Pressure Support *versus* Spontaneous Ventilation during Anesthetic Emergence—Effect on Postoperative Atelectasis: A Randomized Controlled Trial

Heejoon Jeong, M.D., Pisitpitayasaree Tanatporn, M.D., Hyun Joo Ahn, M.D., Ph.D., Mikiyung Yang, M.D., Ph.D., Jie Ae Kim, M.D., Ph.D., Hyeon Yeo, M.D., Hyun Joo Ahn, M.D., Ph.D., Mikyung Yang, M.D., Ph.D., Heejoon Jeong, M.D., Pisitpitayasaree Tanatporn, M.D.

Anesthesiology 2021; 135:1004–14

**ABSTRACT**

**Background:** Despite previous reports suggesting that pressure support ventilation facilitates weaning from mechanical ventilation in the intensive care unit, few studies have assessed its effects on recovery from anesthesia. The authors hypothesized that pressure support ventilation during emergence from anesthesia reduces postoperative atelectasis in patients undergoing laparoscopic surgery using the Trendelenburg position.

**Methods:** In this randomized controlled double-blinded trial, adult patients undergoing laparoscopic colectomy or robot-assisted prostatectomy were assigned to either the pressure support (n = 50) or the control group (n = 50). During emergence (from the end of surgery to extubation), pressure support ventilation was used in the pressure support group versus intermittent manual assistance in the control group. The primary outcome was the incidence of atelectasis diagnosed by lung ultrasonography at the postanesthesia care unit (PACU). The secondary outcomes were PaO2 at PACU and oxygen saturation measured by pulse oximetry less than 92% during 48 h postoperatively.

**Results:** Ninety-seven patients were included in the analysis. The duration of emergence was 9 min and 8 min in the pressure support and control groups, respectively. The incidence of atelectasis at PACU was lower in the pressure support group compared to that in the control group (pressure support vs. control, 16 of 48 [33%] vs. 28 of 49 [57%]; risk ratio, 0.58; 95% CI, 0.35 to 0.91; P = 0.024). In the PACU, PaO2 in the pressure support group was higher than that in the control group (83 ± 13 mmHg; P = 0.034). The incidence of oxygen saturation measured by pulse oximetry less than 92% during 48 h postoperatively was not different between the groups (9 of 48 [19%] vs. 11 of 49 [22%]; P = 0.653). There were no adverse events related to the study protocol.

**Conclusions:** The incidence of postoperative atelectasis was lower in patients undergoing either laparoscopic colectomy or robot-assisted prostatectomy who received pressure support ventilation during emergence from general anesthesia compared to those receiving intermittent manual assistance.

(Anesthesiology 2021; 135:1004–14)

**EDITOR’S PERSPECTIVE**

**What We Already Know about This Topic**

- Pressure support ventilation modalities are now standard on newer anesthesia machines and are commonly used during emergence from anesthesia
- Their benefits in preventing postoperative atelectasis have not been well studied

**What This Article Tells Us That Is New**

- A randomized trial in patients undergoing laparoscopic colectomy or robot-assisted prostatectomy compared pressure support ventilation to spontaneous ventilation with intermittent manual assistance during anesthetic emergence
- The outcome was atelectasis in the postanesthesia recovery unit, using lung ultrasound
- The incidence of atelectasis was significantly lower and the PaO2 was significantly higher with pressure support ventilation; however, in the 48-h postoperative observation period, the incidence of oxygen saturation measured by pulse oximetry less than 92% was not different between groups

Although there have been many studies regarding ventilatory techniques to reduce postoperative pulmonary complications, only a few studies have focused on the period of recovery from anesthesia. The benefits obtained from the protective ventilation techniques may be lost during this emergence process. Whalen et al. found that recruitment maneuver and the application of positive end-expiratory pressure (PEEP) improved intraoperative oxygenation, but the effect dissipated promptly after extubation. Many studies have observed the development of...
null
group allocation. Attending anesthesiologists were not blinded to the group allocation. However, they were not aware of the aim of the study. Attending anesthesiologists were not involved in lung ultrasound examination or data analysis.

Anesthesia and Monitoring

A chest x-ray was performed 1 day before operation to exclude preexisting lung pathologies including atelectasis. No patient received sedating premedication. The induction and maintenance of anesthesia were standardized and identical for all patients. After standard monitoring, IV propofol (2.0 to 2.5 mg/kg) and rocuronium (1.0 mg/kg) were administered for induction, and maintenance was achieved using 1.0 to 2.0 minimum alveolar concentration of sevoflurane and IV remifentanil (0.05 to 0.2 μg · kg⁻¹ · min⁻¹). Rocuronium was continuously infused at a rate of 0.3 to 0.8 mg · kg⁻¹ · h⁻¹ under train-of-four monitoring (target train-of-four count, 1/4) and stopped approximately 40 min before the end of surgery. An additional bolus was allowed if necessary.

Preoxygenation was performed for 2 min (O₂ 4 l/min) in the supine position. After the loss of spontaneous breathing, the patients were bag mask–ventilated with a fraction of inspired oxygen (Fio₂) of 0.8. Endotracheal intubation was performed 4 min after the start of preoxygenation. After intubation, an arterial catheter was placed in the radial artery for blood gas sampling and invasive blood pressure monitoring.

Mechanical ventilation was maintained using an anesthesia machine (Carestation 650; Datex-Ohmeda, Inc.; USA) in a volume-controlled mode. The ventilatory settings in both groups were Fio₂ 0.4; tidal volume (V₉), 8 ml/kg of predicted body weight; inspiratory to expiratory ratio, 1:2; and PEEP, 5 cm H₂O. The respiratory rate (RR) was set to 12 breaths/min and further adjusted to maintain end-tidal carbon dioxide pressure between 33 and 45 mmHg. The recruitment maneuver was not used.

The patients were placed in the lithotomy with Trendelenburg positioning during surgery (approximately 30 degrees head-down position in both laparoscopic colon-ectomy and robot-assisted laparoscopic prostatectomy). Pneumoperitoneum was established with carbon dioxide, and intra-abdominal pressure in all patients was maintained between 12 and 15 mmHg during abdominal insufflation.

Blood pressure was maintained within 20% of the baseline values. Phenylephrine, ephedrine, or nicardipine was administered as required to maintain mean arterial blood pressure within this range. If the heart rate was less than 40/min, IV atropine 0.5 mg was administered. Lactated Ringer’s solution was used as maintenance fluid and infused at a rate of 4 to 6 ml · kg⁻¹ · h⁻¹. If intraoperative bleeding occurred, crystalloid solution was administered to replace blood loss. IV hydromorphone 0.01 mg/kg and paracetamol 1 g were administered 5 min before the end of surgery, and IV patient-controlled analgesia was applied to all patients (bolus dose, fentanyl 10 μg; basal infusion dose, fentanyl 10 μg/h). In the PACU, patients who complained of moderate pain greater than 4, measured using a numeric rating scale (0 = no pain, 10 = worst pain), received rescue opioids (IV hydromorphone 0.01 mg/kg) until the numeric rating scale was 4 or lower.

Study Protocol

The duration of anesthesia emergence was the duration from the end of surgery to extubation. The designated ventilatory support method was maintained during emergence in both groups. At the end of surgery, sevoflurane was ceased, and the attending anesthesiologist began the recovery protocol; the pressure support group received pressure support ventilation. The initial pressure support ventilation setting was a driving pressure of 5 cm H₂O, Peep of 5 cm H₂O, and safety backup ventilation of 12 breaths/min (safety backup ventilation setting, V₉, 8 ml/kg of predicted body weight; and Peep, 5 cm H₂O). The flow trigger and end of breath were set at 2 l/min and 30% of peak flow, respectively. Support amount and safety backup ventilation were adjusted according to the patient’s response to meet the target V₉ of 7 to 8 ml/kg and RR of 10 to 16 breaths/min and decreased gradually as the patient restored his or her own V₉ and RR. Ventilatory support was stopped when the patient showed adequate V₁ (greater than 6 ml/kg) and RR (10 breaths/min or greater) without ventilatory support. However, Peep (5 cm H₂O) was maintained until extubation in the pressure support group. In the control group, the emergence process was led by the discretion of the attending anesthesiologist. The basic strategy was to allow the patient to breathe spontaneously and only help respiration if necessary, with intermittent manual assistance. Both groups received fresh gas flow at 4 l/min and Fio₂ of 0.4 during emergence from anesthesia. In patients who developed oxygen saturation measured by pulse oximetry (SpO₂) less than 90% after extubation, rescue mask ventilation was applied with Fio₂ of 1.0.

A train-of-four of peripheral nerve stimulator was monitored using the ulnar nerve throughout recovery, and neuromuscular blockade was reversed with 0.2 mg/kg pyridostigmine and 0.008 mg/kg glycopyrrolate IV when the train-of-four counts were 3 or greater or sugammadex 2 to 4 mg/kg IV when the train-of-four counts were 2 or less. In both groups, extubation was performed when the patient met the following criteria: obeys commands such as eye-opening or hand-grip, V₁ greater than 250 ml, end-tidal carbon dioxide less than 45 mmHg, RR 10 to 20 breaths/min, and a train-of-four ratio greater than 0.9. After extubation, all patients were transferred to the PACU without oxygen supplementation.

Lung Ultrasonography and Scoring System

All patients were evaluated using lung ultrasonography 30 min after their PACU arrival. Lung ultrasonography was
performed using a Vivid S70N (GE Vingmed Ultrasound AS; Norway) with an 11-MHz linear transducer and real-time B-mode. Inspection of each lung was performed at 12 lung sections (each hemithorax was divided into six sections), determined by parasternal, anterior, and posterior axillary lines (vertically) and by nipple and diaphragm lines (horizontally) as landmarks in the supine position, similar to previous studies.19,20 The 12 lung sections were scanned sequentially from right to left, cranial to caudal, and anterior to posterior. Posterior fields were examined while an assistant held the patient in the 45-degree lateral position. The examination was carried out longitudinally on the acoustic windows of the intercostal spaces, and the ultrasound probe was applied perpendicular to the pleura, with a conventional gel between the transducer and skin. The following signs were assessed: the lung “sliding” sign, A-lines, B-lines, lung pulse, and air bronchograms. Postoperative atelectasis was scored between 0 and 4, according to the degree of de-aeration: score 0: normal lung, or one or two well-spaced vertical lines per intercostal space; score 1: three or more well-spaced vertical lines per intercostal space (B-lines) or juxtapleural consolidation with normal pleural line; score 2: loss of A-line with multiple juxtapleural consolidations and irregular pleural lines; score 3: loss of lung sliding and appearance of lung pulse; score 4: consolidation exceeding 1 cm × 2 cm with or without air bronchogram

Results
Enrollment ceased when the target sample size was obtained. In total, 108 patients were assessed for eligibility between April 2020 and September 2020. Eight patients were excluded due to their refusal (n = 7) or cancellation of surgery (n = 1). The remaining 100 patients were randomized and received their allocated treatment. However, three patients dropped out. One in the control group dropped out due to a technical problem with the ultrasound machine. Two in the pressure support group dropped out due to postoperative pneumothorax and open conversion. (Postoperative pneumothorax in the pressure...
support group was developed from peritoneal carbon dioxide insufflation during surgery. The peritoneal gas traveled to the mediastinum and then pleura through the esophageal hiatus. The amount of pleural air was minimal, but the ultrasonographic diagnosis was impaired.) Finally, 49 and 48 patients in the control and pressure support groups, respectively, were analyzed (fig. 2). There were no missing data for these 97 patients for subsequent analyses. There were no adverse events related to study protocol, including immediate postextubation respiratory failure, in both groups.

The baseline characteristics of the participants, operative, and ventilatory data between the two groups are presented in table 1. The mean duration of emergence (from the end of surgery to extubation) was 8 ± 3 min and 9 ± 4 min in the control and pressure support groups, respectively. We defined anesthesia-induced atelectasis to be clinically significant if more than three sections (approximately 25% of total lung surface) showed any sign of atelectasis. Based on this definition, the incidence of postoperative atelectasis diagnosed by lung ultrasonography was 28 of 49 (57%) and 16 of 48 (33%) in the control and pressure support groups, respectively (fig. 2). There were no adverse events related to study protocol, including immediate postextubation respiratory failure, in both groups.

The percentage of patients who showed $\text{Spo}_2$ less than 92% during the PACU stay was 26% and 23% ($P = 0.680$) in the control and pressure support groups, respectively. $\text{Pao}_2$ at PACU was higher in the pressure support group (83 ± 13 mmHg vs. 92 ± 26 mmHg; $P = 0.034$).

After transfer to the ward, the incidence of $\text{Spo}_2$ less than 92% during the postoperative 48 h was 22% and 19% in the control and pressure support groups, respectively.

Various phenotypes of atelectasis are shown in table 2. The most common atelectasis findings were loss of A-lines with multiple juxtapleural consolidations and irregular pleural lines (score 2, n = 64), followed by multiple B-lines (score 1, n = 51), juxtapleural consolidation with normal pleural line (score 1, n = 19), and loss of sliding and appearance of lung pulse (score 3, n = 2). No patient showed score 4 consolidation. The sum of score was 5 (2 to 8) and 3 (1 to 6) in the control and pressure support groups, respectively (median [interquartile range]; $P = 0.093$).

$\text{Spo}_2$ at extubation was 100 (100 to 100) vs. 100 (100 to 100) in the control and pressure support groups, respectively (median [interquartile range]; $P = 0.715$). The duration of PACU stay was 65 (56 to 79) min vs. 68 (60 to 75) min in the control and pressure support groups, respectively (median [interquartile range]; $P = 0.318$).

$\text{Pao}_2$ at PACU was higher in the pressure support group (83 ± 13 mmHg vs. 92 ± 26 mmHg; $P = 0.034$).

Fig. 1. Lung sonographic signs associated with atelectasis. (A) Score 0: normal lung. Pleura is thin and A-lines are apparent. One or two well-spaced lines per intercostal space are allowed. (B) Score 1: more than three well-spaced vertical lines per intercostal space (B-lines). (C) Score 1: juxtapleural consolidation (arrows) with normal pleural line. Juxtapleural consolidation is caused by a loss of lung aeration. It commonly arises from the pleural line. (D) Score 2: loss of A-line with multiple juxtapleural consolidations and irregular pleural lines are seen. Score 3 (loss of lung sliding and appearance of lung pulse; Supplemental Digital Content 1, http://links.lww.com/ALN/C690) and score 4 (large consolidation, no occurrence in our study) are not presented here.
Twenty patients (22% vs. 19%, control group vs. pressure support group; \( P = 0.653 \)) received supplemental oxygen therapy to maintain \( \text{SpO}_2 \) of 92% or greater. However, none received ventilatory support during the postoperative 48h. Other major postoperative complications did not differ between the groups (Supplemental Digital Content 2, http://links.lww.com/ALN/C691).

The beneficial effect of pressure support ventilation on postoperative atelectasis diagnosed by lung ultrasonography was not changed after post hoc sensitivity analysis using variables that may influence postoperative atelectasis (age, body mass index, cardiovascular disease, ASA Physical Status, and operation duration; table 4).

**Discussion**

In the current study, the pressure support group showed a lower incidence of postoperative atelectasis and higher oxygenation compared to the control group in laparoscopic colectomy and robot-assisted laparoscopic prostatectomy.

Pressure support ventilation is widely utilized in ventilator weaning of patients in the ICU,\(^{23-26}\) and the latest American Thoracic Society (New York, New York) guideline recommends pressure support ventilation for successful weaning.\(^{27}\) However, few studies evaluated it as a ventilatory mode of emergence from anesthesia.

Due to the lack of reports in surgical patients, anesthesiologists may be concerned that some patients who breathe comfortably with pressure support ventilation could develop respiratory failure immediately after extubation, or others may argue that we need to watch our patients’ spontaneous breathing to predict the patients’ physiologic conditions after extubation.\(^{25}\) Pellegrini et al.\(^{28}\) demonstrated that high continuous positive airway pressure reduced respiratory drive and the contractile activity of the diaphragm in patients in the ICU. In our study, pressure support ventilation was not associated with postextubation hypoxia or extubation failure; rather, it contributed to the lower incidence of postoperative atelectasis and higher oxygenation. Pressure support ventilation reduced the risk
of postoperative atelectasis diagnosed by current method ultrasonography regardless of patient’s age, body mass index, cardiovascular disease, ASA Physical Status, or operation duration (table 4). There is no evidence that a short duration of pressure support ventilation would have a significant impact on respiratory muscle dysfunction.

The possible mechanisms for how pressure support ventilation shows a lower incidence of postoperative atelectasis are as follows. First, in inspiratory pressure support, driving pressure helps lung expansion during inspiration with reduced work of breathing by as much as 30 to 40%.\(^{28,29,30}\) Second, PEEP increases the end-expiratory lung volume of the dependent lung region, which is sufficient to prevent or reverse atelectasis in healthy patients undergoing surgery.\(^{31}\)

To date, the use of low Fio\(_2\) has been the most commonly suggested technique to decrease atelectasis during recovery from anesthesia.\(^{5,7,32–36}\) An Fio\(_2\) of 0.3 to 0.4 before extubation resulted in reduced incidence of postoperative atelectasis compared to an Fio\(_2\) of 1.0,\(^{37}\) and the same was observed in patients with chronic obstructive pulmonary disease (COPD)\(^{38}\) and obese patients undergoing laparoscopic surgery.\(^{39}\) However, some studies were unable to show the protective effect of low Fio\(_2\) against atelectasis.\(^{40}\) In the current study, the incidence of postoperative atelectasis was as high as 57% in laparoscopic surgery, even though low Fio\(_2\) (0.4) was administered. Pressure support ventilation reduced the incidence of atelectasis by 42% in these patients. Our finding suggests that pressure support ventilation is another armamentarium against postoperative atelectasis.

Most of the previous studies which compared ventilatory techniques used computed tomography to diagnose immediate postoperative atelectasis.\(^{6,7,33,37}\) In most studies, a single-sliced transverse scan was performed approximately 5 mm above the right dome of diaphragm 15 to 60 min postoperatively.\(^7\) The approximate measurement time was similar to that in our study, but a single cut scan may not reflect the lesions in other lung areas. Lung ultrasonography is a fast, simple, noninvasive, and radiation-free technique in which the entire lung area and dynamic changes during respiration can be examined.\(^{30–41}\) The quantitative association between lung ultrasonography scores of aeration and the volumetric data of atelectasis observed on thoracic computed tomography showed that lung ultrasonography had reliable performance in the diagnosis of postoperative atelectasis, with a sensitivity of 88%, a specificity of 92%, and a diagnostic accuracy of 91%.\(^{41}\) A recent meta-analysis demonstrated that lung ultrasonography had a higher diagnostic ability compared to chest x-ray film for lung consolidation/collapse (lung ultrasonography: sensitivity of 92% and specificity of 92%; x-ray film: sensitivity of 53% and specificity of 78%).\(^{32}\)

However, the atelectasis scoring system using ultrasonography has not yet been standardized.\(^{20,21,43,44}\) Originally, lung ultrasound score was developed for ICU patients to assess the severity of pulmonary disease, including B-lines 3 or greater (score 1), multiple coalescent B-lines (score 2), and consolidation (score 3).\(^{45}\) Several studies have adopted the same system to assess postoperative atelectasis.\(^{46}\) B-lines are hyperechoic lines produced by the interaction between alveolar air and interstitial fluid and can be seen in histologically normal lungs which are deflated to a critical level of density (greater than 0.45 g/ml).\(^{33}\) However, coalescent B-lines, which are common in pulmonary edema and acute respiratory distress syndrome, were not observed in our study, and they were probably not in previous studies either, according to lung ultrasound photos presented.\(^{43,44}\) We found that B-lines in postoperative atelectasis were mostly pseudo B-lines. They were not long enough to reach 8 to...
10 cm in length and usually occur below the subpleural consolidation, not below the pleura. Acosta et al., who first examined the capability of lung ultrasound to diagnose postoperative atelectasis, and others also reported findings similar to ours. Therefore, Monastesse et al. proposed modified lung ultrasound scores that emphasize subpleural consolidation for postoperative atelectasis. Other researchers combined B-lines (score 0 to 3) and subpleural...
consolidation (score 0 to 3)\textsuperscript{1,19} in the assessment of postoperative atelectasis. Our scoring system is similar to that in the proposal by Monastesse et al.,\textsuperscript{21} but we replaced “coalescent B-lines” with “loss of A-line with multiple juxtapleural consolidations and irregular pleural lines” (score 2, the most common finding), and added loss of lung sliding and appearance of lung pulse, which indicate noninflating lungs (score 3).\textsuperscript{20,44} Of note, A-lines, the reverberation artifacts of the pleura, were lost when the lung parenchyma became inhomogeneous with de-aeration.\textsuperscript{44} We did not observe large consolidation (score 4) in anesthesia-induced atelectasis, which is in line with several pediatric cases.\textsuperscript{19,20}

This study has some limitations. First, lung ultrasonography depends on the sonographer’s skill, and requires patient cooperation. Both greatly influence the diagnostic accuracy of lung ultrasonography. Second, the median lung ultrasound score (5 and 3)\textsuperscript{1,19} and the incidence of hypoxia (22% and 19%) during 48 h postoperatively were not different between the two groups. This may be because these outcomes were not powered to see differences, but it may be because the atelectasis occurring postoperatively is low-grade, and the antiatelectasis effect of pressure support ventilation is transient. However, we regard that small bits of improvement collectively contribute to a better outcome. Therefore, lower incidence of immediate postoperative atelectasis with the use of pressure support ventilation will have an important role in a multimodal approach. Third, atelectasis was diagnosed by consensus reading of two sonographers. It is known that inter- or intrarater variability exists. Thus, independent diagnosis by two sonographers and a statistical test for the degree of the agreement would be a more reliable assessment than consensus reading of two sonographers.\textsuperscript{20} Fourth, in this study, low Fio\textsubscript{2} (0.4) was maintained during emergence, and patients did not receive oxygen at PACU to avoid absorption atelectasis in both groups. Usually, higher Fio\textsubscript{2} is used to prevent hypoxemia in these periods.\textsuperscript{20} Therefore, the baseline incidence of atelectasis and outcomes may be different when higher Fio\textsubscript{2} is used. Fifth, there were nine patients with unexpected difficult intubation. Attending anesthesiologists proceeded with the protocol because mask ventilation was adequate and intubation was successful with video-laryngoscope in these patients. However, using low Fio\textsubscript{2} can be risky in patients with the previous difficult intubation. Finally, this study was performed in patients with a relatively low risk of postoperative atelectasis. Thus, the effect of pressure support ventilation is not known in patients with COPD, obesity, or other significant comorbidities.

In conclusion, pressure support ventilation during emergence from general anesthesia showed a lower incidence of postoperative atelectasis compared to the patient’s spontaneous respiration with intermittent manual assistance in laparoscopic colectomy and robot-assisted laparoscopic prostatectomy. Because this result was derived from the low-risk patients of postoperative atelectasis, subsequent validation studies for high-risk patients such as obesity and COPD are required.

Research Support
Support was provided solely from institutional and/or departmental sources.

Competing Interests
The authors declare no competing interests.

Reproducible Science
Full protocol available at: hyunjooahn@skku.edu. Raw data available at: hyunjooahn@skku.edu.

Correspondence
Address correspondence to Dr. Ahn: 81 Irwon-ro, Gangnam-gu, Seoul 06351, South Korea. hyunjooahn@skku.edu. This article may be accessed for personal use at no charge through the Journal Web site, www.anesthesiology.org.

References
3. Östberg E, Thorisson A, Enlund M, Zetterström H, Hedenstierna G, Edmark L: Positive end-expiratory pressure alone minimizes atelectasis formation in...
nonabdominal surgery: A randomized controlled trial. Anesthesiology 2018; 128:1117–24


44. Lichtenstein DA: Lung ultrasound in the critically ill. Ann Intensive Care 2014; 4:1
