 hours postoperatively (Fig 3 and Table 2). That is, those who received CPAP had more rapid recovery of FRC than those who received conservative therapy. The three treatment groups showed similar improvements in FVC and FEV_1 from four to 72 hours postoperatively.

Table 3—*Forced Vital Capacity Throughout Study Period (mean ± SEM)*

	CDB	IS	CPAP
A. Indexed to body surface area (ml/m²).			
Preoperative	1820 ± 120	1620 ± 120	1790 ± 100
4 hr postoperative	710 ± 60*	650 ± 50*	600 ± 50*
24 hr postoperative	880 ± 60	680 ± 40	740 ± 40
48 hr postoperative	950 ± 70	860 ± 60	890 ± 60
72 hr postoperative	1190 ± 80	940 ± 60	1010 ± 60
B. As percentage of preoperative value (%).			
4 hr postoperative	40 ± 4	46 ± 6	35 ± 3
24 hr postoperative	48 ± 3	49 ± 6	43 ± 3
48 hr postoperative	56 ± 5	62 ± 8	51 ± 3
72 hr postoperative	71 ± 6	69 ± 9	59 ± 4
C. As percentage of four-hour postoperative clinical baseline (%).			
24 hr postoperative	132 ± 12	116 ± 8	140 ± 15
48 hr postoperative	149 ± 12	147 ± 13	159 ± 12
72 hr postoperative	185 ± 18	159 ± 14	186 ± 13

*Four-hour postoperative value differed significantly from preoperative value ($p<0.001$). There were no significant differences between groups at any time.

Table 4—*Forced Expiratory Volume in One Second (mean ± SEM)*

	CDB	IS	CPAP
A. Indexed to body surface area (ml/m²)			
Preoperative	1410 ± 100	1280 ± 90	1480 ± 90
4 hr postoperative	580 ± 40*	530 ± 50*	490 ± 40*
24 hr postoperative	700 ± 50	580 ± 50	590 ± 30
48 hr postoperative	740 ± 60	720 ± 50	700 ± 40
72 hr postoperative	940 ± 70	740 ± 50	810 ± 50
B. As percentage of preoperative value (%).			
4 hr postoperative	43 ± 4	46 ± 5	35 ± 3
24 hr postoperative	50 ± 4	50 ± 4	43 ± 3
48 hr postoperative	55 ± 4	62 ± 6	49 ± 3
72 hr postoperative	72 ± 6	64 ± 6	58 ± 3
C. As percentage of 4-hour postoperative clinical baseline (%).			
24 hr postoperative	121 ± 7	116 ± 9	130 ± 11
48 hr postoperative	135 ± 8	147 ± 14	153 ± 11
72 hr postoperative	164 ± 10	148 ± 13	175 ± 9

*Four-hour postoperative values differed significantly from preoperative value ($p<0.001$). No statistically significant differences between groups at any time.

Atelectasis was seen on chest roentgenograms in 41 percent (26 of 63) of subjects at 24 hours and in 35 percent (22 of 63) at 72 hours. At that time, the prevalence was lower in the CPAP group, 23 percent (5 of 22), than in the others, 41 percent (17 of 41) ($p = 0.18$) (Table 6). Decreased breath sounds also were found with comparable frequencies in the three groups (Table 7). The average number of times IS patients

Table 5—*FEV_1/FVC Throughout Study Period (mean ± SEM (%))

	CDB	IS	CPAP
Preoperative	78 ± 2	75 ± 3	82 ± 2
4 hr postoperative	82 ± 3	84 ± 3	84 ± 3
24 hr postoperative	81 ± 3	83 ± 3	81 ± 2
48 hr postoperative	77 ± 2	82 ± 3	80 ± 2
72 hr postoperative	79 ± 2	80 ± 3	81 ± 2

*No significant differences within or between groups at any time.

Table 6—*Number of Patients with Atelectasis Reported from Chest Roentgenograms Preoperatively, and at 24 and 72 Hours, Postoperatively*

	CDB	IS	CPAP
Number of patients receiving roentgenogram	19	22	22
Patients with atelectasis (% of group total)			
Preoperatively	0 (0)	1 (5)	0 (0)
24 hr postoperatively	6 (32)	11 (50)	9 (41)
72 hr postoperatively	8 (42)	9 (41)	5 (23)

were able to keep the spirometer lit for at least three seconds, and the mean volumes at which this was accomplished are shown in Table 8. Patients whose breath sounds were diminished did not improve in this regard from the IS or CDB treatments. However, breath sounds of all patients who received CPAP could be heard well throughout the entire lung fields while these patients wore the masks. Proportions of patients with any recorded temperatures higher than 38.5°C were similar for the three treatment groups: 10 percent, 14 percent, and 9 percent for CDB, IS, and CPAP respectively. Two patients, one who received CDB and one IS, fulfilled the criteria for a diagnosis of pneumonia. *Streptococcus pneumoniae* was isolated from the sputum of both these patients.

Discussion

Pulmonary complications are the major causes of morbidity and mortality after upper abdominal operations. During normal respiration, large intermittent breaths, three times the normal tidal volume, are inspired approximately ten times each hour.[16] Postoperatively, such "sighing" is absent.[16] Shallow, monotonous breathing may decrease ventilation to the dependent lung regions and may contribute to the development of atelectasis. Incisional pain, residual anesthetic effects, and assuming the recumbent position for prolonged periods promote decreased resting lung volume. In addition, when patients remain recumbent for long periods, especially during the first 24 hours postoperatively, their abdominal contents limit diaphragmatic movement. Both the recumbent position[17,18] and a change in breathing pattern may decrease FRC. Diminished expiratory lung volumes are associated with decreased lung compliance, which increases the elastic work of breathing.[19] To minimize this work, patients take shallow, frequent breaths which may further decrease lung volume.[20] This explains the observation that patients who undergo upper abdominal operations often have an increased respiratory rate postoperatively. A primary goal of respiratory therapy should be to increase expiratory lung volume, in particular, FRC.

Table 7—*Number of Patients with Decreased Breath Sounds Recorded After Therapy Preoperatively, and 4, 24, 48, and 72 Hours Postoperatively*

	CDB	IS	CPAP
Patients receiving treatment	20	22	23
Patients with decreased breath sounds (% of group totals)			
Preoperatively	1 (5)	2 (9)	1 (4)
4 hr postoperatively	14 (68)*	13 (60)*	11 (47)†
24 hr postoperatively	11 (55)*	18 (82)*	15 (65)*
48 hr postoperatively	11 (55)*	12 (55)*	15 (65)*
72 hr postoperatively	10 (50)*	6 (27)	8 (36)†

*$p<0.002$ compared to preoperative value (McNemar's test).
†$p<0.01$ compared to preoperative value (McNemar's test). No significant differences between groups at any time.

Table 8—*Use of Incentive Spirometer Each Day: Mean Number of Times Patients Kept Bulb Lit for Three seconds During Each 15 Minute Treatment and Mean Volume of Spirometer (mean ± SEM)*

Time period	No. of times	Volume (ml)
Day of operation	35 ± 6	620 ± 40
First day after operation	64 ± 7	790 ± 60*
Second day after operation	70 ± 6	840 ± 60*
Third day after operation	76 ± 11	1090 ± 150*

*$p<0.01$ compared to day of operation.

Although abnormal physical findings and elevations of temperature may be useful in diagnosing atelectasis, these are insensitive means of detecting decreases in FRC. Large decreases in FVC and FEV_1 appear to occur after upper abdominal operations, but they are effort-dependent and cannot accurately predict a decrease in FRC. Chest roentgenography is useful for identifying patients with atelectasis; however, to accurately assess postoperative expiratory lung volume, FRC was determined.

Of the many therapeutic maneuvers and devices that have been used to prevent postoperative pulmonary complications, the incentive spirometer has gained most popularity and currently is a common mode of postoperative respiratory therapy in the United States. The theoretic basis on which the incentive spirometer was proposed was that it encourages patients to maximally inflate their lungs and to sustain that inflation. Maximal lung inflations are thought to open collapsed alveoli, and thereby, prevent and resolve atelectasis. Maximal lung inflations increase transpulmonary pressure during inspiration. If the reexpanded alveoli remain inflated during expiration, FRC increases.

The control group of patients in this study received a regimen of coughing and deep breathing at the same intervals and for the same duration as incentive spirometry and CPAP were delivered. Coaching the patient to maximally inflate the lungs during conservative therapy was as effective as IS when treatments were delivered at similar intervals.

A major goal of postoperative respiratory therapy is

to increase FRC. Continuous positive airway pressure has been demonstrated to accomplish this by causing an increase in expiratory transpulmonary pressure.[21] Therefore, a method of delivering CPAP with a mask was used for intermittent postoperative therapy. These raw data show that 7.5 cm H_2O CPAP applied for 15 minutes at two-hour intervals was at least as effective as IS and CDB at normalizing FRC after upper abdominal operations. It was not until four hours after extubation that most patients had recovered sufficiently from general anesthesia to perform maneuvers for baseline lung volume determination. Measurements obtained four hours postoperatively revealed the most severe restrictive pulmonary defect of all postoperative lung volume measurements and reflect the clinical baseline justifying the use of aggressive respiratory therapy. When examined relative to the four-hour clinical baseline, CPAP restores FRC more quickly than CDB, with IS intermediate. Because this is a new application of CPAP therapy,[22] the optimal duration of treatment, interval between treatments, and levels of CPAP are not yet known. For this study, 7.5 cm H_2O was selected because it was well-tolerated and has been shown to have few detrimental side effects.[21] Higher levels of CPAP can be delivered by mask and, postoperatively, may be more beneficial than 7.5 cm H_2O.[20,22] Although FRC was not measured while patients wore CPAP masks, all patients experienced a decreased respiratory rate during the use of the mask. Sturgeon and co-workers[23] indicated that increased respiratory rate is associated with decreased lung compliance and decreased FRC. Therefore, it appears likely that FRC was increased during the use of the CPAP mask.

All patients included in this study developed a restrictive pulmonary defect. The 5 percent increase in FEV_1/FVC observed postoperatively may reflect a decrease in lung compliance and increased retractile force of the lung. It is unlikely that this observation is of any clinical significance.

The choice of respiratory therapy between CDB, IS, and mask CPAP may depend upon considerations other than improvement in pulmonary function. IS offers no advantage over CDB but does involve the added expense of the spirometer. Since both CDB and IS require supervision to be effective,[24] CDB is more economic. A vigorous CDB regimen requires no special equipment and can be delivered by less highly trained personnel. The CPAP mask requires nurses, respiratory therapists, or both familiar with its use, but may require less intensive supervision than IS or CDB once the mask has been applied. In addition, CPAP, unlike CDB or IS, does not require the patient to perform a painful task and success of the therapy does not depend upon the patient's effort. Complications associated with the use of CPAP were minimal: several patients experienced eructation, and nearly all reported that they had a dry mouth after wearing the mask. Although gastric distention from swallowing large quantities of gas is a possible complication, it did not occur.

Because 54 percent of these patients were over 50 years old, 16 percent had a preoperative FEV_1/FVC ratio less than 70 percent, 35 percent smoked cigarettes daily, and all had major upper abdominal operations, this patient sample was at high risk for developing postoperative pneumonia.[2,25-27] However, despite a postoperative decrease in FRC in all but two patients, the overall incidence of pneumonia for patients who participated in this study was only 3 percent and occurred in none of the patients who received CPAP. In other published reports, the incidence of pneumonia after upper abdominal operations is approximately 17 percent.[8-10] It is likely that the low incidence of pneumonia in our patients is attributable to the frequent and careful attention to respiratory care that they received, regardless of treatment regimen. All patients, including those who received conservative therapy, were coached to sit at the edge of the bed and take deep breaths with every treatment. Early, supervised, frequent mobilization with coaching to take deep breaths, with or without devices, resulted in a remarkably low incidence of serious pulmonary complications in a population at high risk for such complications.

In summary, patients who undergo upper abdominal operations experience proportional decreases in all lung volumes without clinically significant changes in the FEV_1/FVC ratio, indicating a restrictive pulmonary defect. Patients who received CPAP recovered from the postoperative restrictive defect at least as effectively as those who received IS or CDB, and perhaps more quickly than those who received conservative therapy. Incentive spirometry offered no statistically significant advantage over the CDB regimen. In addition, it appears that frequent, vigorous, and coached respiratory therapy, with or without devices, is associated with decreased incidence of postoperative pneumonia.

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