Comparison of Positive End-Expiratory Pressure of 8 versus 5 cm H$_2$O on Outcome After Cardiac Operations

Jennifer K. Hansen, MD$^{1,2}$, David G. Anthony, MD$^3$, Liang Li, PhD$^4$, David Wheeler, RRT-NPS$^3$, Daniel I. Sessler, MD$^5$, and C. Allen Bashour, MD$^{3,5}$

Abstract

**Purpose:** Postoperative positive end-expiratory pressure (PEEP) selection in patients who are mechanically ventilated after cardiac operations often seems random. The aim of this investigation was to compare the 2 most common postoperative initial PEEP settings at our institution, 8 and 5 cm H$_2$O, on postoperative initial tracheal intubation time (primary outcome); cardiovascular intensive care unit (CVICU); hospital length of stay (LOS); occurrence of pneumonia; and hospital mortality (secondary outcomes). **Materials and Methods:** The electronic medical records of patients who were mechanically ventilated after isolated coronary artery bypass grafting (CABG) or combined CABG and valve operations were reviewed. Propensity score matching was used to compare patients with an initial postoperative PEEP setting of 8 cm H$_2$O ($n = 4722$ [25.9%]) with those who had PEEP of 5 cm H$_2$O ($n = 13535$ [74.1%]) on the primary and secondary outcomes listed earlier. **Results:** There was no difference in initial postoperative intubation time between the PEEP of 8 cm H$_2$O and the PEEP of 5 cm H$_2$O patient groups (mean 11.9 vs 12.0 hours [median 8.2 vs 8.8 hours], $P = .89$). The groups did not differ on the occurrence of pneumonia (0.43% vs 0.60%, $P = .25$) nor on hospital mortality (0.47% vs 0.43%, $P = .76$). Aspiration pneumonia occurrence approached a significant difference (0.06% vs 0.21%, $P$ value $= .052$), as did CVICU LOS (mean: 47.9 vs 49.8 hours [median: 28.5 vs 28.4 hours], $P = .057$), but were not statistically different. There was a slight but likely clinically unimportant difference in hospital LOS (7.7 vs 7.4 days, PEEP = 8 vs 5, $P < .001$). **Conclusion:** Patients being mechanically ventilated after cardiac operations with an initial postoperative PEEP setting of 8 versus 5 cm H$_2$O differed significantly only on hospital LOS but the difference was likely clinically unimportant. Thus, use of 8 cm H$_2$O PEEP in these patients without a clinical indication, although likely not harmful, does not seem beneficial.

Keywords

PEEP, anesthesia, cardiac surgery, coronary artery bypass grafting, mechanical ventilation

Introduction

Initial postoperative positive end-expiratory pressure (PEEP) selection often seems random. Higher initial PEEP settings may reduce ventilator-induced lung injury by avoiding cyclic recruitment/derecruitment and prevent lung collapse.$^{1,2}$ Alternatively, higher PEEP may have adverse effects including overinflation and persistent pulmonary parenchyma air leak. Positive end-expiratory pressures of 8 cm H$_2$O (26%) and 5 cm H$_2$O (74%) are the most commonly used PEEP settings at our institution in mechanically ventilated patients admitted to the cardiovascular intensive care unit (CVICU) after cardiac operations and there is little evidence to support selecting one over the other.$^{3-6}$

This investigation was undertaken to determine whether the higher initial PEEP setting of 8 cm H$_2$O changes patient outcome. Propensity-matched cardiac surgery patients who were mechanically ventilated upon arrival to the CVICU with an initial PEEP of 8 or 5 cm H$_2$O were compared on initial postoperative intubation time (primary), CVICU and hospital length of stay (LOS), incidence of hospital-acquired pneumonia, aspiration pneumonia, and hospital mortality (secondary).

---

1. Anesthesiology Institute, Cleveland Clinic, Cleveland, OH, USA
2. Current Address: Department of Anesthesiology, University of Kansas Medical Center, Kansas City, KS, USA
3. Cardiothoracic Anesthesia, Cleveland Clinic, Cleveland, OH, USA
4. Department of Biostatistics, University of Texas, Anderson Cancer Center, Houston, TX, USA
5. Outcomes Research, Cleveland Clinic, Cleveland, OH, USA

Received September 6, 2012, and in revised form September 11, 2013. Accepted for publication November 4, 2013.

Corresponding Author:
C. Allen Bashour, Department of Cardiothoracic Anesthesia, Cleveland Clinic, Cleveland Clinic, 9500 Euclid Avenue/4-331, Cleveland, OH 44195, USA.
Email: bashoua@ccf.org
Methods

The medical records of adult patients (*n* = 18,257) who underwent isolated coronary artery bypass grafting (CABG; *n* = 13,304) or combined CABG and valve (*n* = 4,953) operations at our institution from January 1, 1995, to December 31, 2006, were reviewed. Patients who underwent isolated valve operations were not included. The investigation cohort included intubated and mechanically ventilated postoperative patients admitted directly to the CVICU. All patients at our institution are admitted to the CVICU after cardiac operations and managed there until they are ready for transfer to a step-down unit. Although these patients are increasingly being extubated after surgery in the operating room, only those admitted on mechanical ventilator support were included in this investigation.7

The ventilator mode and settings most commonly used were pressure control with synchronized intermittent mandatory ventilation; frequency = 10 to 14 breaths/min; tidal volume = 8 mL/kg ideal body weight; PEEP = 5 or 8 cm H2O; and fraction of inspired oxygen (FiO2) = 60%. Positive end-expiratory pressure was measured at the ventilator and recorded as total PEEP from the mechanical and/or digital control panel of the ventilator. The total PEEP may have included intrinsic PEEP, but this was not recorded separately.

Propensity score matching was used to compare patients with an initial PEEP of 8 cm H2O (*n* = 4,722 [26%]) vs 5 cm H2O (*n* = 13,535 [74%]). Patients with other PEEP settings and other than an initial FiO2 = 60% were excluded. Potential confounding variables used in matching that may affect outcomes are shown in Table 1. The primary outcome variable was initial postoperative tracheal intubation time. Secondary outcome

<table>
<thead>
<tr>
<th>Table 1. Descriptive Statistics of the Patient Population Before and After Propensity Matching.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
</tr>
<tr>
<td>Age, years</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>BMI, kg/m2</td>
</tr>
<tr>
<td>Hematocrit, %</td>
</tr>
<tr>
<td>Creatinine, mg/dLb</td>
</tr>
<tr>
<td>Albumin, g/dL</td>
</tr>
<tr>
<td>COPD asthma</td>
</tr>
<tr>
<td>Prior lung surgery</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
</tr>
<tr>
<td>Smoking</td>
</tr>
<tr>
<td>CHF</td>
</tr>
<tr>
<td>Diabetes</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
</tr>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Dialysis</td>
</tr>
<tr>
<td>Abnormal LVF</td>
</tr>
<tr>
<td>Emergency surgery</td>
</tr>
<tr>
<td>No bypass</td>
</tr>
<tr>
<td>CABG with valve procedure</td>
</tr>
<tr>
<td>Redo</td>
</tr>
<tr>
<td>RBC units in OR</td>
</tr>
<tr>
<td>Total CPB time</td>
</tr>
<tr>
<td>Core temp at ICU admission</td>
</tr>
<tr>
<td>Cardiac output at ICU admission</td>
</tr>
<tr>
<td>P/F ratio</td>
</tr>
<tr>
<td>OR intubation time</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; CABG, coronary artery bypass graft; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CPB, cardiopulmonary bypass; ICU, intensive care unit; LVF, left ventricular function; OR, operating room; PEEP, positive end-expiratory pressure; P/F, PaO2/FiO2; RBC, red blood cells; temp, temperature.

Descriptive statistics are expressed as median (Q25, Q75) for continuous variables and count (%) for categorical variables.

*P* values calculated from log-transformed values.
variables included CVICU and hospital LOS, pneumonia, aspiration pneumonia, and hospital mortality.

**Statistical Methods**

The first step of the propensity score analysis was a logistic regression that predicted the probability of PEEP of 8 cm H$_2$O in the investigation population using the variables shown in Table 1. This probability is the propensity score. Patients in the PEEP = 8 cm H$_2$O group were matched to those in the PEEP = 5 cm H$_2$O group, with the closest propensity score in a greedy match algorithm which identified 4695 matched pairs. The quality of match was assessed by examining the standardized differences of variables before and after matching. The matched patients were then compared on their postoperative outcomes. Specifically, initial postoperative intubation time, and CVICU and hospital LOS, were summarized by the Kaplan-Meier method and compared with the log-rank test on the incidence of hospital-acquired pneumonia. Hospital mortality was compared with Fisher exact test.

There were missing values in the preoperative variables: 10 with no PaO$_2$ value; 1 with no CVICU admission core temperature; 600 with no initial cardiac output (the majority of these patients were managed without pulmonary artery catheters); 1048 with no recorded preoperative albumin; and 5505 with no preoperative atrial fibrillation status recorded. Since there were no missing outcome variables, and the missing values in other variables are either sporadic or blocked, missing data were unlikely to cause substantial bias. We thus adopted a simple approach to impute the missing values using regression models of the other measured variables. All analyses were done using SAS 9.1 and R 2.12.2 and the level of statistical significance was set at .05.

**Results**

The investigation cohort consisted of 13 548 (74%) men and 4709 (26%) women who ranged in age from 21 to 95 years. Of these, 4722 (26%) patients had initial PEEP setting of 8 cm H$_2$O and 13 535 (74%) patients had an initial PEEP setting of 5 cm H$_2$O (Table 1). During the investigation period, a PEEP of 8 or 5 cm H$_2$O was used for > 95% of all cardiac surgery patients admitted to the CICU. The interquartile range of PaO$_2$ at CICU admission for all patients was 104 to 187 mm Hg (median = 141 mm Hg). The PaO$_2$—FiO$_2$ ratio interquartile range was 173 to 312 with a median of 235. After matching, there were 4695 patients in each group. A subgroup analysis of patients with chronic obstructive pulmonary disease (COPD)/asthma (n = 885, 441 patients with PEEP of 8 cm H$_2$O and 444 with PEEP of 5 cm H$_2$O) was also performed. Propensity score matching significantly reduced the imbalance between the matched groups (Table 1; Figure 1).

Figure 2 compares the hospital and CVICU LOS and initial postoperative intubation time after matching using Kaplan-Meier curves. The PEEP of 8 cm H$_2$O patients had longer hospital LOS (mean = 7.7 vs 7.4 days, PEEP = 8 vs 5 cm H$_2$O, P < .001 [median each = 6 days]) and CVICU LOS (mean = 49.8 vs 47.9 hours [median = 28.4 vs 28.5 hours], P = .057). There was no difference in initial postoperative intubation time between PEEP of 8 versus 5 cm H$_2$O (mean 11.9 vs 12.0 hours [median 8.2 vs 8.8 hours], P = .89). There was no difference in hospital mortality between groups (0.47 vs 0.43, P = .76; Table 2) and no outcome difference was found in the subgroup analysis of the patients with COPD/asthma.

**Discussion**

Postoperative PEEP selection is often random and the perceived benefit of higher settings is mostly unproven. Although in this investigation the differences in the occurrence of aspiration pneumonia and in CVICU LOS approached statistical significance, and hospital LOS was significantly higher (0.3 days) for patients with an initial PEEP of 8 cm H$_2$O (vs 5 cm H$_2$O), these differences are likely to prove clinically unimportant. It thus seems that increased initial postoperative PEEP of 8 cm H$_2$O compared to PEEP of 5 cm H$_2$O is neither harmful nor beneficial.

It is well known that PEEP maintains functional residual capacity by maintaining alveolar recruitment and thereby improving gas exchange. Positive end-expiratory pressure facilitates weaning FiO$_2$ and in doing so reduces secondary lung injury risk by shortening exposure to high FiO$_2$ (O$_2$ toxicity) and positive pressure (barotrauma) ventilation. Alternatively, high PEEP may cause barotrauma or impede venous
return and decrease cardiac output, especially in patients with low ejection fractions or who are being supported on filling-dependent cardiac assist devices. Higher PEEP is better used in cases where there is known benefit for a treatable condition, for example, to maintain alveolar recruitment in refractory acute lung injury (ALI) or while a patient is being treated for fluid overload.

Although in this patient cohort, the mean initial PaO2/FiO2 ratio of 249 is within the defined ALI range, ALI in these patients is likely related to the acute and transitory effects of mechanical ventilation (cycle induced) and cardiopulmonary bypass (cytokine-mediated inflammation) from which they can typically quickly recover. Although high PEEP and low tidal volume improves oxygenation and reduces secondary lung injury in patients with ALI,4,8,9 in this investigation the higher initial PEEP setting of 8 cm H2O, although low compared to PEEP typically used in ALI, did not confer an outcome benefit that was clinically meaningful.

The vast majority of patients return to the CVICU immediately after cardiac operations on mechanical ventilator support and are thus potentially subject to mechanical ventilation cycle-induced pulmonary inflammatory changes in addition to inflammation inconsistently associated with cardiopulmonary bypass. Respiratory therapist-driven best practices for determining initial ventilator settings and postoperative weaning strategies are being continuously refined.

The known benefits of increased PEEP have led to its early use to improve oxygenation and prevent or reduce atelectasis in patients recovering from cardiac surgery. It has been shown that mechanical ventilation using higher PEEP and lower tidal volumes is associated with decreased pulmonary inflammatory markers. Higher PEEP improves oxygenation and prevents atelectasis.10,11 Additionally, lung recruitment maneuvers, appropriate use of sedation, and adequate pain control can facilitate a rapid transition to spontaneous-unassisted ventilation.

A lung protective strategy of higher PEEP and lower tidal volumes for patients with ALI has been shown to shorten mechanical ventilation time and improve outcome.12 A meta-analysis of high PEEP settings used in the treatment of patients with ALI found an absolute risk reduction in early mortality of 4%.13 Unlike other patients with ALI, postoperative ALI seen in this patient cohort is typically transitory and rapidly recoverable, thus higher PEEP in these patients is unlikely to be necessary.

**Limitations**

We incorporated preexisting comorbidities (Table 1) into the group descriptions, as previous studies have shown that risk factors for prolonged intubation and mechanical ventilation in cardiac surgery patients correlate with preoperative respiratory and cardiac function.7,14 The primary analysis of this article is a propensity score-matched comparison between patients with PEEP of 8 cm H2O and PEEP of 5 cm H2O. A limitation of this technique is that it can only balance “measured” characteristics of the patients, and it is impossible to elucidate every possible preoperative condition that may cause a difference in patient outcome. For example, subclinical lung disease or early, undiagnosed infection may lead to changes in lung compliance that will not be captured with preoperative testing but will manifest following surgery. Current diagnostic techniques are relatively insensitive for discovery of such subtle lung disease. Another limitation is that the number of clinical event outcomes (Table 2) is small in this data set, which may lead to low statistical power for some statistical tests.

Initial PEEP settings in some patients may have been adjusted up or down prior to extubation, and this was not accounted for in the analysis. Some patients initially admitted to the CICU on PEEP of 5 cm H2O may have worsened and PEEP in these patients may have been increased to improve oxygenation. Duration of PEEP settings and postoperative adjustments before extubation were not analyzed and could have affected the results.

Additionally, some patients may have received higher PEEP because of certain intraoperative conditions perceived by the...
provider as an indication for higher PEEP. Some of these factors may have not been included in propensity scoring, thus it is likely that some patients received higher PEEP for reasons not included in this analysis. Also, perioperative variables like fluid administration and fluid balance that may affect initial intubation time, CVICU, and hospital LOS were not included in the analysis. We did not include data on intraoperative ventilator settings, $\text{SaO}_2$, peak airway pressures, or intraoperative crystalloid fluid administration, and this could also have affected the results.

The weaning protocol used stems from our scope of practice, the nature of our patients, and the principle that early extubation is beneficial. Our cardiothoracic critical care protocols are designed for extubation and discharge to step-down units on a 24-hour, 7-day-a-week basis. We have used a strategy that encourages rapid weaning as soon as patients are able to breathe spontaneously, clear secretions, and protect their airways recognizing that suitability for extubation is usually considered after PEEP has been weaned to $5 \text{ cm H}_2\text{O}$.

The general practice for weaning patients in the CVICU on PEEP of greater than $5 \text{ cm H}_2\text{O}$ is to wean the $\text{FiO}_2$ to $40\%$, then wean the PEEP to $5 \text{ cm H}_2\text{O}$ followed by CPAP trials and tracheal extubation if $\text{PaO}_2/\text{FiO}_2$ is acceptable and all other extubation criteria are met. We did not analyze data for the timing of these ventilator transitions, and this may have impacted CVICU LOS and other outcomes.

**Conclusion**

Propensity-matched patients admitted directly to the CVICU after cardiac surgery with an initial PEEP of $8 \text{ cm H}_2\text{O}$ versus PEEP of $5 \text{ cm H}_2\text{O}$ differed only on hospital LOS, and the difference was likely clinically unimportant. There was no difference in initial postoperative intubation time, CVICU LOS, pneumonia, or hospital mortality. Thus, initial application of higher PEEP after cardiac operations is likely neither beneficial nor harmful. Whether there is a subset of patients who may benefit from preferential use of either PEEP setting cannot be determined from this investigation.

**Declaration of Conflicting Interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) disclosed receipt of the following financial support for the research, authorship and/or publication of this article: The study was supported solely by internal funds. None of the authors has a personal financial interest related to this research.

**References**


