# Publications Reference List

## Lung Protective Ventilation in the OR

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Postoperative Pulmonary Complications


Evidence is emerging that early identification of modifiable risk factors and implementation of protective management strategies may lead to reduction of severe postoperative pulmonary complications.


Intraoperative use of lower tidal volumes could reduce the incidence of postoperative lung injury, pulmonary infections and atelectasis. Intraoperative use of higher levels of PEEP and recruitment maneuvers also reduce the incidence of these complications. It is difficult, if not impossible, to separate the beneficial effects of lower tidal volumes from that of higher levels of PEEP and RM.


The introduction of an anesthetic protocol to reduce adverse effects of anesthesia was associated with a reduction of Phase I recovery time in adult patients undergoing general endotracheal anesthesia. These anesthetic management changes were primarily associated with a decreased rate of postoperative respiratory depression, nausea and vomiting.


This review discusses the relevant literature on definition and methods to predict the occurrence of postoperative pulmonary complications, the pathophysiology of ventilator-induced lung injury with emphasis on the non-injured lung, and protective ventilation strategies, including the respective roles of tidal volumes, PEEP and recruitment maneuvers. The authors propose an algorithm for protective intraoperative mechanical ventilation based on evidence from recent randomized controlled trials.


Intraoperative protective ventilation was associated with a decreased risk of postoperative respiratory complications. A PEEP of 5 cm H2O and a plateau pressure as low as reasonably possible to reduce driving pressure and achieve adequate ventilation and oxygenation were identified as protective mechanical ventilator settings. These findings suggest that protective thresholds differ for intravenous ventilation in patients with normal lungs compared with those used for patients with acute lung injury.


The authors investigated the association of tidal volume, the level of PEEP and driving pressure during intraoperative ventilation with the development of postoperative pulmonary complications. In patients having surgery, intraoperative high driving pressure and changes in the level of PEEP that result in an increase of driving pressure are associated with more postoperative pulmonary complications.


The authors showed that rates of postoperative pulmonary complications are higher after pressure-controlled ventilation than after volume-controlled ventilation, in part due to more variable and higher driving pressures and tidal volumes, exacerbated by low or no PEEP. Their data support volume-controlled ventilation during surgery, particularly for patients more likely to suffer postoperative pulmonary complications.


In this analysis of administrative data on file, high intraoperative FiO2 was associated in a dose-dependent manner with major respiratory complications and with 30-day mortality. The effect remained stable in a sensitivity analysis controlled for oxygenation.


Perioperative lung-protective ventilation has been recommended to reduce pulmonary complications after cardiac surgery. The protective role of a small tidal volume has been established, whereas the added protection afforded by alveolar recruiting strategies remains controversial. Among patients with hypoxemia after cardiac surgery, the use of an intensive vs. a moderate alveolar recruitment strategy resulted in less severe pulmonary complications while in the hospital.


The incidence of patients with a predicted increased risk of PPCs is high. A large proportion of patients receive high tidal volume and low PEEP levels. PPCs occur frequently in patients at increased risk, with worse clinical outcomes.


PPCs are a common and significant predictor of patient morbidity and mortality. Anesthesists are well-positioned to implement perioperative management strategies to reduce PPCs. Preoperatively, these strategies should include optimization of cardiopulmonary reserve, early smoking cessation, and pre-habilitation exercise programs. Intraoperatively, the focus should be on shorter duration of surgery, careful and quantitatively monitored NMBA, and lung-protective ventilation strategies. Postoperatively, effective analgesia and lung-expansion techniques, including CMAP and physiotherapy, can reduce PPCs.


In the intraoperative period, avoidance of GA in favor of RA will reduce PPC risk. In those receiving a GA, protective ventilation should be used, particularly a small tidal volume of 6-8 ml/kg of ideal body weight, supplemented with recruitment maneuvers and PEEP if required. The ideal level of PEEP remains controversial, with <5cm H2O being acceptable in low-risk patients, but higher levels will be required in more challenging patients.


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The authors investigated the association of blood transfusion, tidal volume and airway pressure during intraoperative ventilation with the development of ARDS. The authors concluded non-protective ventilation settings, mainly high airway pressures, were found as a risk factor for postoperative ARDS together with blood transfusion. Thus, limiting tidal volume size, but especially airway pressure with intraoperative ventilation, may mitigate the risk of lung injury induced by blood transfusions.
Intraoperative Lung Protective Ventilation


Ventilation with tidal volume 0 > 10 mL/kg PBW is still common, although poor correlation with PBW suggests it may be unintentional. BM ≥ 30, female gender and height < 165 cm may predispose patients to receiving large tidal volumes during general anesthesia. Further awareness of patients’ height and PBW is needed to improve intraoperative ventilation practices. The impact on clinical outcomes needs confirmation.


A prospective, randomized, open-label trial of protective ventilation in 56 patients undergoing more than 2 hours of open abdominal surgery showed that lower tidal volumes, PEEP, and recruitment maneuvers led to significantly improved pulmonary function tests in 5 days after surgery, fewer chest x-ray findings, and improved Clinical Pulmonary Infection Scores.


Use of intraoperative lung-protective mechanical ventilation combining lower tidal volumes (VT), moderate PEEP and recruitment maneuvers may help reduce postoperative pulmonary complications in patients undergoing major surgery.


Obese patients present specific lung physiology and mechanics characteristics, frequent respiratory comorbidities, and increased risk of postoperative pulmonary complications. Intraoperatively, lung-protective ventilation with low tidal volumes, recruitment maneuvers with greater PEEP levels, and the judicious use of oxygen concentrations are recommended. Focused postoperative care seeking to minimize atelectasis formation is critical.


Most general anesthetics with tracheal intubation at the institutions surveyed are currently performed with a median tidal volume <8 mL per kg of PBW, most are managed with PEEP of ≤5 cm H₂O, and approximately half utilize both. Given the diversity of the institutions included, this is likely reflective of practice in U.S. academic medical centers. The utilization of higher tidal volumes without PEEP in control groups for clinical research studies should be reconsidered.


This individual patient meta-analysis of 2,127 patients ventilated under general anesthesia for surgery from 15 randomized controlled trials shows that intraoperative ventilation with low tidal volume protects against postoperative pulmonary complications (PPC), but further trials are necessary to define the role of intraoperative higher PEEP to prevent PPC after major abdominal surgery.


In non-obese patients without ARDS undergoing open abdominal surgery, mechanical ventilation should be performed with low tidal volumes (approximately 6 to 8 mL/kg combined with low PEEP because the use of higher PEEP combined with recruitment maneuvers does not confer further protection against PPCs and can deteriorate the hemodynamics.


Protective ventilation can reduce the risk of ALI development in patients who underwent major surgery. However, there is insufficient evidence that such beneficial effects can be translated to more clinically relevant outcomes such as mortality, length of stay in the ICU or duration of MV.

**HEDENSTIerna, Göran, EDMARK, Lennart.** Protective Ventilation during Anesthesia: Is It Meaningful? Anesthesiology, 2016, 125.6: 1079-1082. (Editorial)

During anesthesia of an adult patient with healthy lungs and a normal BMI, tidal volume is not a major concern, recruitment maneuvers may not be necessary provided that a graded PEEP is applied that keeps airways open, and the patient should be delivered to the postoperative area with an open lung, which should be kept open.


Intraoperative LTV ventilation in conjunction with PEEP and intermittent recruitment maneuvers is associated with significantly improved clinical pulmonary outcomes and reduction in length of hospital stay in otherwise healthy patients undergoing general surgery. Providers should consider application of all 3 elements for a comprehensive protective ventilation strategy.


Because definitive evidence is lacking, future research in the field of MV should address the protective role of a personalized approach based on non-invasive monitoring and how this approach can be performed in real life. As suggested in this review, even small improvements in this approach may have a large impact on healthcare systems.


The authors report an intervention to reduce VTs in an academic anesthesia department. By modifying default anesthesia machine ventilator settings, this quality improvement project lowered VT, more consistent use of PEEP, lower ΔP, and greater overall compliance with LPV strategies.


There is marked variability across individual anesthesia providers in the use of intraoperative protective mechanical ventilation. This study’s results suggest that this variability is driven by the individual preference of the anesthesia provider, rather than patient and procedural characteristics.
Positive End Expiratory Pressure


This review discusses the mechanisms contributing to anesthesia-induced respiratory system physiologic derangements, and provides a review of relevant literature and recommendations for interventions to counteract these effects. The authors identify reduction in resting lung volume and high FIO2 as primary determinants of perioperative atelectasis formation. They discuss the role of alveolar recruitment following induction of anesthesia, application of adequate PEEP to keep the lung open throughout the perioperative period, and the impact of FIO2 and CPAP during emergence.

PEEP may affect the lung, heart and brain with several mechanisms. The role of PEEP in clinical practice is still debated but, in selected categories of patients with a careful monitoring, it may play an important role in improving outcomes.

The protective effects of PEEP are procedure-specific, with meaningful effects observed in patients undergoing major abdominal surgery. This study's results suggest that default mechanical ventilator settings should include PEEP of 5–10 cm H2O during major abdominal surgery.

This paper shows that the Open Lung Approach (OLA), i.e. the application of a PEEP level titrated to achieve an optimized respiratory system compliance immediately after a lung recruiting maneuver, is able to reverse several detrimental effects of pneumoperitoneum on lung mechanics and gas exchange.

This study concludes the use of an intraoperative OLA ventilation strategy results in better respiratory system mechanics, lower driving pressure and improved ventilatory efficiency, when compared with a conventional tidal volume ventilation strategy and fixed standard PEEP of 5 cm H2O, or with a RM strategy without an individualized post-RM PEEP titration.

Postoperative spirometry test results are not affected by the PEEP level during intraoperative ventilation during anesthesia for open abdominal surgery in patients at high risk of PPC. Spirometry test results on postoperative day five are associated with the development of PPCs during this time period.

During mechanical ventilation with protective tidal volumes in patients undergoing open abdominal surgery, lung recruitment followed by PEEP of 12 cm H2O decreased the incidence of intra-tidal R/D and did not worsen overdistension, when compared to PEEP ≤2 cm H2O.

The protective effects of PEEP are procedure-specific, with meaningful effects observed in patients undergoing major abdominal surgery. This study's results suggest that default mechanical ventilator settings should include PEEP of 5–10 cm H2O during major abdominal surgery.

This study found that pneumoperitoneum-induced atelectasis persists after removal of insufflation and effects patient recovery in the postoperative period. PEEP counterbalances the diaphragm's cranial shift and increases the functional residual capacity during pneumoperitoneum.

This prospective randomized study JASA 1, BMI <30, undergoing laparoscopic surgical approach determined the effect of PEEP on the respiratory system and cardiac function. Ventilation with PEEP at 10 cm H2O led to significant improvements in both respiratory and cardiac parameters. A reduction in pulmonary vascular resistance and enhanced washout of expiratory CO2 occurred. Ten cm H2O and, to a lesser extent, 5 cm H2O of PEEP decreased LV stroke work.

High PEEP should not be considered as a standard measure to use in all patients undergoing general anesthesia, but moderate PEEP could be preferable in specific cases such as obese patients, Trendelenburg positioning and long duration of surgery. In the average patient, we suggest starting from 0-2 cm H2O, considering recruitment maneuvers and a PEEP increase if oxygenation deteriorates during the course of surgery. In all cases, AP and plateau pressure should be maintained as low as possible, respectively below 13 and 16 cm H2O when clinically feasible.
Tidal Volume


Fifteen patients with BMI 49.8 were studied during anesthesia for laparoscopic gastric bypass surgery, which identified optimal PEEP level of PEEP needed to maintain a stable end-expiratory lung volume and minimize shunt at 25±1 cm H2O. Hemodynamics were well-maintained in spite of the high level of PEEP and reverse Trendelenburg positioning. The authors also reported that during the maintenance of anesthesia, an FiO2 value of approximately 0.3 was used, and the PaO2/FiO2 value was around 350 mmHg, which is markedly higher than that found in previous studies using lower PEEP levels in morbidly obese patients.

This study found alveolar-arterial difference in oxygen tension was always significantly higher in morbidly obese patients. The alveolar-arterial difference in oxygen tension was not affected by body position, pneumoperitoneum or the mode of ventilation. Arterial oxygenation during laparoscopy was observed to be only affected only by body weight and could not be improved by increasing either the VT or RR.

As compared with a practice of nonproactive mechanical ventilation, the use of a lung-protective ventilation strategy in intermediate-risk and high-risk patients undergoing major abdominal surgery was associated with improved clinical outcomes and reduced health care utilization.

Lung injury due to intraoperative single-lung ventilation may contribute to pulmonary complications after Minimally Invasive Esophagectomy (MIE). Low VT ventilation could decrease ventilation-associated lung inflammation, thus minimizing pulmonary complications after MIE.

The authors found a VT of 6 mL/kg PBW ventilation with a PEEP of 3 cm H2O during hepatectomy caused inflammation in the airway and reduced oxygenation after the surgery, whereas VT of 12 mL/kg ventilation with a PEEP of 3 cm H2O did not. There appears to be more lung inflammation with low tidal volume with low PEEP, which may be due to repeated alveolar collapse and re-expansion (i.e., atelectrauma).

Low tidal volumes (defined as < 10 mL/kg) should be used preferentially during surgery. They decrease the need for postoperative ventilatory support (invasive and non-invasive). Further research is required to determine the maximum peak pressure of ventilation that should be allowed during surgery.

Anesthetized patients who received ventilation with lower tidal volumes during surgery had a lower risk of lung injury and pulmonary infection than those given conventional ventilation with higher tidal volumes. Implementation of a lung-protective ventilation strategy with lower tidal volumes may lower the incidence of these outcomes.

A recruitment maneuver followed by PEEP effectively improves intraoperative PaCO2 in morbidly obese patients throughout the course of operation, but it promptly dissipates after trocar/extubation. Further studies are required to examine if immediate post-extubation use of lung expansion strategies (CPAP) could improve pulmonary outcomes in bariatric patients.

In patients undergoing laparoscopy, PEEP increased respiratory elastance but did not improve oxygenation. The addition of a recruitment maneuver increased respiratory elastance and oxygenation in normal-weight and obese patients.

Repeated ARMs, either with or without PEEP, improve early postoperative oxygenation and shorten time to extubation. ARMs without PEEP result in lower airway pressure and less hemodynamic impairment in patients who were undergoing bariatric surgery.
Implementing precise control of arterial oxygenation may avoid the risks associated with excessive and inadequate oxygenation. However, currently there is no direct evidence to support the immediate implementation of permissive hypoxemia, and a comprehensive evaluation of its value in critically ill patients should be a high research priority.

Perioperative supplemental oxygen therapy shows a significant beneficial effect in the prevention of SSIs. We recommend its use along with maintenance of normothermia, meticulous glycemic control, and preservation of intravascular volume perioperatively in the prevention of SSIs.

Administration of 80% oxygen compared with 30% oxygen did not result in a difference in risk of surgical site infections after abdominal surgery.

Administration of 80% oxygen in the perioperative period was associated with significantly increased long-term mortality and this appeared to be statistically significant in patients undergoing cancer surgery but not in non-cancer patients.

Current recommendations for oxygen therapy are a useful guide for clinicians at the bedside. The goal of improving patient outcomes through carefully targeted administration of oxygen offers opportunities for innovation in devices, diagnostics and therapies.