Positive End-Expiratory Pressure following Coronary Artery Bypass Grafting*


Pulmonary dysfunction commonly follows open heart surgery. To evaluate the effects of positive end-expiratory pressure (PEEP) upon the course and severity of impaired oxygen transfer and roentgenographic evidence of atelectasis after coronary artery bypass grafting (CABG), we randomly assigned 44 patients to positive pressure ventilation and 0, 5, or 10 cm H₂O PEEP. Study groups did not differ with respect to preoperative P(A-a)O₂ or time on cardiopulmonary bypass. We observed a significant reduction of P(A-a)O₂ during positive pressure ventilation with 10 cm H₂O PEEP and FIO₂ = 0.6 (182 ± 6 vs 135 ± 7 mm Hg, p < .005). Following extubation, P(A-a)O₂ measurements of the three groups did not differ when compared 24, 48, 72, 96, or 120 hours after surgery. Roentgenographic atelectasis scores did not differ on the fifth postoperative day. Five days after CABG, P(A-a)O₂ exceeded preoperative P(A-a)O₂ (29 ± 1 vs 18 ± 1 mm Hg, p < .001), although the roentgenographic distances from hemidiaphragm to lung apex were unchanged (21.2 ± 0.9 vs 22.0 ± 0.9 cm). We conclude that routine PEEP improves pulmonary oxygen transfer but, once discontinued, PEEP does not maintain beneficial effect upon impaired oxygen transfer or roentgenographic evidence of atelectasis following CABG.

Pulmonary complications remain important causes of morbidity and mortality following cardiovascular surgery. Atelectasis occurs in 62 to 84 percent of patients who undergo open heart surgery, and arterial hypoxemia commonly accompanies atelectasis. Because of the risks associated with postoperative atelectasis and arterial hypoxemia, a number of therapeutic measures are commonly prescribed to maintain pulmonary inflow. In a recent survey, O'Donohue* reported that postoperative prophylactic measures for lung expansion are prescribed for all high-risk patients in 50 percent of United States hospitals. These measures include incentive spirometry, chest physical therapy, intermittent positive pressure breathing (IPPB), blow bottles, and intermittent continuous positive airway pressure (CPAP).

The application of positive end-expiratory pressure (PEEP) following open heart surgery remains controversial. Housman et al* reported benefits associated with the routine administration of PEEP, whereas Good et al* and Drugge et al* concluded that PEEP offered no advantage over standard ventilatory techniques. The latter two studies examined arterial oxygenation during the first postoperative day. Since arterial hypoxemia following open heart surgery is often prolonged, and since airway collapse in the immediate postoperative period may cause postoperative hypoxemia, we hypothesized that routine PEEP can reverse postoperative atelectasis and decrease the duration and severity of arterial hypoxemia after open heart surgery. To test this hypothesis, we randomly assigned 44 patients to positive pressure ventilation (PPV) with or without PEEP following open heart surgery. We report results of arterial blood gas analyses and chest roentgenograms during the first five postoperative days.

Methods

All patients who underwent coronary artery bypass grafting (CABG) between October 2 and December 18, 1983 were included in the study. General anesthesia was maintained with isoflurane and thiopental sodium, and the lungs were not ventilated during cardiopulmonary bypass. Before surgery, 68 of 91 patients gave informed consent in accordance with the LDS Hospital guidelines for human subjects. The following data were recorded before randomization: 1) age; 2) sex; 3) height; 4) weight; 5) preoperative PaO₂, PaCO₂, and pH; 6) smoking history; 7) anesthesia time; 8) bypass time; 9) transfused blood volume; and 10) net fluid balance during surgery.

Upon returning to the thoracic surgical intensive care unit, those patients with signed informed consent were evaluated for randomized treatment assignment. Twenty-four patients were excluded at that time or shortly thereafter because of severe left ventricular dysfunction requiring pharmacologic support (dopamine) or intraaortic balloon assist devices (n = 12), blood pressure < 100/60 or oliguria (n = 7), or PEEP ordered by the attending surgeon to treat pulmonary edema (n = 5). The remaining 44 patients were randomly assigned by computer to one of three groups. The computer program maintained an equal distribution of any individual surgeon's patients among the three treatment groups. Group A (n = 17) was continued that time or shortly thereafter because of severe left ventricular dysfunction requiring pharmacologic support (dopamine) or intraaortic balloon assist devices (n = 12), blood pressure < 100/60 or oliguria (n = 7), or PEEP ordered by the attending surgeon to treat pulmonary edema (n = 5). The remaining 44 patients were randomly assigned by computer to one of three groups. The computer program maintained an equal distribution of any individual surgeon's patients among the three treatment groups. Group A (n = 17) was excluded to ambient pressure following a positive pressure breath and were extubated from ambient pressure, group B (n = 15) received 5 cm H₂O PEEP during PPV and 5 cm H₂O CPAP through a demand valve system (Bournes Bear I) for one-half hour prior to extubation, and group C

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(n = 12) received 10 cm H2O PEEP during PPV and 5 cm H2O CPAP for 4 hours prior to extubation. Static thoracic compliance (Ct) was measured prior to initiating PEEP. All patients received PPV at a tidal volume (corrected to eliminate retained circuit volume) of 12 ml/kg ideal body weight and a rate adequate to maintain the arterial pH between 7.35 and 7.50. Patients were extubated when they were alert and standard extubation criteria had been satisfied. Each patient received instruction in the use of an incentive spirometer prior to surgery and performed supervised deep breathing exercises four times daily during the first three postoperative days.

PaO2, PaCO2, and pH were measured (Radiometer ABL2) after FIO2 had been measured (Ventronic Polargraphic 5570): 1) supine, FIO2 = 0.6, one-half hour after randomization; 2) supine, FIO2 = 0.6, six hours after randomization; 3) seated, FIO2 = 0.4 immediately prior to extubation; 4) seated, FIO2 = 0.4 delivered for 20 minutes from a reservoir bag to a one-way valve (Hans-Randolph 1500) and mouthpiece, 24 and 48 hours after randomization; 5) seated, FIO2 = 0.21, 72, 96, and 120 hours after randomization. The alveolar-arterial oxygen tension gradient (P(A-a)O2) was calculated after atmospheric pressure had been corrected for the level of PEEP.

A standard posteroanterior roentgenogram was performed preoperatively and on the fifth postoperative day. These roentgenograms were graded for atelectasis by a chest radiologist (IT) who did not know the treatment assignments. All roentgenograms were scored for atelectasis according to the methods described by Good et al. 0 = no atelectasis; 1 = plate-like atelectasis; 2 = partial lower lobe collapse; and 3 = complete lower lobe collapse. In addition, the distance from the right hemidiaphragm to the inferior border of the right second rib was measured according to previously described standards.

Statistical methods included comparison of the preoperative and intraoperative characteristics of the study groups by two-tailed Student’s t-test and comparison of postoperative P(A-a)O2 by analysis of covariance. Postoperative P(A-a)O2 values were compared by one-tailed tests because the direction of the change (decreased P(A-a)O2 with PEEP) was predicted and p < .05 was accepted as significant. Atelectasis scores of preoperative and postoperative chest roentgenograms were compared by chi-square analysis.

Results

Patient Characteristics

The three study groups did not differ with respect to smoking history, preoperative P(A-a)O2, anesthesia time, time on cardiopulmonary bypass, blood volume

| Table 1—Descriptive Data for Patients Assigned to PEEP or Ambient Pressure† |
|---------------------------------|--------------|--------------|--------------|
| Measurement                  | Group A    | Group B    | Group C     |
| (Ambient Pressure)           | (PEEP= 5 cm H2O) | (PEEP= 10 cm H2O) |
| N                            | 17          | 15          | 12          |
| Age (yrs)                    | 62.7±1.7    | 60.9±2.9    | 55.8±2.7*   |
| Smoking (pack yrs)           | 20.6±7.3    | 18.9±6.4    | 23.9±8.5    |
| Preop P(A-a)O2 (mm Hg)       | 17.5±1.1    | 20.4±2.6    | 17.5±1.8    |
| Anesthesia time (min)         | 290.6±10.1  | 321.0±17.1  | 250.4±17.5  |
| Bypass time (min)             | 124.9±7.5   | 124.3±8.4   | 125.6±15.3  |
| Actual-ideal weight (kg)      | 14.0±2.0    | 15.6±3.3    | 13.2±2.9    |
| Transfused blood (ml)         | 288±104     | 421±85      | 250±67      |
| Net fluid after bypass (ml)   | +4,493±585  | +5,653±591  | +6,164±382* |
| Ct (ml/cm H2O)                | 49±9        | 40±10       | 50±10       |

*p<.05 when compared with group A

†± SEM

replaced, Ct, or weight in excess of ideal body weight (Table 1). Patients randomly assigned to PPV with 10 cm H2O PEEP were on the average seven years younger than those who received PPV without PEEP (p<.05). The mean (±SEM) net intraoperative fluid balance of subjects assigned to 10 cm H2O PEEP (6,164±382 ml) exceeded the mean intraoperative fluid balance of subjects who received PPV without PEEP (4,493±585 ml, p<.05). PEEP was delivered until the endotracheal tubes were removed. The mean ± SEM durations of PEEP were 12.8±0.8 hours, 11.1±1.3 hours, and 9.3±0.6 hours for patients supported with 0, 5, and 10 cm H2O PEEP respectively.

Arterial Blood Gas Analysis

The mean (±SEM) P(A-a)O2 one-half hour after randomization to 10 cm H2O PEEP was 168±10 mm

![Figure 1. Alveolar-arterial oxygen tension gradients (P(A-a)O2) for three study groups as a function of time.](image-url)
Hg. This was significantly lower than the mean P(A-a)O₂ of subjects who received PPV without PEEP (224 ± 12 mm Hg, p<.005). Although PPV with 5 cm H₂O PEEP was associated with a lower P(A-a)O₂ (203 ± 10 mm Hg), this decrease did not differ significantly from the P(A-a)O₂ of subjects receiving PPV without PEEP. The P(A-a)O₂ measurements of subjects who received 10 cm H₂O PEEP remained lower than those of patients supported with PPV six hours after randomization (135 ± 7 vs 182 ± 6 mm Hg, p<.005) and immediately prior to extubation (88 ± 4 vs 108 ± 3 mm Hg, p<.005). Once PEEP was discontinued, the P(A-a)O₂ of the three study groups did not differ during the first five days after surgery (Fig 1). Analysis of covariance performed upon P(A-a)O₂ measurements 72, 96, and 120 hours after surgery demonstrated a small decrease of P(A-a)O₂ (mean = 2.4 mm Hg) attributable to 10 cm H₂O PEEP (p<.04). No significant correlation was identified between net intraoperative fluid balance and P(A-a)O₂ measured 72 (r = -.24), 96 (r = -.05), or 120 hours (r = -.10) after cardiopulmonary bypass. Five days after cardiopulmonary bypass, P(A-a)O₂ of all patients (29 ± 1 mm Hg) exceeded their preoperative P(A-a)O₂ (18 ± 1 mm Hg, p<.001).

Chest Roentgenograms

Five days after CABG, the standard posteroanterior roentgenogram demonstrated atelectasis involving the left lung in 77 percent and the right lung in 75 percent of patients. Platelike atelectasis was common, and complete lobar collapse was uncommon. Chi-square analysis of atelectasis scores did not demonstrate a difference between patients who received 5 or 10 cm H₂O PEEP and those who were not treated with PEEP (Fig 2). Similarly, the mean apex to diaphragm distances of the three study groups did not differ (Table 2).

Duration of Hospitalization and Complications of PEEP

The three study groups did not differ with respect to duration of hospitalization. Mean (± SEM) lengths of stay were 8.7 (± 0.4), 8.9 (± 0.4), and 8.8 (± 0.5) days for subjects randomized to 0, 5, and 10 cm H₂O PEEP respectively. The routine administration of 5 and 10 cm H₂O PEEP to patients without cardiovascular compromise was not associated with complications.

Discussion

This study demonstrated that the routine application of 5 or 10 cm H₂O PEEP during postoperative positive pressure ventilation does not markedly alter the course of arterial hypoxemia or roentgenographic evidence of atelectasis after open heart surgery. Covariance analysis of arterial blood gas measurements performed on the third, fourth, and fifth postoperative days demonstrated a small (2 mm Hg) decrease of P(A-a)O₂ attributable to 10 cm H₂O PEEP. However, this response offered no clinical benefit. In addition, the use of PEEP was not associated with a decreased duration of hospitalization.

Methods of selecting the level of PEEP for the prevention of pulmonary dysfunction have varied. A number of investigators have routinely administered 5 to 10 cm H₂O PEEP. Others have chosen the level of PEEP which produces the highest static thoracic compliance. Levels of PEEP in excess of 10 cm H₂O have not been administered largely because more than 10 cm H₂O PEEP often decreases cardiac output. In the present study, we randomly assigned patients to 5

Table 2—Comparison of Standardized Posteroanterior Chest Roentgenographic Measurements†

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(0 PEEP)</td>
<td>(5 cm H₂O)</td>
<td>(10 cm H₂O)</td>
</tr>
<tr>
<td>Preoperative</td>
<td>19.9 ± 0.7</td>
<td>22.9 ± 0.9</td>
<td>22.0 ± 0.9</td>
</tr>
<tr>
<td>Postoperative day 5</td>
<td>19.1 ± 0.6</td>
<td>21.4 ± 0.6</td>
<td>21.2 ± 0.9</td>
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†Mean ± SEM distance from the right hemidiaphragm to the apex of the right lung (cm)
or 10 cm H2O PEEP. Ten cm H2O PEEP resulted in significant decreases of P(A-a)O2, whereas 5 cm H2O produced a small decrease of P(A-a)O2. These observations suggest a nonlinear response of lung volume to PEEP, as has been described in patients with hypoxicemic respiratory failure.8,9 We did not determine what PEEP level resulted in the highest static thoracic compliance, but Good et al8 found that 3 to 9 cm H2O PEEP represented optimum levels of PEEP for similar patients following open heart surgery.

A number of investigations have suggested that PEEP may reverse postoperative pulmonary complications which lead to arterial hypoxemia.7,8,9,14,15 Anderson et al14 reported that PEEP produced a mean increase of 7 mm Hg in PaO2 on the first three days after upper abdominal surgery, and Schmidt et al15 observed a reduced incidence of hypoxicemic respiratory failure when PEEP was used postoperatively. Few studies have addressed the effects of PEEP upon respiratory complications following open heart surgery.16 Good et al8 concluded that the routine application of PEEP after open heart surgery offered no advantage over standard ventilatory techniques. However, the authors reported that PEEP significantly increased PaO2/PAO2 during the first 15 hours after cardiopulmonary bypass, raising the possibility that PEEP might alter the course or severity of arterial hypoxemia following CABG. We found that PEEP during postoperative positive pressure ventilation provided no sustained benefit to patients undergoing CABG.

Prolonged cardiopulmonary bypass and excessive intraoperative fluid administration have been associated with atelectasis and arterial hypoxemia following cardiopulmonary bypass.1,4,22 The duration of cardiopulmonary bypass was comparable for our study groups, but those patients who were ventilated postoperatively with 10 cm H2O PEEP had received more fluid intraoperatively than patients ventilated without PEEP. Excess intraoperative fluid could have produced lung edema and atelectasis and negated the effects of PEEP. This possibility appears unlikely in view of the lack of a positive correlation between fluid balance and P(A-a)O2 and the absence of roentgenographic evidence of pulmonary edema on the final day of arterial blood gas analysis. Furthermore, previous work suggests that small increases in pulmonary extravascular water observed after CABG do not impair gas exchange.23 In the present study, absence of roentgenographic evidence of pulmonary edema suggests that increases of pulmonary extravascular water were small since standard chest roentgenograms can detect increases of wet lung to dry lung weight of 35 percent or more.24

The absence of a sustained benefit from the routine application of PEEP is consistent with the concept that PEEP can reverse arterial hypoxemia, but does little to reverse underlying pathophysiologic mechanisms responsible for arterial hypoxemia.16,25 Early administration of PEEP to patients at risk for the adult respiratory distress syndrome has no effect on the incidence of pulmonary dysfunction or adult respiratory distress syndrome.26 Positive end-expiratory pressure does not decrease lung water content, and decreases of PaO2 occur rapidly after PEEP is discontinued in the setting of noncardiogenic pulmonary edema.17,25,26 Since most evidence suggests that arterial hypoxemia following cardiopulmonary bypass results from airway collapse rather than pulmonary microvascular injury,27,28 the application of PEEP immediately after surgery might decrease the requirement for other measures directed at lung expansion, eg, incentive spirometry. In the present study, we found that routine PEEP during postoperative positive pressure ventilation provided no additional benefit when patients routinely performed incentive spirometry following CABG. Because incentive spirometry performed by our patients may have obscured a beneficial effect from PEEP, the question remains as to whether or not the early application of PEEP would allow a reduction in the use of other measures directed at lung inflation after CABG.

In summary, we have drawn the following conclusions: 1) 10 cm H2O PEEP decreases P(A-a)O2 and increases PaO2 during positive pressure ventilation following CABG and appears well-tolerated by patients without prior hypotension or oliguria; and 2) once discontinued, routine PEEP does not alter the course of arterial hypoxemia or roentgenographic evidence of atelectasis. Based upon these conclusions, we believe that routine PEEP offers no benefit after CABG unless it is required to improve immediate postoperative arterial oxygen tension.

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