Perioperative lung-protective ventilation strategy reduces postoperative pulmonary complications in patients undergoing thoracic and major abdominal surgery

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The occurrence of postoperative pulmonary complications is strongly associated with increased hospital mortality and prolonged postoperative hospital stays. Although protective lung ventilation is commonly used in the intensive care unit, low tidal volume ventilation in the operating room is not a routine strategy. Low tidal volume ventilation, moderate positive end-expiratory pressure, and repeated recruitment maneuvers, particularly for high-risk patients undergoing major abdominal surgery, can reduce postoperative pulmonary complications. Facilitating perioperative bundle care by combining prophylactic and postoperative positive-pressure ventilation with intraoperative lung-protective ventilation may be helpful to reduce postoperative pulmonary complications.

Key Words: Lung-protective ventilation, Mechanical ventilation, Pulmonary complications.

Introduction

The occurrence of postoperative pulmonary complications (PPCs) is strongly associated with increased hospital mortality and prolonged postoperative hospital stays. The mortality rate associated with PPCs is 10% to 20% after major surgery [1]. One cohort study of 33769 surgical cases [2] showed that unplanned reintubation within the first 3 postoperative days is highly associated with a 72-fold increased risk of death. Therefore, preventing these complications has become a high priority of intraoperative and postoperative anesthetic management.

Mechanical ventilation is mandatory during general anesthesia in patients undergoing surgical procedures. Setting a tidal volume (VT) of ≥ 10 ml/kg in anesthetized patients undergoing surgery has been advocated to prevent atelectasis and hypoxemia. However, the results of many experimental and clinical studies have suggested that high-VT ventilation may cause or aggravate lung injury. Lung-protective ventilation reduces morbidity and mortality among patients with acute lung injury (ALI) and acute respiratory distress syndrome [3,4]. Lung-protective ventilation uses a low tidal volume and moderate positive end-expiratory pressure (PEEP) with an intermittent recruitment maneuver (RM). However, intraoperative VT of ≥ 10 ml/kg is

only used in 18% of cases during surgery, and low tidal volume ventilation is not a routine strategy [5]. In this review, the currently used perioperative ventilation strategies and the rationale for using a lung-protective ventilation strategy will be addressed. Furthermore, we discuss perioperative surgical factors and recent advances for reducing PPCs.

Perioperative Tidal Volume and PEEP

A VT of 10 to 15 ml/kg has been advocated to maintain normal ventilation and prevent atelectasis caused by low-VT ventilation in anesthetized patients undergoing surgery [6]. Although lung-protective ventilation has become the routine ventilator strategy in the intensive care unit (ICU), some reports indicate that the incidence of using high-VT ventilation in the operating room is not low. Two retrospective observational studies [5,7] reported that about 30% of adult patients receive a high VT of > 10 ml/kg of their ideal body weight and that high-risk patients continue to receive nonprotective ventilation, although the use of nonprotective ventilation has decreased over time. In addition, Blum et al. [8] reported no difference in the intraoperative ventilation strategy between patients with and without ALI, suggesting that anesthesiologists do not routinely implement lung-protective ventilation in patients with known ALI.

Whether intraoperative PEEP reduces the risk of postoperative mortality and pulmonary outcomes remains unclear [9]. One randomized controlled trial in nonobese patients undergoing planned abdominal surgery showed that a high PEEP (12 cmH_2O) and RM strategy during open abdominal surgery was not associated with a lower incidence of postoperative pulmonary complications than was a low PEEP level (0–2 cmH_2O) [10]. Moreover, Levin et al. [11] reported that a low VT with PEEP of 2.2 to 5.0 cmH_2O increases the 30-day mortality rate and hospital length of stay. A meta-analysis confirmed that a high PEEP does not prevent postoperative pulmonary complications when a low VT is used [12]. The optimal PEEP level for lung-protective ventilation remains underdetermined, but a PEEP level of > 5 cmH_2O is recommended in obese patients or patients undergoing laparoscopic surgery [13,14].

Beneficial Effects of Lung-protective Ventilation

Causality between intraoperative atelectasis and PPCs has not been clearly demonstrated. Nevertheless, atelectasis can develop anytime during anesthesia and last into the early postoperative period. Impaired oxygenation, forced vital capacity, and forced expired volume in 1 sec are significantly correlated with the atelectatic area confirmed by computed tomography [15]. Moreover, the distal airway can be injured by regional atelectasis, but injury is not localized to atelectatic regions; it can also occur in remote nonatelectatic areas [16]. As a result, the pathophysiological changes associated with atelectasis can impair oxygenation, decrease compliance, increase pulmonary vascular resistance, and injure the lungs [17].

Biotrauma from mechanical ventilation can develop into multiple system organ failure due to release of lung-originating inflammatory mediators into the systemic circulation [18]. Imai et al. [19] showed that an 8 h injurious ventilation strategy in a rabbit model can result in increased rates of kidney and small intestinal epithelial cell apoptosis accompanied by biochemical evidence of organ dysfunction. Short-term nonprotective mechanical ventilation ($\geq$ 5 h) supports local bronchoalveolar inflammatory changes and activates coagulation in patients without preexisting lung injury [20,21].

Nonventilatory Factors Influencing PPCs

Many risk factors predispose patients to PPCs and can be divided into patient-related and surgery-related factors. The surgical site is the most important predictor of overall PPCs. Patients undergoing thoracic or upper abdominal surgery have a high incidence of PPCs because of the close proximity of the surgical incision to the diaphragm. In addition, laparoscopic abdominal surgery operations can lower reoperation rates and pulmonary complications compared with open surgery [22].

Atelectasis is mainly caused after an open laparotomy in up to 90% of patients under general anesthesia [17]. Suitable epidural pain control significantly reduces the incidence of pulmonary complications (atelectasis, pneumonia, and respiratory failure) after major thoracic and abdominal surgery [23–25]. The effects of epidural analgesia can vary depending on the severity of the underlying lung disease. Patients with chronic obstructive pulmonary disease seem to derive the most benefit from epidural analgesia [26].

One-lung Ventilation

ALI after thoracic surgery has been reported since the first use of one-lung ventilation during lung surgery. Many studies have investigated the risk factors for, pathogenesis of, and management of postoperative ALI. A retrospective study reported that the prevalence of post-pneumonectomy pulmonary edema was 2.5% and the mortality rate was 100.0% in affected patients [27]. Similar to two-lung ventilation, high tidal volumes during one-lung ventilation can cause or contribute to PPCs. A retrospective study of patients who underwent pneumonectomy showed that a peak airway pressure of > 40 cmH_2O during surgery is correlated with the occurrence of PPCs [28]. Another study found that patients receiving higher intraoperative VT (8.3

ml/kg, predicted body weight) have a higher incidence of post-pneumonectomy respiratory failure than do patients with a low VT (6.7 ml/kg) [29]. Frequent alveolar RM can be applied to avoid ALI after adding low-VT ventilation [30]. Licker et al. [31] reported that a lung-protective ventilation strategy with frequent RM results in a decreased incidence of ALI and atelectasis and a shorter hospital stay in patients undergoing lung cancer surgery compared with patients who received a conventional ventilation strategy.

Cardiopulmonary Bypass (CPB)

Postoperative pulmonary dysfunction is an obvious complication after CPB. While the systemic inflammatory response syndrome induced by CPB plays a major role, pulmonary dysfunction is generated from a variety of factors that are not all associated with CPB itself. Protective ventilatory strategies can be helpful for preventing PPCs after CPB. A lung-protective low tidal volume (8 ml/kg) plus high PEEP (10 cmH$_2$O) was applied for 6 h after CPB in patients who underwent coronary artery bypass surgery [32]. Serum and bronchiolar lavage levels of the inflammatory cytokines interleukin (IL)-6 and IL-8 were significantly lower at 6 h than in a nonprotective ventilation group with high tidal volumes (10–12 ml/kg) plus low PEEP (2–3 cmH$_2$O). Sundar et al. [33] compared extubation between patients undergoing elective cardiac surgery who received a low VT (6 ml/kg) and high VT (10 ml/kg). They reported that more patients were extubated in the low VT group at 8 h and that these patients also had a lower reintubation rate postoperatively. A cohort study of 3434 patients undergoing cardiac surgery demonstrated that a high VT is an independent risk factor for multiple organ failure and prolonged ICU stay [34].

Recruitment Maneuver and Perioperative Positive-pressure Ventilation

A well-designed study investigated postoperative lung function in patients on low VT ventilation without RM during upper abdominal surgery [35]. However, no significant benefit on postoperative lung function was demonstrated. Low-VT ventilation is reported to promote atelectasis [6]. RMs are used to reinflate collapsed alveoli, sustained pressure above the tidal ventilation range is applied, and PEEP is used to prevent derecruitment with use of a lower VT [17].

Severgnini et al. [36] examined the effects of intraoperative low VT, higher PEEP level, and RMs during open abdominal

surgery lasting 2 h. That study showed that lung-protective ventilation improves respiratory function and reduces the modified clinical pulmonary infection score after surgery. However, no difference was observed in the length of hospital stay between the groups. The Intraoperative PROtective VEntilation (IMPROVE) trial was performed with low-VT ventilation, moderate PEEP, and repeated RMs, particularly for high-risk patients undergoing major abdominal surgery [37]. It demonstrated that the incidence of PPCs within the first 7 days after surgery was lower with lung-protective ventilation than without ventilation. The proportion of patients on noninvasive ventilation or intubation was lower in the protective ventilation group during the first 7 days postoperatively. Importantly, the length of hospital stay was also shorter in the protective ventilation group.

The facilitation of perioperative bundle care by combining prophylactic and postoperative positive-pressure ventilation with intraoperative lung-protective ventilation [38] may be more helpful in reducing postoperative morbidity. The purpose of this ventilation strategy is to minimize lung volume reduction throughout the pre-, intra-, and postoperative periods. In this strategy, preoperative noninvasive positive-pressure ventilation using pressure support ventilation (PSV) and PEEP or continuous positive-pressure ventilation (CPAP) effectively attenuates reduced lung volume. Lung-protective ventilation is continued throughout the surgical procedure. The same noninvasive respiratory support (PSV + PEEP or CPAP) is performed during the early postoperative period. Finally, performing postoperative CPAP or PSV and PEEP improves gas exchange and pulmonary function after extubation for major thoracic and abdominal surgery and could help prevent postoperative acute respiratory failure in patients at high risk for PPCs [39].

Conclusion

Preventing PPCs has become a high priority of intraoperative and postoperative management. Although lung-protective ventilation has become routine in the ICU, low-VT ventilation in the operating room is not a routine strategy. Low-VT ventilation, moderate PEEP, and repeated RMs, particularly for high-risk patients undergoing major abdominal surgery, can reduce PPCs. Facilitating perioperative bundle care by combining prophylactic and postoperative positive-pressure ventilation with intraoperative lung-protective ventilation may be more helpful in reducing PPCs. Further investigations are needed to determine how results can be applied and implemented in routine clinical practice.

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