

A randomized controlled trial comparing periodic mask CPAP with physiotherapy after abdominal surgery

LINDA DENEHY and SARA CARROLL School of Physiotherapy, University of Melbourne, Australia
GEORGE NTOUMENOPOULOS Alfred Hospital, Prahran, Victoria, Australia
SUSAN JENKINS School of Physiotherapy, Curtin University of Technology, Western Australia

ABSTRACT Background and Purpose. *Physiotherapists use a variety of techniques aimed at improving lung volumes and secretion clearance in patients after surgery. Periodic continuous positive airway pressure (PCPAP) is used to treat patients following elective upper abdominal surgery. However, the optimal method of application has not been identified, more specifically, the dosage of application of PCPAP. The present randomized controlled trial compared the effects of two dosages of PCPAP application and 'traditional' physiotherapy upon functional residual capacity (FRC), vital capacity (VC), oxyhaemoglobin saturation (SpO₂), incidence of post-operative pulmonary complications and length of stay with a control group receiving 'traditional' physiotherapy only. Method.* Fifty-seven subjects were randomly allocated to one of three groups. All groups received 'traditional' physiotherapy twice daily for a minimum of three post-operative days. In addition, two groups received PCPAP for 15 or 30 minutes, four times per day, for three days. **Results.** Fifty subjects (39 male; 11 female) completed the study. There were no significant differences in any variables between the three groups. The overall incidence of post-operative pulmonary complications was 22% in the control group, 11% and 6% in the PCPAP 15-minute and PCPAP 30-minute groups, respectively. Length of hospital stay was not significantly different between the groups but for subjects who developed post-operative pulmonary complications, the length of stay was significantly greater ($Z = -2.32$; $p = 0.021$). **Conclusions.** The addition of PCPAP to a traditional physiotherapy post-operative treatment regimen after upper abdominal surgery did not significantly affect physiological or clinical outcomes.

Key words: abdominal surgery, CPAP, physiotherapy, post-operative pulmonary complications

INTRODUCTION

The aim of physiotherapy in patients after upper abdominal surgery is to minimize post-operative pulmonary complications,

thereby reducing patient morbidity and preventing a prolonged hospital admission (Bartlett et al., 1973; Roukema et al., 1988). To meet this objective, physiotherapists use a variety of techniques designed to improve

lung volumes and to clear excess bronchial secretions (Stiller and Munday, 1992). Several forms of peri-operative treatment are based on the use of positive pressure devices for patient management. The focus of the present research is the use of periodic continuous positive airway pressure (PCPAP) after upper abdominal surgery.

It is well-accepted that functional residual capacity (FRC) decreases after surgery (Craig, 1981; Wahba, 1991) and the magnitude of the change may vary with the type of surgery performed (Wahba, 1991). This reduction may result in FRC falling below closing volume, leading to dependent small airways closure and arterial hypoxaemia (Wilson, 1983). The application of PCPAP after upper abdominal surgery has been shown to improve FRC when compared to other forms of post-operative prophylaxis (Stock et al., 1985; Lindner et al., 1987). There is support for the improvement of atelectasis with PCPAP application after abdominal surgery (Andersen et al., 1980; Williamson and Modell, 1982; Stock et al., 1985; Duncan et al., 1987). However, the effects of PCPAP on the incidence of clinically significant post-operative pulmonary complications are unclear (Stock et al., 1985).

The method of application of PCPAP in previous literature is extremely diverse; the frequency, duration of application and number of days or hours of treatment varies between studies. Specifically, the duration of PCPAP used varies from 30 breaths per hour (Ricksten et al., 1986) to three continuous hours daily (Lindner et al., 1987). Where three hours' duration was used, PCPAP was administered only once. For intermittent treatment with PCPAP over three days, reflecting the clinical practice of the present study, it was decided to compare 15 minutes' with 30 minutes' duration of application. If an optimal duration of appli-

cation can be established, the effectiveness of PCPAP treatment may be enhanced. The present study compared the effects of two different durations of PCPAP application and 'traditional' physiotherapy upon FRC, VC, SpO₂, the incidence of post-operative pulmonary complications and length of hospital stay, in a control group receiving 'traditional' physiotherapy without PCPAP and in subjects after upper abdominal surgery.

METHOD

Subjects

Fifty-eight consecutive adult subjects admitted for elective upper abdominal surgery who met the inclusion criteria at the Austin and Repatriation Medical Centre, Melbourne, Australia were studied. The study was approved by the Human Research Ethics Committee of the hospital and written, informed consent was obtained from each subject. Subjects were considered for inclusion if they:

- Were admitted for upper abdominal surgery which was defined as surgery involving an incision above the umbilicus (Celli et al., 1984).
- Understood instructions given in English.
- Had a forced expiratory volume in one second (FEV₁) more than 50% of predicted value.

Subjects were withdrawn from the study if they missed more than two treatment sessions or were unable to co-operate with measurement procedures after surgery.

Procedure

Subjects were randomly allocated to one of three treatment groups by use of sealed

envelopes. The control group received 'traditional' physiotherapy without PCPAP, twice daily for a minimum of 10 minutes, for three post-operative days. The other two groups received PCPAP for 15 minutes or 30 minutes, respectively, four times per 24 hours, in addition to 'traditional' physiotherapy.

Physiotherapy treatment

All subjects received pre-operative education about the effects on the lungs of the surgical process and the benefits of early ambulation after surgery. They were instructed in deep-breathing exercises, including sustained maximal inspiration (Bakow, 1977), the forced expiration technique (Pryor 1991) and supported coughing. A written instruction sheet outlining the breathing and coughing exercises was given to all subjects. Post-operatively, all subjects received physiotherapy treatment twice daily, for the first three days, for a minimum of 10 minutes per session. This treatment ('traditional physiotherapy'), comprised deep-breathing exercises, forced expiration technique and supported cough. The subjects were ambulated as soon as the physiotherapist assessed that they were able. All treatments were performed by the ward physiotherapist with subjects sitting upright in bed or in a chair. The post-operative instruction sheet was placed in a position which could be seen by subjects and adherence to hourly deep-breathing exercises was encouraged, but not measured formally. For subjects in the PCPAP groups, physiotherapy treatment was given immediately before PCPAP application at 1100 and 1500 hours on the first three post-operative days.

PCPAP treatment

The CPAP circuit consisted of a nasal mask and strap (ResMed Ltd, Sydney, Australia)

attached to a Dragar CPAP unit (CF800 Draegerwerk, Germany) with an Ambu positive end expiratory pressure valve (Ambu International, Denmark) set at 10 cm H₂O (Figure 1). The circuit was run on 30% oxygen at a total flow rate of 30 l/min for both PCPAP groups. The accuracy of the CPAP pressure applied was determined using the CPAP unit inbuilt manometer. A deflection in pressure of ± 2 cm H₂O during treatment was considered acceptable. A timer with an audible alarm (Lab Supply, Melbourne, Australia) was attached to the CPAP unit to facilitate accurate application times. The set application times for PCPAP treatment were 0700, 1100, 1500 and 1900 hours. Nursing staff administered the PCPAP at 0700 and 1900 hours, the 1100 and 1500 hour applications were administered by the attending physiotherapist.

Measurement

Pre-operatively, subjects' demographic details, including age, height, sex, history of cigarette smoking, and colour and amount of sputum expectorated were recorded. The American Society of Anesthesiologists (ASA) scores were also recorded. Their ASA score (numbered 1-5) divides patients into five groups and collectively rates the risk to the patient of general anaesthesia. The attending anaesthetist ascribes a score to each patient upon pre-operative assessment. In addition, measurement of FEV₁ was performed by use of an ambulatory spirometer (Glaxo Australia, Melbourne, Australia). The highest of the three technically correct FEV₁ measurements was used in the analysis.

Bedside FRC was measured by use of multiple breath helium dilution with a thermal conductivity analyser (MD2, PK Morgan, Gillingham, UK) and watersealed spirometer (Godart pulmotest 1954, Biltho-



FIGURE 1: Patient receiving CPAP via a nasal mask and Dragar CPAP unit post-operatively.

van, Holland) using a standard measurement technique (Quanjer et al., 1993). Measurements were performed pre-operatively and on the first, second, third and fifth post-operative days with subjects sitting in a chair. Care was taken to ensure that subjects was sitting as upright as possible. Once helium concentration had reached equilibrium, two VC manoeuvres were performed and the highest value recorded. Oxyhaemoglobin saturation was measured with subjects seated in a chair, by use of a pulse oximeter and finger sensor (8500M, Nonin Medical, Plymouth, Minnesota USA) immediately before FRC measurement. Saturations were measured for 10 minutes with the patient breathing room air. Saturations were sampled every 20 seconds and all data were stored in the oximeter memory and down loaded using an interface to an Epson printer (model LQ 1000 Seiko Epson, Nagano, Japan). Mean data were used in analyses. Both FRC and SpO_2 were measured at least two hours after the 0700-hour PCPAP treatment but before the 1100-hour intervention.

Two physiotherapists were responsible for the FRC measurements. The researchers were blind to final FRC values during measurement as only initial and final helium concentrations were recorded and calculation of FRC was then necessary. Intra-rater reliability of the principal researcher was tested before the study, using 10 subjects with no history of respiratory disease. Subjects were tested twice on the same day with repeated measurements of FRC 20 minutes apart. The intra-class correlation coefficient (ICC 3,1) demonstrated good agreement (0.98), and the standard error measure (SEM) was 72 ml. Inter-rater reliability of FRC measurements for the principal researcher and the second physiotherapist was tested in a further study using 15 subjects, without a history of respiratory disease, who performed two FRC measurements separated by 20 minutes. One test was performed by the first physiotherapist, the other by the second physiotherapist, and the order of testing was alternated. The ICC (2,1) also demonstrated good inter-rater agreement (0.94), and the SEM was 126 ml.

Pain was assessed, by use of a visual analogue scale, with subjects at rest immediately before each post-operative measurement session using a 10-cm horizontal ungraduated line, with two verbal anchors, 'No pain' and 'The worst possible pain'. All subjects were asked to mark the line at a point which they felt reflected their pain at the time of measurement. Chest radiographs were taken pre-operatively and on the third day after surgery. These were compared, and the post-operative film scored retrospectively by a radiologist blinded to treatment group by use of the following scale:

- 0 = No abnormality detected.
- 1 = Minor collapse or consolidation at one or both lung bases.
- 2 = Moderate collapse or consolidation at one lung base.
- 3 = Moderate collapse or consolidation at both lung bases or lobar collapse of one lobe.
- 4 = Major collapse or consolidation (lobar), more than one lobe.

Intra-rater reliability of the radiologist was studied using repeat viewing of the same 46 chest radiographs from subjects in the study, in random order, one week after initial scoring. The ICC (3,1) obtained was 0.84, indicating good intra-rater agreement (Portney and Watkins, 1993).

The maximum oral temperature documented daily, type of analgesia, post-operative sputum colour and volume, and surgical details were recorded from the subjects' notes. The incidence of clinically significant post-operative pulmonary complications and length of post-operative hospital stay were also documented. A post-operative pulmonary complication was defined as an oral temperature higher than 38°C for more than 24 hours, a chest radi-

ograph score of two or more, and one of: raised white cell count; altered sputum; microbiological isolation of a potential pathogen from sputum; or use of additional antibiotic treatment (Wilson et al., 1988).

Data management

Data were analysed by use of *Statview SE* and *Graphics* (Abacus Concepts, Inc., Berkeley, USA). FRC and VC were presented as a percentage of pre-operative value. The continuous variables FRC, SpO₂ and pain scores were analysed by use of a two-way analysis of variance (ANOVA) for repeated measures. Simple effects testing by use of factorial ANOVA and the Scheffé-*f* test were used to determine where differences existed in significant results. Chest radiograph scores were compared by use of a Kruskal-Wallis analysis of variance by ranks. Post-operative length of stay, duration of anaesthesia, and age were each compared by use of a one-way ANOVA. Differences in length of stay and SpO₂ between subjects with a post-operative pulmonary complications and those without were tested by use of a Mann-Whitney U test because of unequal sample sizes. Nominal data were compared by use of chi-square test. Throughout the data, sample size varies as *Statview SE* omits subjects with any missing data from analysis. Alpha was set at 0.05.

RESULTS

Fifty-eight subjects (45 male; 13 female) were recruited; one subject was excluded because his FEV₁ was less than 50% predicted and seven subjects were withdrawn from the study. Two of these seven subjects missed more than two PCPAP treatments and one subject refused all measurements. The remaining four subjects refused or were

unable to perform FRC measurements as a result of nausea or vomiting, the presence of a large nasogastric tube and, in one case, as a result of severe oxyhaemoglobin desaturation to 85% when supplemental oxygen was removed. Fifty subjects (39 male; 11 female) ranging in age from 58 to 83 years completed the study. Demographic and surgical details of the 50 subjects are given in Table 1. There were no significant differences in descriptive or operative data between the groups. One subject died of

surgical complications on the 32nd day of admission. All subjects received the treatment to which they had been allocated.

Forty subjects (80%) performed lung volume measurements (FRC and VC) on all five occasions and the data from only these patients were included in analyses of FRC and VC: 13 in the control group; 15 in the 15-minutes' CPAP group; and 12 in the 30-minutes' CPAP group. There were no significant differences between the groups in the pre-operative FRC values (see Table 1).

TABLE 1: Descriptive and operative data giving means (standard deviations), except where indicated				
Data	Control n=18 (3 females)	15 min CPAP n=17 (5 females)	30 min CPAP n=15 (3 females)	p value
Age (years)	73.3 (5.8)	72.5 (6.5)	70.5 (6.3)	0.421
Frequency of smoking:				
current smoker	2	3	0	0.645
ex-smoker	11	7	10	
never smoked	5	7	5	
Pre-op Fev ₁ (litres)	23 (0.6)	2.3 (0.8)	2.4 (0.6)	0.972
Pre-op FRC(litres)	3.5 (0.8)	3.5 (0.9)	3.2 (0.8)	0.551
Type of surgery:				
colorectal	10	14	11	0.531
hepatobiliary	6	2	3	
other	2	1	1	
Duration of anaesthesia (hours)	2.6 (0.6)	2.9 (0.9)	3.0 (0.9)	0.278
Type of analgesia:*				
epidural	12	11	10	0.925
PCA	3	3	4	
narcotic infusion	2	2	1	
Frequency of ASA:**				
1	3	1	1	0.902
2	5	9	8	
3	6	4	3	
4	1	2	1	
5	0	0	0	
Post-operative length of stay (days)	123 (4.8)	11.5 (4.1)	12.5 (4.8)	0.714

CPAP = continuous positive airway pressure; FEV₁, forced expiratory volume in one second; FRC = functional residual capacity; ASA = American Society of Anesthetists classification of co-morbidity; PCA = patient controlled analgesia.
* Analgesia data from two subjects are missing. ** Not all ASA scores recorded by anaesthetists, data from six subjects are missing.

There was no significant difference in FRC between the groups, nor was there a significant group \times time interaction when FRC was compared between groups for the first, second, third and fifth post-operative days. There was, however, a significant difference in mean FRC values across time ($F(3,111) = 5.29$; $p = 0.002$). Upon testing for simple effects, differences in FRC were evident between days 2 and 5 values. The FRC reduced to its lowest value in all groups by the second post-operative day. This was followed by a gradual recovery, although pre-operative values had not been reached by the fifth post-operative day (Table 2). Considerable variability was observed in post-operative FRC values between subjects. Functional residual capacity was as low as 45–50% of pre-operative values in five subjects on Day 1 post-operatively, and in seven patients on days 2 and 3.

Vital capacity decreased to between 60% and 70% of pre-operative values, most commonly by the second post-operative day. There was no significant difference in VC between the three groups, nor was there a significant difference between groups in the pattern of change which occurred over time. VC did change significantly across time (F

(3,108) = 24.84; $p < 0.001$) reaching its lowest values on the first and second post-operative days and returning toward pre-operative values by the fifth day (see Table 2). Upon simple effects testing, differences in VC were evident comparing Day 1 with days 3 and 5 and between Day 2 and days 3 and 5.

There were no significant differences in mean SpO₂ between groups and no significant difference in the pattern of SpO₂ changes between groups over the post-operative measurement period. There was a significant difference in SpO₂ values across time ($F(3,120) = 17.45$; $p = 0.001$). Upon simple effects testing, these differences were found to be between days 1 and 5, and Day 2 compared with days 3 and 5. Oxyhaemoglobin saturation reduced to its lowest level in all groups by the second post-operative day and gradually returned toward pre-operative values on subsequent days (Table 3). Mean SpO₂ values remained above 90% for all groups, however, 26% of subjects had values of 90% or below on Day 1 post-operatively, increasing to 29% on Day 2. By Day 3 only 7% of patients had saturations below 90%.

Pain scores at rest were low, reduced further over time from surgery ($F(3,117) =$

TABLE 2: Mean (SD) results for FRC* and VC** presented as a percentage of pre-operative value for each group on each of four post-operative days

Post-operative day	Control		15-minutes' CPAP		30-minutes' CPAP	
	VC	FRC	VC	FRC	VC	FRC
1	70.2 (14.6)	82.4 (11.6)	64.4 (14.0)	78.9 (20.2)	60.9 (15.8)	82.6 (16.6)
2	64.4 (12.7)	72.9 (13.9)	64.9 (13.7)	77.6 (19.9)	59.9 (12.2)	74.7 (12.7)
3	80.0 (15.2)	82.5 (20.4)	69.6 (15.4)	77.6 (23.1)	70.0 (11.1)	83.6 (18.3)
5	86.8 (17.1)	78.0 (19.5)	82.5 (13.7)	88.2 (18.2)	77.1 (10.2)	90.5 (20.7)

FRC = functional residual capacity; VC = vital capacity. *Change in FRC across time was significant at $p = 0.002$ (Day 2 compared with Day 5). **Change in VC across time was significant at $p < 0.001$ (days 1 and 2 compared with days 3 and 5). CPAP = continuous positive airway pressure.

TABLE 3: Mean (SD) results for SpO₂ for each group on each of four post-operative days

Post-operative day	Control (n=16)	15 minutes' CPAP (n=14)	30 minutes' CPAP (n=13)
1	97 (1.2)	97 (1.2)	97 (1.2)
2	92 (2.5)	93 (2.7)	93 (2.3)
3	91 (3.3)	92 (2.7)	94 (2.3)
5	94 (2.2)	96 (1.7)	95 (1.3)

CPAP = continuous positive airway pressure; SpO₂ = oxyhaemoglobin saturation. *Change in SpO₂ across time was significant at $p = 0.0001$ (Day 1 compared with Day 5 and Day 2 compared with days 3 and 5).

5.90; $p < 0.001$) and did not differ significantly between groups. Upon simple effects testing, significant differences in pain scores were found between days 1 and 5. Mean scores in cm (SD) on Day 1 post-operatively were: control group 1.7 (1.7); 15-minutes' PCPAP group 2.8 (2.4); 30-minutes' PCPAP group 2.5 (2.0), and on Day 5 after surgery, were control group 1.4 (1.3), 15-minutes' PCPAP group 1.0 (1.2) and 30-minutes' PCPAP group 1.3 (0.8).

There was no significant difference in mean length of stay between the groups ($F(2,47) = 0.34$; $p = 0.714$) (see Table 1), nor was there any difference in mean chest radiograph score between the groups ($H(2,46) = 2.90$; $p = 0.235$). However, 69.6% of all subjects had some degree of collapse or consolidation on chest radiographs on the third post-operative day. The proportion of subjects with reported chest radiograph changes (score one, two, three or four) was less in both PCPAP groups; however, this was not statistically significant (chi-square test (2) = 4.47; $p = 0.107$). In subjects receiving PCPAP, 60% in the 15-minutes' PCPAP group and 57% in the 30-minutes' PCPAP group had evidence of chest radiograph changes compared with 88% in the control group. The proportion of subjects having moderate (score 2 or 3) collapse or consolidation on chest radiograph was similar in all groups.

The incidence of post-operative pulmonary complications was low (14%) and occurred in seven subjects across all groups, rendering statistical analysis inappropriate. Post-operative pulmonary complications occurred in 22% (4/18) of control group subjects, 11% (2/17) and 6% (1/15) of PCPAP 15-minute and PCPAP 30-minute groups, respectively. Subjects who developed post-operative pulmonary complications had significantly lower SpO₂ on days 2 (89 (± 1.8) compared with 92.7 (± 2.8)), ($Z = -2.95$; $p = 0.003$) and 5 (93 (± 1.4) compared with 95 (± 1.7)), ($Z = -3.05$; $p = 0.002$) compared with subjects who did not. FRC was also significantly reduced on Day 3 in subjects with post-operative pulmonary complications (69% ($\pm 28.8\%$) compared with 83% ($\pm 18.2\%$)) ($Z = -2.06$; $p = 0.039$). In addition, patients with post-operative pulmonary complications had a significantly longer post-operative stay in hospital, 13 (range 12–19) days compared with 11 (range 6–25) days ($Z = -2.32$; $p = 0.021$).

DISCUSSION

The present study found no significant differences in FRC, VC, SpO₂ or pain scores between the group receiving 'traditional' physiotherapy comprising deep-breathing exercises, forced expiration technique, cough and early ambulation and the two



groups that received PCPAP in addition to 'traditional' physiotherapy'. Mean values for FRC, VC and SpO₂ reduced significantly after surgery, reaching lowest values on days 2 and 3 post-operatively. The incidence of post-operative pulmonary complications demonstrated a trend toward being lower in the group receiving 30-minute applications of PCPAP. For subjects who developed post-operative pulmonary complications, the median length of stay was significantly greater, however, there was no significant difference between the three groups.

The pattern and magnitude of change in both FRC and VC are consistent with other reports (Latimer et al., 1971; Ali et al., 1974; Craig, 1981; Ali et al., 1984; Stock et al., 1985; Ricksten et al., 1986) showing significant deterioration in pulmonary function after upper abdominal surgery. The delay in maximum reductions of FRC until the second post-operative day suggests that, potentially, intervention may minimize this physiological change in the post-operative period (Craig, 1981). Previous studies report that FRC reduced to its lowest value in the first 24 hours after surgery (Ali et al., 1984; Lindner et al., 1987). In the present study it was found that lowest values of FRC were reached on the second or third post-operative day. The timing of FRC measurement may influence this result, with studies varying measurement time between days 1 and 3 (Lindner et al., 1987; Wahba, 1991). Additionally, the time of operation on the day of surgery may have influenced the present results. Surgery was performed both in the morning (30% of subjects) and afternoon (70% of subjects) on the wards where measurement took place.

The application of PCPAP has been shown to improve FRC in different subject groups (Andersen et al., 1980; Stock et al.,

1985; Lindner et al., 1987; Putensen et al., 1993). The mechanisms by which CPAP increases FRC are thought to be through progressive increases in alveolar volume with increases in the magnitude of positive end expiratory pressure (Katz et al., 1981; Peruzzi 1996) and by increasing transpulmonary pressure at end expiration, favouring recruitment of collapsed alveoli (Lum et al., 1990). It is suggested that, in subjects with atelectasis after surgery, application of PCPAP may recruit collapsed alveoli by promoting collateral airflow (Andersen et al., 1979), aided by the phenomenon of alveolar interdependence (West, 2000). Stock et al. (1985) state that after surgery FRC may improve more quickly with PCPAP application compared with a regimen of deep breathing and coughing or incentive spirometry. All subjects in their study also received early and frequent mobilization, similar to the present study. Although there was a trend toward faster improvement in FRC in the PCPAP groups in the present study, results failed to reach statistical significance. This may be due to the large variability in FRC values combined with small subject numbers in each treatment group. The rationale for presenting values as a percentage of pre-operative FRC, was to minimize individual variation. Subject responses to the surgical process, as measured by changes in FRC, showed considerable variation in the present study which is consistent with other reports in patients after upper abdominal surgery (Stock et al., 1985; Kesten and Rebeck 1990) and cardiac surgery (Jenkins et al., 1989). Variability resulting from measurement error using the portable FRC measurement system described was relatively small and therefore could account for only a small degree of the variability obtained in FRC values.

Subjects who received 30-minute PCPAP applications four times daily did not show any greater improvement in mean FRC than those having 15-minute applications. It was hypothesized that a longer duration of PCPAP may have been successful in recruiting a greater number of alveoli and therefore improve the measured FRC. In addition, it was thought that after 30 minutes' application there may have been a greater carryover effect of alveolar recruitment. However there has been no research which documents the carryover effects of intermittent application of PCPAP. It is unclear whether extending the application time to one or two hours, or altering the frequency of application, would be more effective in recruiting alveoli, keeping them open and thereby improving FRC. This is an area which needs further investigation.

In addition, the timing of PCPAP application in relation to subjects' return to the ward from theatre may have an important influence on its effectiveness. Some authors suggest that early application within the first hour after surgery may be more beneficial in recruiting alveoli than intermittent applications over three days (Ricksten et al., 1986; Lindner et al., 1987).

Previous research using PCPAP after surgery has described inconsistent application times as well as variable PCPAP treatment regimens, making comparison of study results difficult. Although the time, frequency and level of positive pressure of PCPAP application varied between studies, all studies reported favourable outcomes from its use. In the present study, the frequency of application (four times daily) of PCPAP may have been insufficient to promote a significant improvement in lung volumes. However, to date there is no reported research which examines the effectiveness of individual components of the

PCPAP treatment regimen in isolation. Many facilities require increased nursing care ratios or patients to remain in a high dependency environment when receiving regular PCPAP treatment, although this was not the case in the present study. Because of this, it may be possible that the costs of supplying PCPAP four times daily for three post-operative days, outweighs the benefits of use of this technique as a prophylactic measure after upper abdominal surgery.

The development of clinically significant post-operative pulmonary complications in the present study was defined by use of a combination of clinical and radiological criteria. The definition of post-operative pulmonary complications used in previous literature varies considerably. In studies which define post-operative pulmonary complications based only on chest radiograph changes, the reported incidence of post-operative pulmonary complications may be as high as 70% (O'Donohue, 1985; Dilworth and White 1992) compared with an incidence of post-operative pulmonary complications of 5–20% in studies using a combination of outcome variables for definition (Craven et al., 1974; Celli et al., 1984; Hall et al., 1996; Chumillas et al., 1998). The results for post-operative pulmonary complications obtained in the present study were consistent with those reports which used a combination of variables for measurement.

More recently, researchers have attempted to define post-operative pulmonary complications with reference to the clinical significance of the problem, including consideration of both hospital and patient costs. A significant complication has been defined as one which may cause an unexpected progression of post-operative recovery to a second disease entity (O'Donohue, 1992). Although it may be

useful to discern between self-limiting clinical sequelae and those which may result in increased resource use, specific criteria for this definition have not been reported. Patients who develop significant post-operative pulmonary complications would be expected to have a significantly longer post-operative length of hospital stay, utilize more services, and as a consequence, incur greater hospital costs. In the present study, there was no difference in length of stay between treatment groups but those identified with a post-operative pulmonary complications had a significantly longer hospital stay and significantly lower FRC and SpO₂. This result is corroborated by the work of Ali et al. (1984), who found that FRC, VC and partial pressure of oxygen were significantly reduced in subjects who developed a post-operative pulmonary complications after open cholecystectomy. The degree of hypoxaemia appears to be closely related to FRC (Alexander et al., 1973; Ali et al., 1984). Few studies have examined the relationship between hypoxaemia and the development of post-operative pulmonary complications, although Aldren and colleagues (1991) report a strong correlation between these variables over five post-operative days.

There was a trend for post-operative pulmonary complications to be lowest in the group which received 30-minute applications of PCPAP treatment. It is possible that application of 30 minutes of PCPAP promoted clinically, but not statistically significant increases in FRC, allowing this volume to remain greater than closing volume, thereby reducing the extent of small airway closure. This conclusion may also be supported, in part, by the lower incidence of chest radiograph changes of atelectasis or consolidation in this group compared with the other groups.

The mean age of subjects was over 70 years. Subject populations studied in previous research comparing different methods of post-operative prophylaxis have been generally younger, with reported mean ages between 50 and 60 years (Dohi and Gold, 1978; Ricksten et al., 1986; Lindner et al., 1987; Hall et al., 1991a; Olsen et al., 1997; Chumillas et al., 1998). Increasing age is cited as a significant risk factor for developing post-operative pulmonary complications (Hall et al., 1991b; Calligaro et al., 1993; Kroenke et al., 1993). This is most probably due to alterations in lung volumes with increasing age, specifically the relationship between FRC and closing volume (Leblanc et al., 1970; Craig, 1981).

The age of the present study population, together with the site (McKeague and Cunningham, 1997) and duration (Windsor and Hill, 1988) of surgery and the median ASA classification of two (Hall et al., 1991a) defines a high-risk group of patients (see Table 1). Therefore, other factors may have contributed to the low incidence of post-operative pulmonary complications in this patient group. A combination of factors, including the methods of prophylactic peri-operative care (O'Donohue, 1992) and the management of post-operative pain, may have been influential. All subjects received pre-operative education and instruction by the physiotherapist. Olsen et al. (1997) reported that subjects who received pre-operative physiotherapy had a significantly lower incidence of post-operative pulmonary complications after upper abdominal surgery compared to a control group who had no physiotherapy. Indeed, early sitting out of bed and mobilization in this group of subjects may have been appropriate post-operatively prophylaxis, without any further treatment. There is

support for this assumption in the cardiac surgery population (Jenkins et al., 1989; Stiller et al., 1991) but not yet in upper abdominal surgery.

In addition, the type and effectiveness of pain management may also be important. Pain was measured at rest prior to other measurements. Seventy per cent of patients received epidural analgesia, and this has been associated with a lower incidence of post-operative pulmonary complications (Ballantyne et al., 1998).

The risk factors for developing post-operative pulmonary complications after upper abdominal surgery remain controversial, despite the fact that many papers are published which attempt to provide risk factor classifications (Hall et al., 1991b; Brooks-Brunn, 1995). The interplay of pre-operative, intra-operative and post-operative factors in the development of post-operative pulmonary complications are extremely complex and, as yet, no valid model for predicting outcome has been developed. It is possible that, despite using the risk classification of Hall et al. (1991b), who studied over 1000 patients after abdominal surgery, the subjects in the present study should not, in fact, be considered high risk. Although they were older and had undergone upper abdominal surgery, few were current smokers or had a history of respiratory disease, and post-operative pain scores were low. These factors may help to explain the low incidence of post-operative pulmonary complications in this group of subjects and, combined with inadequate statistical power, failed to demonstrate any differences in the major outcome variables.

The most important limitation of the present study is the small number of subjects. In addition, subjects' adherence to practice of deep breathing and coughing exercises taught by the physiotherapist was

not measured. Adherence to practice is difficult to assess but may influence morbidity (Ferri et al., 1998). Deep-breathing exercises performed regularly may provide prophylaxis against reductions in lung volumes and post-operative pulmonary complications (Bartlett, 1982; O'Donohue, 1992; Celli, 1993). A further limitation of the present study was that the day of ambulation of subjects in each group was not documented prospectively. All subjects got out of bed and ambulated as soon as possible after surgery but future research should aim to document the commencement and frequency of mobilization as this may be an important prophylactic treatment in its own right (Dean, 1987; Jenkins et al., 1989).

The present study was difficult to perform because measurement of FRC by use of multiple breath helium dilution at the bedside in the early post-operative period presented many obstacles. Primarily, the presence of a wide bore nasogastric tube made achievement of a closed circuit between subjects and spirometer very difficult. Nausea, commonly present after abdominal surgery, was often exacerbated by the presence of the large mouthpiece and nasal occlusion required during measurement of FRC. These were significant factors in loss of lung volume data in the study. All groups received conventional post-operative physiotherapy management in the present study because existing research supports the role of physiotherapy in some form in minimizing post-operative pulmonary complications in this patient group, however, the specific treatment modalities included vary considerably throughout the world. To include a 'no-treatment' control group may have raised ethical objections in the centre where the study was performed.

In conclusion, the application of PCPAP

treatment for 15 or 30 minutes, when added to a traditional post-operative physiotherapy regimen, did not significantly affect FRC, VC or SpO₂ after upper abdominal surgery. The incidence of post-operative pulmonary complications was low in all groups but demonstrated a trend toward being decreased in the patients who received 30 minutes of PCPAP, four times daily, for three post-operative days. The generalizability of these results is limited by small sample sizes combined with large variability in subjects' response to surgery. Future research should investigate the use of PCPAP in subjects with established pulmonary complications after surgery. The role of other prophylactic measures, such as pre-operative physiotherapy and early ambulation alone, in altering the incidence of post-operative pulmonary complications after upper abdominal surgery should also be studied.

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REFERENCES

- Aldren C, Barr L, Leach R. Hypoxaemia and postoperative pulmonary complications. *British Journal of Surgery* 1991; 78: 1307-1308.
- Alexander JJ, Spence AA, Parikh RK, Stuart B. The role of airway closure in postoperative hypoxaemia. *British Journal of Anaesthesia* 1973; 45: 34-40.
- Ali J, Serrette C, Wood L, Anthonisen N. Effect of post-operative intermittent positive pressure breathing on lung function, *Chest* 1984; 85: 192-196.
- Ali J, Weisel RD, Layug AB, Kripke BJ, Hechtman HB. Consequences of postoperative alterations in respiratory mechanics. *American Journal of Surgery* 1974; 128: 376-382.
- Andersen J, Olsen B, Eikhard B, Jansen E, Qvist J. Periodic continuous positive airway pressure, CPAP, by mask in the treatment of atelectasis. *European Journal of Respiratory Disease* 1980; 61: 20-25.
- Andersen J, Qvist J, Kann H. Recruiting collapsed lung through collateral channels with positive end-expiratory pressure. *Scandinavian Journal of Respiratory Disease* 1979; 60: 260-266.
- Bakow ED. Sustained maximal inspiration: a rationale for its use. *Respiratory Care* 1977; 22: 379-382.
- Ballantyne J, Carr D, deFarranti S, Suarez T, Lau J, Chalmers T et al. The comparative effects of postoperative analgesic therapies on pulmonary outcome: cumulative meta-analyses of randomized, controlled trials. *Anesthesia and Analgesia* 1998; 86: 598-612.
- Bartlett R. Postoperative pulmonary prophylaxis. *Chest* 1982; 81: 1-3.
- Bartlett R, Gazzaniga A, Geraghty T. Respiratory maneuvers to prevent postoperative pulmonary complications: a critical review. *Journal of the American Medical Association* 1973; 224: 1017-1020.
- Brooks-Brunn JA. Postoperative atelectosis and pneumonia. *Heart and Lung* 1995; 24: 94-115.
- Calligaro KD, Azurin DJ, Dougherty MJ, Dandora R, Bajgier SM. Pulmonary risk factors of elective abdominal aortic surgery. *Journal of Vascular Surgery* 1993; 18: 914-920.
- Celli B. Perioperative respiratory care of the patient undergoing upper abdominal surgery. *Clinics in Chest Medicine* 1993; 14: 253-261.
- Celli B, Rodriguez K, Snider G. A controlled trial of intermittent positive pressure breathing, incentive spirometry and deep breathing exercises in preventing pulmonary complications after abdominal surgery. *American Review of Respiratory Disease* 1984; 130: 12-15.
- Chumillas S, Ponce JL, Delgado F, Viciano V, Mateu M. Prevention of postoperative pulmonary complications through respiratory rehabilitation: a controlled clinical study. *Archives of Physical and Medical Rehabilitation* 1998; 79: 5-9.
- Craig DB. Postoperative recovery of pulmonary function. *Anesthesia and Analgesia* 1981; 60: 46-52.
- Craven JL, Evans GA, Davenport PJ, Williams RHP. The evaluation of the incentive spirometer in the management of postoperative pulmonary complications. *British Journal of Surgery* 1974; 61: 793-797.
- Dean E. Mobilisation and exercise. In: Frownfelter D, Dean E (eds). *Principles and Practice of*

- Cardiopulmonary Physical Therapy. New York: Mosby, 1987; 265-296.
- Dilworth JP, White RJ. Postoperative chest infection after upper abdominal surgery: an important problem for smokers. *Respiratory Medicine* 1992; 86: 205-210.
- Dohi S, Gold MI. Comparison of two methods of postoperative respiratory care. *Chest* 1978; 73: 592-595.
- Duncan S, Negrin R, Mihm F, Guilleminault C, Raffin T. Nasal continuous positive airway pressure in atelectasis. *Chest* 1987; 92: 621-624.
- Ferri M, Brooks D, Goldstein R. Compliance with treatment-an ongoing concern. *Physiotherapy Canada* 1998; 1: 286-290.
- Hall JC, Tarala R, Harris J, Tapper J, Christiansen K. Incentive spirometry versus routine chest physiotherapy for prevention of pulmonary complications after abdominal surgery. *Lancet* 1991a; 337: 953-956.
- Hall JC, Tarala RA, Hall JL, Mander J. A multivariate analysis of the risk of pulmonary complications after laparotomy. *Chest* 1991b; 99: 923-927.
- Hall JC, Tarala RA, Tapper J, Hall JL. Prevention of respiratory complications after abdominal surgery: a randomised clinical trial. *British Medical Journal* 1996; 312: 148-152.
- Jenkins SC, Soutar SA, Loukota JM, Johnson LC, Moxham J. Physiotherapy after coronary artery surgery: are breathing exercises necessary? *Thorax* 1989; 44: 634-639.
- Katz J, Ozanne G. Time course and mechanisms of lung volume increase with PEEP in acute pulmonary failure. *Anesthesiology* 1981; 54: 9-16.
- Kesten S, Rebuck A. Ventilatory effects of nasal continuous positive airway pressure. *European Respiratory Journal* 1990; 3: 498-501.
- Kroenke K, Lawrence VA, Theroux JF, Tuley M, Hilsenbeck S. Postoperative complications after thoracic and major abdominal surgery in patients with and without obstructive lung disease. *Chest* 1993; 104: 1445-1451.
- Latimer R, Dickman M, Day W, Gunn M, Schmidt C. Ventilatory patterns and pulmonary complications after upper abdominal surgery determined by preoperative and postoperative computerized spirometry and blood gas analysis. *American Journal of Surgery* 1971; 122: 622-632.
- Leblanc P, Ruff F, Milic-Emili J. Effects of age and body position on 'airway closure' in man. *Journal of Applied Physiology* 1970; 28: 448-451.
- Lindner K, Lotz PAhnefeld F. Continuous positive airway pressure effect on functional residual capacity, vital capacity and its subdivisions. *Chest* 1987; 92: 66-70.
- Lum H, Huang I, Mitzner W. Morphological evidence for alveolar recruitment during inflation at high transpulmonary pressure. *American Physiological Society* 1990; 90: 2280-2286.
- McKeague H, Cunningham AJ. Postoperative respiratory dysfunction: is the site of surgery crucial? *British Journal of Anaesthesia* 1997; 79: 415-416.
- O'Donohue WJ. Prevention and treatment of postoperative atelectasis: can it and will it be adequately studied? *Chest* 1985; 87: 1-2.
- O'Donohue W. Postoperative pulmonary complications. *Postgraduate Medicine* 1992; 91: 167-175.
- Olsen MF, Hahn I, Nordgren S, Lönroth H, Lundholm K. Randomized controlled trial of prophylactic chest physiotherapy in major abdominal surgery. *British Journal of Surgery* 1997; 84: 1535-1538.
- Peruzzi W. The current status of PEEP. *Respiratory Care* 1996; 41: 273-279.
- Portney L, Watkins M. *Foundations of Clinical Research: Applications to Practise*. New York: Appleton & Lange, 1993.
- Pryor J. The forced expiration technique. In: Pryor J (Ed.). *Respiratory Care*. London: Churchill Livingstone, 1991; 79-99.
- Putensen C, Hormann C, Baum M, Lingnau W. Comparison of mask and nasal continuous positive airway pressure after extubation and mechanical ventilation. *Critical Care Medicine* 1993; 21: 357-363.
- Quanjer PH, Tammeling G, Cotes J, Pedersen O, Peslin R, Yernault J-C. Lung volumes and forced ventilatory flows. *European Respiratory Journal* 1993; 6: 5-40.
- Ricksten S, Bengtsson A, Soderberg C, Thorden M, Kvist H. Effects of periodic positive airway pressure by mask on postoperative pulmonary function. *Chest* 1986; 89: 774-781.
- Roukema J, Carol E, Prins J. The prevention of pulmonary complications after upper abdominal surgery in patients with noncompromised pulmonary status. *Archives of Surgery* 1988; 123: 30-34.
- Stiller KR, Munday RM. Chest physiotherapy for the surgical patient. *British Journal of Surgery* 1992; 79: 745-749.
- Stock M, Downs J, Gauer P, Alster J, Imrey P. Prevention of postoperative pulmonary complications with CPAP, incentive spirometry, and conservative therapy. *Chest* 1985; 87: 151-157.
- Wahba R. Perioperative functional residual capacity. *Canadian Journal of Anaesthesia* 1991; 38: 384-400.

Williamson D, Modell J. Intermittent continuous positive airway pressure by aask. *Archives of Surgery* 1982; 117: 970-972.

Wilson APR, Treasure T, Grüneberg RN, Sturridge ME, Burrige J. Should the temperature chart influence management in cardiac operations? *Journal of Thoracic and Cardiovascular Surgery* 1988; 96: 518-523.

Wilson R. Intermittent CPAP to prevent atelectasis in postoperative patients. *Respiratory Care* 1983; 28: 71-73.

Windsor JA, Hill GL. Risk factors for postoperative pneumonia. *Annals of Surgery* 1988; 208: 209-214.

*Address for correspondence: Linda Denehy, School of Physiotherapy, University of Melbourne, Parkville 3010, Victoria, Australia
(E-mail: l.denehy@physio.unimelb.edu.au).*

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