

Role of continuous positive airway pressure to the non-ventilated lung during one-lung ventilation with low tidal volumes

N.H. Badner¹, C. Goure¹, K.E. Bennett², G. Nicolaou¹

¹Department of Anesthesia and Perioperative Medicine, Schulich School of Medicine, University of Western Ontario;

²Department of Anesthesia and Critical Care Medicine, Emory University, Atlanta, Georgia, USA.

HSR Proceedings in Intensive Care and Cardiovascular Anesthesia 2011; 3(3): 189-194

ABSTRACT

Introduction: In multiple study populations large tidal volumes (8 - 12 ml/kg) have deleterious effects on lung function in multiple study populations. The accepted approach to hypoxemia during one-lung ventilation is the application of continuous positive airway pressure to the non-ventilated lung first, followed by application of positive end-expiratory pressure to the ventilated lung. To our knowledge the effectiveness of positive end-expiratory pressure or continuous positive airway pressure on maintaining PaO₂ with one-lung ventilation was not studied with smaller tidal volume (6ml/kg) ventilation. Our objective was to compare continuous positive airway pressure of 5 cm H₂O or positive end-expiratory pressure of 5 cm H₂O during small tidal volume one-lung ventilation. **Methods:** Thirty patients undergoing elective, open thoracotomy with one-lung ventilation were randomized to continuous positive airway pressure or positive end-expiratory pressure and then crossed over to the other modality.

Results: There was a statistically significant higher PaO₂ (141±81.6 vs 112±48.7, p = 0.047) with continuous positive airway pressure than positive end-expiratory pressure while on one-lung ventilation. Two patients desaturated requiring 100% O₂ with both positive end-expiratory pressure and continuous positive airway pressure. On two occasions the surgeon requested the continuous positive airway pressure be discontinued due to lung inflation.

Conclusion: The use of continuous positive airway pressure of 5 cm H₂O to the non-ventilated lung while using small tidal volumes for one-lung ventilation improved PaO₂ when compared with positive end-expiratory pressure of 5 cm H₂O to the ventilated lung.

Keywords: one-lung ventilation, lung-protective ventilation, hypoxia, CPAP, PEEP.

INTRODUCTION

Traditionally the practice for intra-operative management of ventilation during thoracic surgery has been the use of tidal volumes in the range of 8-12 ml/kg (LTV).

These volumes were thought to minimize atelectasis during one-lung ventilation (OLV) and maximize oxygenation and ventilation (1). Recently, much research was performed in multiple study populations, including patients being ventilated for relatively short periods of time in the operating room (OR), suggesting that these larger tidal volumes have deleterious effects on patients that include intra-operative pulmonary hyperinflation and increased inflammatory markers (2, 3) This exposure to

Corresponding author:

Dr N H Badner

Department of Anesthesia and Perioperative Medicine

LHSC – Victoria Hospital

800 Commissioners Rd E, London, Ontario

Canada N6A 5W9

e.mail: neal.badner@lhsc.on.ca

volutrauma might lead to serious complications such as pulmonary edema and acute lung injury (ALI) (4, 5). Thoracic surgery patients having underlying lung disease and being exposed to lung resection and prolonged duration of OLV are at high risk of developing postoperative ALI. As such, there has been an increasing recommendation to apply small or 'protective' tidal volume ventilation to this surgical population (6, 7).

One of the concerns with all thoracic procedures employing OLV is intra-operative hypoxia due to the large shunt that develops when only one lung is being ventilated.

The accepted approach to hypoxemia during OLV is first the application of continuous positive airway pressure (CPAP) to the non-ventilated lung followed, if necessary, by the application of positive end-expiratory pressure (PEEP) to the ventilated lung (1).

The research upon which this recommendation is based however, has been performed in patients who have been ventilated with larger tidal volumes (8-12). Since it is both easier to apply PEEP to the operative lung than CPAP to the non-operative lung and causes less interference with surgical exposure, it is often employed first (1, 10).

Application of PEEP for the treatment of hypoxia in the setting of smaller tidal volumes in two-lung ventilation is now considered the standard of care (13), but it has still to our knowledge not been compared with CPAP in OLV with small tidal volume ventilation.

As lung protective ventilation strategies become more uniformly employed in the OR for thoracic surgery, we felt it was important to re-examine the role of CPAP and PEEP to improve arterial oxygenation during OLV. Our primary objective was therefore to determine whether CPAP or PEEP provide better oxygenation during small tidal volume (STV) one-lung ventilation

compared to OLV. Secondly we wished to determine the incidence of hypoxia (oxygen saturation < 90%) on OLV, and the need for rescue maneuvers such as two-lung ventilation (TLV) and clamping of the operative pulmonary artery.

METHODS

Following IRB approval and written informed consent patients scheduled for open thoracotomy and lung resection (wedge resection, lobectomy, or pneumonectomy) requiring double-lumen endobronchial tube (DLT) placement and one-lung ventilation were enrolled. Patients were excluded for the presence of severe cardiac, renal or hepatic disease.

Demographic data including age, gender, height, weight, ASA status, calculated ideal body weight [men: $50 + 0.91(\text{cm Ht} - 152.4)$ and women: $45.5 + 0.91(\text{cm Ht} - 152.4)$] (14), FEV₁, DLCO, FEV₁ 25-75%, and FEV₁/FVC ratio, indication for surgery, procedure performed, DLT size, and presence of co-morbid diseases were recorded. General anesthesia was induced at the discretion of the attending anesthesiologist. A DLT of appropriate size was placed and the position verified in both the supine and lateral decubitus position with fiberoptic bronchoscopy. Positive pressure ventilation was commenced using a Datex/Ohmeda S/5 anesthesia delivery unit (ADU) (Datex-Ohmeda, Bromma, Sweden), using tidal volumes of 6 ml/kg based on the ideal body weight and volume-controlled ventilation. The respiratory rate was titrated to produce a normal arterial partial pressure of carbon dioxide (PaCO₂). Maintenance of anesthesia consisted of one minimum alveolar concentration (MAC) volatile anesthetic (or less) in air/O₂ (FiO₂ = 0.6 - 0.7), +/- opioids and muscle relaxants to ensure normal hemodynamic parameters. Patients were randomized (by computer generated

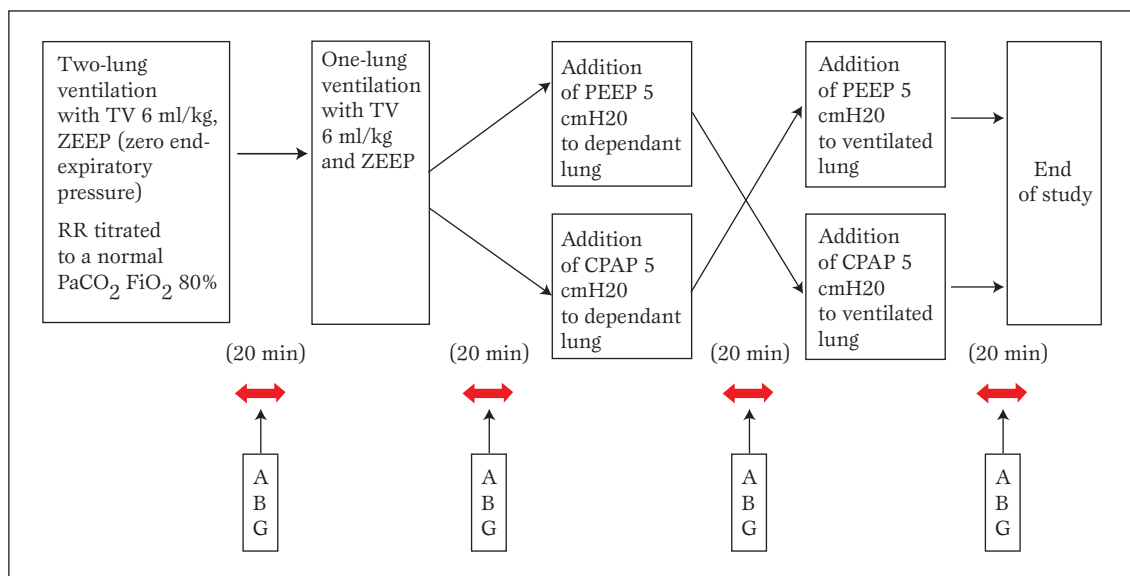


Figure 1 - Study flow diagram. ZEEP – zero end-expiratory pressure, RR – respiratory rate, TV – tidal volume, PaCO₂ – arterial partial pressure of carbon dioxide, ABG – arterial blood gases, CPAP - continuous positive airway pressure, PEEP - positive end-expiratory pressure.

random number and sealed envelopes) pre-operatively into one of two groups (PEEP of 5 cm of H₂O or CPAP of 5 cm H₂O), then after twenty minutes in the first intervention were crossed over into the other intervention. Arterial blood gas (ABG) samples were taken preoperatively, then after placement in the lateral decubitus position 20 minutes after induction of anesthesia on two lung ventilation (2LV), 20 minutes after OLV using zero end expiratory pressure (ZEEP) and then 20 minutes after the introduction of either PEEP or CPAP and then 20 minutes after the alternate therapy (see Figure 1). Analysis was performed using the GEM Premier 3000 (Instrumentation Laboratory, Lexington, Massachusetts). CPAP was delivered using a disposable Broncho-Cath CPAP system (Mallinkrodt Medical, Athlone, Ireland).

Airway pressures were measured using the D-lite spirometry system (Datex/Ohmeda) in conjunction with the S/5 ADU. The presence of intra-operative hypoxia (oxime-

ter SpO₂ or ABG SaO₂ < 90%), its duration and timing (in relationship to interventions) and the need for re-expansion and ventilation of the operative lung, as well as the need to increase FiO₂ > 0.7 were also recorded.

Sample size calculations were performed on the basis of the outcome and data in Cohen et al. (11), which showed a treatment effect of PEEP during OLV and ZEEP during OLV (control measurement) of approximately 25 mmHg (105 mmHg vs. 80 mmHg respectively) and a standard deviation (SD) to 40 mmHg. Using alpha of 0.05, and beta of 0.80 it was determined that 24 patients were needed.

This was increased to 30 to allow for the potential for patients to drop out prior to completion. Statistical analysis consisted of paired t-tests, and repeated measures ANOVA for parametric data as well as chi-squared analysis for non-parametric data. A p value less than 0.05 was considered statistically significant.

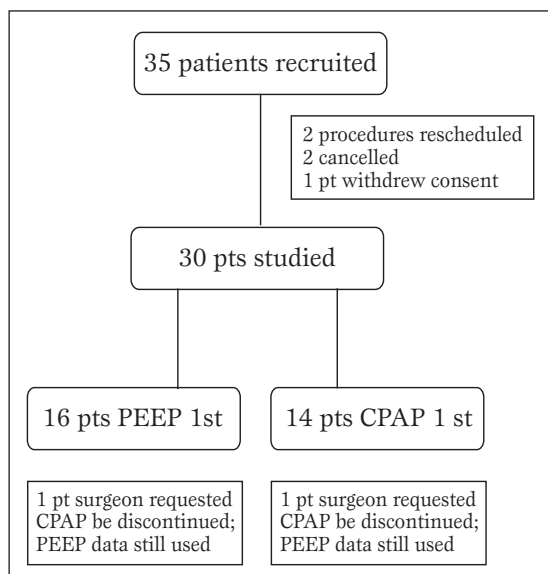


Figure 2 - Patient recruitment and allocation. *pt* - patient - CPAP - continuous positive airway pressure, PEEP - positive end-expiratory pressure.

RESULTS

As illustrated in *Figure 2*, 35 patients gave consent, one patient withdrew consent, two had their procedure cancelled and two had their procedure rescheduled. There were no differences in demographic and prerandomization ventilatory data between the PEEP first and the CPAP first groups (*Table 1 and 2*). *Table 3* shows a statistically significantly higher PaO₂, bigger change from OLV with ZEEP and smaller A-a gradient with 5 cm H₂O CPAP in the non-ventilated lung than with 5 cm H₂O PEEP in the ventilated lung while on OLV. Two patients in each group had episodes of oxygen desaturation requiring 100% O₂. On two occasions the surgeon requested the CPAP be discontinued due to lung inflation and difficulty with the surgical exposure. One patient had CPAP first and the other PEEP. All other data from these two patients were analyzed other than that during the CPAP phase.

DISCUSSION

We found that the use of 5 cm H₂O CPAP on the non-ventilated lung while using small tidal volumes for one lung ventilation produced a larger PaO₂ and a smaller A-a gradient than the use of 5 cm H₂O PEEP on the

Table 1 - Preoperative data in continuous positive airway pressure (CPAP) and positive end-expiratory pressure (PEEP) groups. Values are expressed as mean (standard deviation). BMI - body mass index, BW - body weight, *pk-yr* - pack years, Hgb - hemoglobin, FEV1/FVC - forced expiratory volume in 1 second/forced vital capacity, *preop* - preoperative, mmHg - millimeters of mercury.

	CPAP 1st	PEEP 1st
Age (yr)	63 (7.6)	67 (13.7)
height (cm)	168 (10.4)	167 (10.3)
BMI (kg/m ²)	27.7 (5.5)	25.8 (5.32)
ideal BW (kg)	61 (11.1)	62 (11.7)
smoking (pk-yr)	27 (22.9)	34 (20.0)
Hgb (g/L)	132 (15)	134(18)
Operative lung (R:L)	12:4	7:7
FEV1/FVC	0.7 (0.10)	0.7 (0.10)
preop PaO ₂ (mmHg)	70 (8.8)	76 (12.1)
preop PaCO ₂ (mmHg)	39 (3.5)	40 (2.1)

Table 2 - Ventilatory data in continuous positive airway pressure (CPAP) and positive end-expiratory pressure (PEEP) groups. Values are expressed as mean (standard deviation). PA/W - airway pressure, cm H₂O - centimeters of water, FiO₂ - inspired concentration of oxygen, #/min - number/minute.

	CPAP	PEEP
PaCO ₂ (mmHg)	46 (6.1)	43 (9.1)
PA/W peak (cm H ₂ O)	26 (5.8)	26 (5.9)
P A/W plateau (cm H ₂ O)	19 (4.7)	20 (4.2)
FiO ₂	0.7 (0.08)	0.7 (0.08)
Respiratory Rate (#/min)	13.8 (2.3)	13.0 (2.5)

Table 3 - Oxygenation comparison between continuous positive airway pressure (CPAP) and positive end-expiratory pressure (PEEP) groups. Values are expressed as means (SD). OLV – one lung ventilation, A-a gradient – alveolar to arterial gradient, SaO₂ – ABG arterial oxygen saturation.

	CPAP	PEEP	P value
PaO ₂	141 (81.6)	112 (48.7)	0.049
Change in PaO ₂ from OLV	29.6 (83.0)	- 3.8 (51.4)	0.047
PO ₂ A-a gra- dient	298 (106)	335 (83)	0.032
ABG SaO ₂	96.8 (3.6)	96.3 (3.6)	0.3
Oximeter SpO ₂	96.4 (3.2)	96.2 (3.3)	0.6

ventilated lung during OLV. Our findings are both similar in effect and magnitude as those seen with previous studies using larger tidal volumes (8, 11). We did not find any significant differences in peripheral SpO₂ or the incidence of oxygen desaturations requiring treatment. Our finding is somewhat disappointing as the use of PEEP leads to significant improvement in patient's oxygenation with STV in patients undergoing general anesthesia with 2LV (13), in those undergoing OLV who have developed significant hypoxia (10), and those with acute respiratory distress syndrome (14). This was our preferred outcome as it is much easier to apply PEEP to the ventilated lung than CPAP to the non-ventilated lung during OLV and it causes less interference with surgical exposure (1, 11).

Other than the use of STV our study differed from the original comparisons of CPAP and PEEP for OLV in that we chose a value of 5 cm H₂O as opposed to the value of 10 used by Capan et al. (8) and Cohen et al. (11). We wished to avoid the use of 10 cm of H₂O as it can cause significant distention of the operative lung and inhibit surgery and was based on the knowledge that

smaller amounts of CPAP of 2 and 5 cm of H₂O are still effective (9). We also chose an inspired oxygen concentration of 0.6-0.7 which was somewhat between the 1.0 used by Capan et al. (8) and Hogue (9), and 0.5 used by Cohen et al (10,11). This decision was based on the desire to provide some nitrogen to the ventilated lung and thereby minimize atelectasis while at the same time maximize the inspired concentration of oxygen.

Though the design of our study was not double-blinded, the laboratory personnel analyzing the PaO₂ values (our primary outcome) and the statistician had no knowledge of the treatment arm sequence. This similar methodology was used in the earlier studies using LTV (8-12). The crossover design of our study also ensured that the patients served as their own control to account for differences within the population. Interestingly, this methodology was not used by Capan et al (8) or Cohen et al (11) though Hogue (9) and Slinger et al (12) did use this technique.

Another limitation of our study was the fact that we did not apply a lung recruitment manoeuvre (RM) prior to the initiation of PEEP to the ventilated lung. This is known to improve oxygenation with or without the use of PEEP in patients undergoing thoracic surgery with OLV (15-18). Though similar in their goals these RMs were all applied differently and some require several manoeuvres or calculations (15-18). Also, studies advocating STV with PEEP for OLV did not utilize a recruitment manoeuvre upon its initiation (1, 3-7). Lastly, a recent survey showed that more sophisticated ventilatory management including RMs are rarely used intraoperatively by anaesthesiologists (13) making our study more applicable to the general anesthesiologist. We therefore chose to utilize the same methodology as Capan et al (8) and Cohen et al. (10, 11) had utilized with

their LTV OLV studies which did not involve the application of a lung recruitment manoeuvre. We also did not measure the actual end expiratory pressure that existed which may have been different than that supplied due to the occurrence of autopeep. Finally, we did not control the anesthetic provided to our patients. We did however limit the amount of volatile agent to less than one MAC to minimize the effects that these agents might have on hypoxic pulmonary vasoconstriction.

In conclusion, our study showed that the use of 5 cm H₂O CPAP to the non-ventilated lung improved oxygenation more than 5 cm H₂O PEEP to the ventilated lung in patients undergoing OLV with STV but had no effect on peripheral oxygen saturation or the incidence of oxygen desaturation.

REFERENCES

1. Karzai W, Schwarzkopf K. Hypoxemia and one-lung ventilation. *Anesthesiology* 2009; 10: 1402-11.
2. Michelet, P, D'Journo XB, Roch A, et al. Protective ventilation influences systemic inflammation after esophagectomy. *Anesthesiology* 2006; 105: 911-9.
3. Schilling T, Kozian A, Huth C, et al. The pulmonary immune effects of mechanical ventilation in patients undergoing thoracic surgery. *Anesth Analg* 2005; 101: 957-65.
4. Fernandez-Perez ER, Keegan MT, Brown DR, et al. Intraoperative Tidal volume as a risk factor for respiratory failure after pneumonectomy. *Anesthesiology* 2006; 105: 14-8.
5. Licker M, Diaper J, Villiger Y, et al. Impact of intraoperative lung-protective interventions in patients undergoing lung cancer surgery. *Critical Care* 2009; 13: 41.
6. Schultz MJ, Haitsma JJ, Slutsky AS, Gajic O. What tidal volumes should be used in patients without acute lung injury? *Anesthesiology* 2007; 106: 1226-31.
7. Lohser J. Evidence-based management of one-lung ventilation. *Anesthesiol Clin* 2008; 26: 241-72.
8. Capan LM, Turndorf H, Patel C, et al. Optimization of arterial oxygenation during one-lung anesthesia. *Anesth Analg* 1980; 59: 847-51.
9. Hogue C. Effectiveness of low levels of nonventilation lung continuous positive airway pressure in improving arterial oxygenation during one-lung ventilation. *Anesth Analg* 1994; 79: 364-7.
10. Cohen E, Eisenkraft JB. Positive end-expiratory pressure during one-lung ventilation improves oxygenation in patients with low arterial oxygen tensions. *J Cardiothorac Vasc Anesth* 1996; 10: 578-82.
11. Cohen E, Eisenkraft JB, Thys DM. Oxygenation and hemodynamic changes during one-lung ventilation: effects of CPAP 10, PEEP10 and CPAP10/PEEP 10. *J Cardiothorac Vasc Anesth* 1988; 2: 34-40.
12. Slinger P, Triolet W, Wilson J. Improving arterial oxygenation during one-lung ventilation. *Anesthesiology* 1988; 68: 291-95.
13. Blum JM, Fetterman DM, Park PK, et al. A description of intraoperative ventilator management and ventilation strategies in hypoxic patients. *Anesth Analg* 2010; 110: 1616-22.
14. ARDS Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *New Engl J Med* 2000; 342: 1301-8.
15. Slinger PD, Kruger M, McRae K, Winton T. Relation of the static compliance curve and positive end-expiratory pressure to oxygenation during one-lung ventilation. *Anesthesiology* 2001; 95: 1096-102.
16. Cinnella G, Grasso S, Natale C, et al. Physiologic effects of a lung recruiting strategy applied during one lung ventilation. *Acta Anesthesiol Scand* 2008; 52: 766-75.
17. Tusman G, Bohm S, Sipmann FS, Maisch S. Lung recruitment improves the efficiency of ventilation and gas exchange during one-lung ventilation anesthesia. *Anesth Analg* 2004; 98: 1604-9.
18. Tusman G, Bohm SH, Melkum F, et al. Alveolar recruitment strategy increases arterial oxygenation during one-lung ventilation. *Ann Thorac Surg* 2002; 73: 1204-9.
19. Fan E, Wilcox ME, Brower RG, et al. Recruitment maneuvers for acute lung injury. *Am J Resp Crit Care Med* 2008; 178: 1156-63.

Cite this article as: Badner NH, Goure C, Bennett KE, Nicolaou G. Role of continuous positive airway pressure to the non-ventilated lung during one-lung ventilation with low tidal volumes. *HSR Proceedings in Intensive Care and Cardiovascular Anesthesia* 2011; 3(3): 189-194

Source of Support: Nil. **Conflict of interest:** None declared.

Acknowledgements: We wish to thank the Schulich School of Medicine and Dentistry division of Thoracic Surgery as well as the members of the Victoria Hospital Department of Anesthesiology and Perioperative Medicine for their cooperation in this study.