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Pressure-Controlled Mechanical Ventilation Is More Advantageous in the Follow-up of Patients with Chronic Obstructive Pulmonary Disease after Open Heart Surgery

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ABSTRACT

Objective: Cardiopulmonary bypass deteriorates pulmonary functions to a certain extent. Patients with chronic obstructive pulmonary disease (COPD) are associated with increased mortality and morbidity risks in the postoperative period of open-heart surgery. In this study we compared 2 different mechanical ventilation modes, pressure-controlled ventilation (PCV) and volume-controlled ventilation (VCV), in this particular patient population.

Patients and Methods: Forty patients with severe COPD were assigned to 1 of 2 groups and enrolled to receive PCV or VCV in the postoperative period. Arterial blood gases, respiratory parameters, and intensive care unit and hospital stays were compared between the 2 groups.

Results: Maximum airway pressure was higher in the VCV group. Pulmonary compliance was lower in the VCV group and minute ventilation was significantly lower in the group ventilated with PCV mode. The respiratory index was increased in the PCV group compared with the VCV group and with preoperative findings. Duration of mechanical ventilation was significantly shorter with PCV; however, intensive care unit and hospital stays did not differ.

Conclusion: There is not a single widely accepted and established mode of ventilation for patients with COPD undergoing open-heart surgery. Our modest experience indicated promising results with PCV mode; however, further studies are warranted.

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INTRODUCTION

Cardiopulmonary bypass (CPB) used during cardiac surgery leads to a certain degree of deterioration in pulmonary functions [Clark 2006; Tireli 2006; Ugurlucan 2008; Ugurlucan 2013]. Chronic obstructive pulmonary disease (COPD) is included in different risk scoring systems as a comorbidity factor leading to prolonged intubation durations and early mortality [Grover 1990; Hattler 1994; Roques 1999; Gao 2003]. COPD includes a variety of pulmonary problems associated with longstanding irreversible damage to pulmonary structures or overreaction of bronchoconstriction against external stimuli and is related to increased mortality and morbidity in patients undergoing open heart surgery [Samuels 1998]. Moreover, breathing difficulties, which are progressive, unrelated to cardiac disorders, and require beta-agonist and steroid therapy, may be included in this spectrum as well.

The literature includes many reports indicating that CPB has deleterious effects on the lungs. When COPD is present as a major risk factor for patients undergoing open heart surgery, the mechanical ventilation mode during the postoperative intensive care unit (ICU) stay becomes a vital entity. Well-known mechanical ventilation modes, such as volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV), each have certain risks and benefits [Munoz 1993; Cinella 1996; Campbell 2002; Chiumello 2002; Davidson 2002]. Theoretically, because there is increased bronchoconstriction and increases in the amounts of bronchial secretions, PCV is speculated to be more beneficial.

We aimed to evaluate and compare the clinical results of VCV and PCV modes of ventilation in patients with COPD who underwent coronary artery bypass grafting (CABG).

PATIENTS AND METHODS

Between April 2009 and July 2012, 40 consecutive patients with severe COPD who underwent isolated CABG surgery were enrolled into this double-blind and randomized study.

Patient Selection

Each patient underwent a spirometer test and was seen by a pulmonologist in the preoperative period. Pulmonary disease was diagnosed by clinical history and pulmonary function tests. Smoking history was present in all patients, and all the patients were instructed to quit smoking. The diagnosis of COPD was established by the presence of one or more of the following criteria: room air partial oxygen pressure (PaO_2) ≤80mmHg, partial carbon dioxide pressure ($PaCO_2$) ≥45mmHg, and forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) ≤75% of predicted value. The patients fulfilling these criteria were included in the study protocol. Patients were encouraged to do respiratory exercises with incentive spirometry for 4 to 6 weeks prior to the surgical intervention. Oral or inhalation steroids and bronchodilator therapy were prescribed and continued until the surgery and were resumed postoperatively after extubation for pulmonary function optimization, with close follow-up by the intensive care pulmonologists.

Exclusion Criteria

Excluded from the study were patients who underwent redo operations, emergent cases, patients with impaired left ventricular functions (ejection fraction of <50%), patients with a history of renal and/or hepatic insufficiency or cerebrovascular accident, and patients with concomitant cardiac pathologies requiring additive surgery.

Randomization

Patients were divided into 2 groups when they were transferred to the ICU, group 1 (n = 20), the VCV group, and group 2 (n = 20), the PCV group. Randomization of the patients was arranged by a free-use web-based system (http://www.tufts.edu/~gdallal/PLAN.HTM).

Anesthesia Protocol

General anesthesia was initiated with induction of etomidate and sufentanil 0.25-0.5μg/kg. Muscle relaxation was achieved with vecuronium bromide. Maintenance of the anesthesia was with sevofluorane inhalation and supplements of sufentanil at the discretion of the attending anesthesiologist. Arterial, central venous, and Swann-Ganz catheters were inserted after intubation. Following intubation, intrinsic positive end expiratory pressure (PEEPi), minute ventilation, blood pressure, and central venous pressure were recorded. PEEPi was measured by occluding the airway completely at the end of expiration.

Surgery Protocol

In all patients, the revascularization procedures were performed with CPB by using standard aortic and 2-stage venous cannulations. After median sternotomy, a pedicled left internal mammary artery (LIMA) and adequate length saphenous vein were harvested. Maximum care was taken not to open the pleura during LIMA dissection; however, when accidentally injured, the left pleura was widely opened. All patients received a bolus of heparin (300 U/kg) with subsequent doses titrated to maintain the activated coagulation time longer than 480 seconds during CPB. Management of CPB included systemic temperature drift to 28°C, alpha-stat pH management, and targeted mean perfusion pressure between 50 and 80 mmHg at pump flow rates of 2.0 to 2.4 L/min per m2. In all patients, the LIMA was used to revascularize the left anterior descending coronary artery, whereas saphenous veins were used to revascularize other myocardial territories. Two chest tube drains were placed to the mediastinum and/or left pleura. The intraoperative characteristics of all patients are listed in Table 2.

ICU Follow-up

Chest roentgenogram was performed preoperatively, on admission to the ICU, and every day postoperatively in the hospital. During mechanical ventilation, arterial blood gas analysis, maximum airway pressure, respiratory index (RI) (RI = PaO_2/FiO_2, and minute ventilation (Vmin) were recorded in 2-hour intervals. The respiratory rate was adjusted to 14-18 breaths/min with an inspiration/expiration ratio of 1/3. In VCV mode, tidal volume was managed as 7-8 mL/kg. In PCV mode, inspiratory pressure was adjusted to produce the lowest pressure that allows enough tidal volume, approximately 7-8 mL/kg. Applied PEEP was 80% of the measured PEEPi at the beginning of the operation.

Extubation Criteria

Extubation was performed when patients were awake, cooperative, hemodynamically stable, and able to actively cough with low amounts of tracheal secretions, with room air oxygen saturation (SaO_2) >90% and FiO_2 <40%. All patients were managed by the same standardized cardiovascular, respiratory, and renal protocols aiming for early extubation.

STATISTICAL ANALYSIS

Statistical analysis was performed with the computer program Statistical Package for the Social Sciences (SPSS) 15.0 (SPSS Inc., Chicago, IL, USA) for Windows by a professional statistician. Data are expressed as mean ± standard deviation.

All univariate comparisons were performed using the Student's t test in cases in which the data were normally distributed. Because the normality assumption was not valid for FEV_1, intubation time, duration of ICU stay, and duration of hospitalization, the Wilcoxon's rank sum test was used for these analyses. All outcome comparisons were 1 sided to compare the methods used in each group and the occurrence of improved outcomes. Comparisons of patient characteristics were 2 sided.

All longitudinal comparisons were performed using repeated measures analysis of variance (RM-ANOVA). The variables analyzed were the 4 RI values from each patient and the percentage change from pretreatment to posttreatment RI calculations (3 values per patient). The method of analysis accounts for the fact that the multiple RI values per patient are interdependent.

Longitudinal comparisons of arterial blood gas analysis were performed using RM-ANOVA. To deal with the apparent lack of normality of some variables, the method was applied twice: once to the observations themselves and once to the ranks of the

Table 1. Preoperative Demographic Data*

Variable	Group 1 (n = 20)	Group 2 (n = 20)	*P*
Mean age, years	52.7 ± 8.4	54.7 ± 11.3	NS
Sex (female)	7	6	NS
Patients requiring therapy for COPD	All	All	NS
BSA, m^2	2.3 ± 0.12	2.4 ± 0.09	NS
Hypertension	12	11	NS
Smoking history	All	All	NS
Diabetes mellitus	7	8	NS
Carotid or peripheral arterial disease	5	4	NS
Remote MI (>1 month)	4	5	NS
Mean EF (%)	58.3 ± 5.7 %	55.9 ± 9.9 %	NS
Mean CCSAC	2.2 ± 0.6	2.7 ± 0.9	NS

*NS indicates not significant; BSA, body surface area calculated by the Roisen formula; MI, myocardial infarction; EF, ejection fraction; CCSAC, Canadian Cardiovascular Society Anginal Class

Table 2. Intraoperative Data*

Variable	Group 1 (n = 20)	Group 2 (n = 20)	*P*
Mean bypass number	2.8 ± 0.4	3.2 ± 0.1	NS
Operation time, minutes	194.24 ± 29.43	176.37 ± 89.2	NS
Cross-clamp time, minutes	48.07 ± 13.82	44.62 ± 19.95	NS
CPB time, minutes	72.4 ± 14.71	83.21 ± 39.23	NS
Transfusion of packed red blood cells, mL	140.23 ± 31.89	190.67 ± 57.13	NS

*NS indicates not significant

Table 3. Preoperative Respiratory Characteristics*

Parameter	Group 1 (n = 20)	Group 2 (n = 20)	*P*
FEV_1, %	44.7 ± 4.9	45.2 ± 5.1	NS
FVC, %	61.2 ± 3.8	60.8 ± 4.4	NS
PCO_2, mmHg	46.3 ± 4.1	44.8 ± 5.6	NS
PO_2, mmHg	68.8 ± 7.9	69.2 ± 6.4	NS
SaO_2, %	92.4 ± 4.8	90.5 ± 3.7	NS
RI, PaO_2/FiO_2	211 ± 85	217 ± 103	NS

*NS indicates not significant

Table 4. Postoperative Pulmonary and Hemodynamic Findings*

Parameter	Group 1 (n = 20)	Group 2 (n = 20)	*P*
pH	7.39 ± 0.7	7.40 ± 0.9	NS
PCO_2, mmHg	40.4 ± 3.7	39.8 ± 6.3	NS
PO_2, mmHg	127.1 ± 35.2	116.4 ± 29.8	NS
RI, PaO_2/FiO_2	273 ± 44	328 ± 53	.046
Paw, cmH_2O	29.4 ± 6.2	24.8 ± 3.9	.019
PEEPi, cmH_2O	1.7 ± 0.9	1.9 ± 1.1	NS
Vmin	7.0 ± 1.9	7.9 ± 1.4	.027
Compliance, cmH_2O/L	43.2 ± 10.7	49.1 ± 13.3	.038
Heart rate, beats/min	98.2 ± 29.3	105.4 ± 32.6	NS
Systolic BP, mmHg	137.6 ± 14.5	131.9 ± 22.4	NS
CVP, mmHg	9.2 ± 3.5	10.4 ± 2.1	NS

*NS, indicates not significant; Paw, maximum airway pressure; Vmin, minute volume; BP, blood pressure; CVP, central venous pressure

observations, using the methodology proposed by Spearman. Thus, the results of the parametric analysis were confirmed in all instances by the nonparametric test. The values at each time point were also compared using Wilcoxon's rank sum test.

A *P* value less than 0.05 was considered statistically significant.

RESULTS

Preoperative Characteristics

The mean age of the patients was 52.7 ± 8.4 years in group 1 and 54.7 ± 11.3 years in group 2. There were 7 females and 13 males in the VCV group and 6 females and 14 males in the PCV group. The body surface areas were 2.3 ± 0.12 m2 and 2.4 ± 0.09 m2 in group 1 and group 2, respectively. All the patients in both groups had positive smoking histories. Twelve patients had hypertension in group 1 and 11 patients had hypertension in group 2. Diabetes mellitus and carotid or peripheral arterial disease were present in 7 patients and 8 patients in the VCV group and 5 patients and 4 patients in the PCV group, respectively. Four patients had experienced myocardial infarction more than 1 month preoperatively in group 1 and 5 patients had a myocardial infarction history beyond 1 month in group 2. Mean ejection fractions were 58.3% ± 5.7 % in the VCV group and 55.9% ± 9.9 % in the PCV group. Canadian Cardiovascular Society Anginal Class mean calculations were 2.2 ± 0.6 and 2.7 ± 0.9 in group 1 and group 2, respectively. There were no statistically significant differences between the two groups in sex, age, left ventricular ejection fraction, and additional comorbidity factors, including diabetes mellitus, hypertension, carotid or peripheral arterial disease, preoperative respiratory parameters, and preoperative use of steroids (Table 1).

The respiratory parameters of patients, including spirometer measurements and blood gas analysis in group 1 and group 2, are summarized in Table 3. During the preoperative period, the values of FEV_1, FVC, partial carbon dioxide pressure (PCO_2), partial oxygen pressure (PO_2), SaO_2, and RI did not differ significantly between the 2 groups (Table 3).

Operative Characteristics

The mean number of bypassed coronary arteries was 2.8 ± 0.4 in group 1 and 3.2 ± 0.1 in group 2. The operations lasted a mean of 194.24 ± 29.43 minutes in the VCV group and 176.37 ± 89.2 minutes in the PCV group. Cross-clamp and CPB times were 48.07 ± 13.82 minutes and 44.62 ± 19.95 minutes and 72.4 ± 14.71 and 83.21 ± 39.23 minutes in group 1 and group 2, respectively. The types of operations, aortic cross-clamp times, and CPB times did not significantly differ between group 1 and 2 (Table 2). All of the patients recovered uneventfully after the operation. No infections or major blood loss needing reoperation occurred. Surgical mortality in 30 days was zero.

ICU Findings

In group 2, right-sided pneumothoraxs occurred in 2 patients on the postoperative first and third days. One of the patients required chest tube insertion, and in the other patient, since the pulmonary sequestration was less than 20%, an invasive procedure was not performed and the pneumothorax was resorbed after 5 days. In another patient, subcutaneous emphysema was detected at the upper left hemithorax, which was treated with oxygen therapy.

The maximum airway pressure was 29.4 ± 6.2 cmH_2O with the VCV mode, which was significantly higher than the PCV

Table 5. Postoperative Demographics*

Parameter	Group 1 (n = 20)	Group 2 (n = 20)	*P*
Ventilation, hours	19.3 ± 9.1	16.4 ± 7.2	.049
ICU stay, hours	43.2 ± 18.1	37.4 ± 20.4	NS
Hospital stay, hours	9.4 ± 3.9	8.0 ± 2.8	NS

*NS indicates not significant

mode (24.8 ± 3.9 cmH_2O) (P = 0.019). Minute ventilation was significantly lower in the group ventilated with the PCV mode (7.0 ± 1.9 versus 7.9 ± 1.4; P = 0.027). Moreover, pulmonary compliance was significantly lower in group 1 than group 2 (43.2 ± 10.7 mL/cmH2O versus 49.1 ± 13.3 mL/cmH_2O) (P = 0.038). The RI was 211 ± 85 in group 1 and 217 ± 103 in group 2 in the preoperative period, which was not significantly different between the 2 groups (P > 0.05); however, in the postoperative period respiratory indices were 328 ± 53 in patients who received PCV mode ventilation, whereas it was 273 ± 44 n patients who received VCV mode ventilation (treatment effect, P = 0.046, RM-ANOVA). Changes in arterial blood gases, systolic and central venous pressures, heart rates, respiratory indices, and ventilator parameters are summarized in Table 4.

The duration of mechanical ventilation differed significantly between the 2 groups (19.3 ± 9.1 hours in group 1 versus 16.4 ± 7.2 hours in group 2, P = 0.049); however, ICU and hospital stays were similar (Table 5).

DISCUSSION

It is well known that open-heart surgery compromises pulmonary compliance [Clark 2006; Tireli 2006; Ugurlucan 2008; Ugurlucan 2013]. The damage secondary to CPB may be in a range between minimal dyspnea to adult respiratory distress syndrome, which is sometimes lethal [Clark 2006]. Thus, respiratory management before, during, and after cardiac surgery is vitally important. In our study, we compared 2 well-known ventilation modes, VCV and PCV, during the ICU follow-up of patients with COPD who underwent CABG.

VCV is usually accepted as an easier mechanical ventilation method for physicians to precisely monitor the tidal volumes of the intubated patients and safely manage their oxygenation. On the other hand, the main advantage of PCV is that it prevents insult to the lungs from excessively high pressure; however, because the lungs have dynamic volumes and changes in tidal volume with every breath, frequent alterations of arterial oxygenation and PCO_2 are accepted as the disadvantages of this mode [Munoz 1993; Campbell 2002; Chiumello 2002; Gruber 2008].

Respiratory impairment is a multifactorial consequence following cardiac surgery and, in part, occurs independently of CPB [Clark 2006; Tireli 2006; Ugurlucan 2008; Ugurlucan 2013]. When blood interacts with the artificial surfaces of CPB, neutrophils are activated. This activation induces proinflammatory mediators such as interleukins, TNF-α, complement factors such as C3a and C5a, and platelet-activating factors. In addition, activated neutrophils secrete proteolytic enzymes such as elastase and collagenase, leading to cellular and parenchymal damage. To prevent such consequences of CPB, research has been widely performed to find ways to partially inhibit the CPB-related whole-body inflammatory response by intraoperative administration of various pharmacological agents [Rahman 2000; Cağli 2005; Gerrah 2005].

Additionally, it has been shown that during CPB, bronchial arterial blood flow decreases [Schlensak 2002]. As a result, ischemic injury occurs in the lungs. In order to prevent or minimize the issue, Onorati et al [Onorati 2006] tried to increase bronchial arterial flow by intraaortic balloon pump counterpulsation during open cardiac surgery while the cross-clamp was still on. Their study indicated significantly better ventilation times, RI, and respiratory system compliance, although ICU and hospital stay lengths were not significantly different [Onorati 2006].

Karaiskos et al [Karaiskos 2004] showed the efficiency of leukocyte filtration to prevent the side effects of CPB in patients with COPD. These authors reported that ICU and hospital stays were shorter and RIs were higher in the leukocyte filtration group than in the control group [Karaiskos 2004].

Today, off-pump CABG without CPB is a widely used procedure in selected patients because the inflammatory effects of CPB are avoided, providing fewer pulmonary side effects. However, in a study by Cimen et al [Cimen 2003], the extubation times and hospital stay durations were not found to be shorter in this particular group. Although the hospital stay was not significantly different between the 2 groups in our study, the ventilation time was significantly shorter in the PCV group. The 2 patients with pneumothorax and 1 patient with subcutaneous emphysema in this particular group were most probably responsible for elongated hospital and ICU stays and the increased morbidity.

In a review evaluating ventilatory approaches in COPD patients, Davidson et al [Davidson 2002] suggested that PCV might be more helpful for ventilation rather than VCV. According to this review, PCV is more similar to the normal breathing pattern, and VCV has a potential risk for patients in whom high PEEP may be dangerous [Davidson 2002]. Campbell and Davis [Campbell 2002] emphasized that PCV offers no advantage over VCV in patients who are not breathing

spontaneously, but they suggested that PCV might reduce the work of breathing and improve comfort for patients with increased respiratory demands.

We observed a lower maximum airway pressure by keeping the tidal volume the same in the PCV and VCV modes. The main reason for lower maximum airway pressure during PCV is that this mode has an intrinsic decreasing flow pattern. The RI, which was the parameter that we used to check oxygenation, was found to be significantly better in the PCV mode. This may indicate that the PCV mode after cardiac surgery reduces alveolar damage. The better minimum volume with PCV might have facilitated the reestablishment of lung volume during the postoperative period, which is highly compromised during the surgery.

The disadvantage of PVC mode is that depending on the individual pulmonary properties of the patient, the volume given differs with every breath. Sometimes sedation of the patients must be increased to overcome this effect [Munoz 1993; Campbell 2002; Chiumello 2002; Gruber 2008]. Although in our study we did not precisely measure the amount of administered anesthetics, because the ventilation times in both groups were similar, our results confirm the benefits of refraining from elongated periods of sedation.

In conclusion, there is not a widely accepted or established mode of ventilation for patients with COPD undergoing open-heart surgery. PCV requires close follow-up; however, it is easily applied in the current era with modern mechanical ventilators. Worldwide research has been widely conducted to find ways to decrease the mortality and morbidity rates in this particular group of patients with COPD who are scheduled for open cardiac surgery. Based on our modest experience comparing widely applied PCV and VCV modes, we propose the use of PCV ventilation until extubation during the early ICU follow-up period of patients with compromised pulmonary function.

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