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Research Paper

An Insight in lung protection and complications in Anaesthesia

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Abstract
Perioperative pulmonary complications are known to be a major cause of morbidity and mortality, and as such, contribute a large burden to the health care system globally. Anesthesiologists have an important role during the perioperative period to identify patients at risk of these complications and intervene in order to reduce them. After describing perioperative pulmonary complications and risk factors for such, this article will address preoperative, intraoperative, and postoperative lung protective strategies to try and reduce the risk of these complications.

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Perioperative Pulmonary Complications

Pulmonary complications have been shown to be a major cause of morbidity and mortality in the perioperative period, in both cardiothoracic surgical populations, and non-cardiothoracic surgery [12345]. Several large studies that have looked at perioperative pulmonary complications (PCC) include a 2000 prospective cohort study of over 80,000 American veterans [6], a 2006 systematic review by the American College of Physicians (ACP) [23], and a 2011 multi-center, European observational study [7]. However, there are some inconsistent findings between these studies. Factors that make it difficult to study PCC include the disparate populations used, the wide variety of surgical procedures involved, and the large list of potential pulmonary complications to consider. PCC can encompass a wide variety of pathologies, such as exacerbation of chronic lung disease, pneumothorax, pulmonary embolism, pulmonary edema, atelectasis, pneumonia, acute lung injury (ALI), acute respiratory distress syndrome (ARDS), and respiratory failure [245], the latter of which can be fatal in up to 20% of patients within 30 days following surgery [4]. In the thoracic surgical population specifically, PCC occur in up to 20% of patients and account for most of the expected 5% mortality in this population [8]. In non-cardiothoracic surgery, there has been less research into PCC compared to cardiac complications, even though PCC have been shown to occur with a similar, if not higher, frequency, depending on the study [2349]. In fact, in a retrospective cohort study of over 45,000 patients undergoing bowel surgery, Fleisher and Linde-Zwirble [10] found a 19% rate of PCC compared to just a 1.2% rate of cardiac complications, with the PCC costing almost 3.5% more.

Intraoperative Lung Protective Strategies

Intraoperative interventions that may reduce PCC include lung protective mechanical ventilation, judicious fluid administration, and adequate analgesia. The use of volatile anesthetics in lung protection will be briefly discussed in this section as well.

Historically, large tidal volumes up to 15 ml/kg were used in the perioperative period in order to avoid atelectasis. However, given the work done in ARDS management, mechanical ventilation is now known to be associated with inflammation and cell injury. Markers of these processes have been found to be elevated in patients ventilated with larger tidal volumes. Thus, the current trend in mechanical ventilation is to use tidal volumes of approximately 6 ml/kg, which is a normal spontaneous tidal volume. Volumes larger than this have been shown to be a major risk factor for the development of ALI in mechanically ventilated patients (so-called ventilator induced lung injury or VILI) [25]. A prospective study found that tidal volumes > 700 ml and peak airway pressure > 30 cmH_2O were independently associated with the development of ARDS [26]. It is important to remember that the majority of these findings have even been shown in patients with previously healthy lungs.

ALI is the most common cause of postoperative respiratory failure and may be associated with mortality rates as high as 45% [27]. Though good quality randomized-controlled trials looking specifically at the interaction between perioperative mechanical ventilation strategies, ALI and PCC are lacking, it would seem reasonable to apply the lung protective strategies learned from ARDS management to the operative period.

Fluid management has always been a controversial issue. Excessive intraoperative fluid resuscitation and transfusion have been shown to be risk factors for the development of perioperative ALI and ARDS [2728]. This is especially true in cardiothoracic surgery, where fluid overload may add to the pulmonary endothelial damage already caused by the inflammatory reaction from mechanical ventilation and cardiopulmonary bypass [293031]. This leads to capillary damage and pulmonary edema [32]. In a 2012 meta-analysis of major surgeries, liberal fluid management was associated with a higher risk of pulmonary edema, pneumonia, and hospital length of stay [33]. On the other hand, a concern with restrictive fluid management is the possible contribution to decreased organ perfusion and dysfunction, particularly the kidneys, as well as decreased perfusion of the surgical anastamosis [31]. The current trend in ideal fluid management for major surgeries is individualized to optimize cardiac output and oxygen delivery, while avoiding excessive fluid administration. Hemodynamic endpoints such as stroke volume, cardiac output, and measures of fluid responsiveness such as pulse pressure and stroke volume variation (collectively referred to as goal directed fluid therapy) may provide a superior alternative to fixed regimens [31].

Postoperative Lung Protective Strategies

As alluded to in several of the preceding sections, decreased lung volumes and atelectasis occur in the perioperative period for a number of different reasons: surgical trauma causing diaphragmatic dysfunction; anesthetic related attenuation of respiratory muscle function; pain; positional dependence; and impaired mucociliary clearance [1]. Whatever the reason, decreased lung volumes and atelectasis are known to be associated with pulmonary complications [1]. Thus, postoperative interventions that focus on lung expansion techniques have been shown to reduce PCC by up to 50%, especially in upper abdominal and thoracic surgery. These strategies include respiratory physiotherapy, incentive spirometry, and non-invasive ventilation (NIV). According to the 2006 ACP review, for patients having abdominal surgery, any of these lung expansion techniques were better than no intervention in reducing PCC [2349].

Respiratory physiotherapy can include deep breathing, cough, postural drainage, percussion, vibration, suctioning, and ambulation. Incentive spirometry is an easy and inexpensive way to encourage deep breathing [234]. A prospective observational study of Australian patients undergoing upper abdominal surgery developed a clinical rule for predicting the risk of postoperative pulmonary complications from five patients and procedure related risk factors, including duration of anesthesia, type of surgery, smoking status, respiratory comorbidities, and exercise capacity measured by maximal oxygen uptake. The study concluded that these risk factors may be helpful in prioritizing which patients should receive postoperative respiratory physiotherapy [40].

NIV may be useful in patients who are unable to participate in incentive spirometry or respiratory physiotherapy. Continued positive airway pressure is particularly useful in those who have OSA. Benefits of NIV compared to invasive ventilation include fewer complications, lower morbidity and mortality rates, shorter hospital length of stay, and reduced costs overall. Evidence of benefit has been established in patients undergoing major thoracoabdominal or cardiac surgery, those with hypercapneic respiratory failure due to COPD or deformities of the chest wall, cardiogenic pulmonary edema, and in weaning from invasive mechanical ventilation. NIV may be used in both prophylactic and therapeutic fashions [41]

Are lung-protective techniques relevant to patients without ARDS or who are undergoing surgical procedures?

Many operating theatre patients will be elective cases with relatively normal lungs; some, however, will be emergencies, with high levels of inflammatory stimulus and who may well be at elevated risk of lung injury. Prevention or re-expansion of atelectatic areas may, therefore, be important, as may be the avoidance of lung stretch or shearing effects. Some studies have suggested that low tidal volumes and PEEP are not used widely in theatre. Jaber et al. found that PEEP was used in 20% of cases and tidal volumes larger than 10 $ml.kg^{-1}$ in 20% of cases **38**. However, in recent years, more sophisticated ventilators have become available, allowing the use of intra-operative PEEP, and there has been an adoption of some of the ventilation techniques used more commonly in the ICU.

However, PEEP alone is not enough to re-inflate atelectatic lungs. Rothen et al. used computed tomography (CT) studies to examine how much inflation was typically required **39**; this was the equivalent of a single vital capacity breath. Recruitment techniques have been developed to open the lung and then attempt to keep it open by applying suitable levels of PEEP. After a vital capacity recruitment manoeuvre, PEEP 10 cm H_20 appeared to prevent recurrence of atelectasis **40**. Therefore, low tidal volume, PEEP and lung recruitment could have a role in the operating theatre.

Futier et al. studied 400 adults at intermediate- to high risk of PPCs after major abdominal surgery during the Intra-operative Protective Ventilation (IMPROVE) trial **41**, looking for a composite primary outcome of major pulmonary and extrapulmonary complications. The intervention involved intra-operative lung-protective measures, including low tidal volumes (6–8 $ml.kg^{-1}$ of predicted body weight), PEEP (6–8 cmH_2O) and recruitment manoeuvres (30 cm H_2O held for 30 s), vs. no recruitment, no PEEP and tidal volumes of 10–12 $ml.kg^{-1}$. This is in marked contrast to past years, where high tidal volumes (10–15 $ml.kg^{-1}$) had been recommended during anaesthesia to reduce atelectasis **42**. However, over time, evidence has demonstrated a risk of alveolar overdistension and extrapulmonary damage due to cytokine release leading to the current interest in lung-protective ventilation. Futier et al. found a 69% reduction in the probability of a major pulmonary or extrapulmonary event when lung-protective measures were used **41**. Intra-operative lung-protective ventilation during abdominal surgery, including low tidal volumes, PEEP and recruitment manoeuvreshave also been shown to reduce postoperative Clinical Pulmonary Infection Scores (CPIS) **43**. These randomised clinical trial results conflict with an observational study which found increased mortality with low tidal volumes and low PEEP **44**. However, this may well be explained by important differences in patient characteristics, and resulting likelihood of a poor outcome **45**.

The LAS VEGAS study observed practice, outcomes and predictive factors in 9864 patients across 29 countries and 146 hospitals in 2013 **5**. Importantly, peak pressure was a ventilatory variable associated with severe PPCs (a separate analysis of plateau or driving pressure was not performed, because all are closely associated with each other). Intra-operative low oxygen saturations, transfusion of red cells, urgent or emergency surgery, and some pre-operative medical factors (including a history of obstructive sleep apnoea (OSA)) were also associated with the development of PPCs. Laparoscopic surgery was negatively associated with PPC occurrence. Perhaps surprisingly, the LAS VEGAS study failed to show a relationship between PEEP level and PPCs.

PROVHILO examined the role of intra-operative high PEEP (12 cm H_2O) plus recruitment manoeuvres in patients receiving low tidal volume ventilation (8 $ml.kg^{-1}$) vs. low tidal volume with no PEEP and no recruitment. No difference in outcome was found between the two groups, other than a small increase in intra-operative cardiovascular instability in the PEEP group. The conclusion was that this higher level of PEEP and recruitment did not protect against PPCs during open abdominal surgery **46**.

Summary

Pulmonary complications are one of the major causes of morbidity and mortality in the perioperative period. Anesthesiologists have the important role of being able to identify patients at risk preoperatively, and can intervene during the whole perioperative period to try and mitigate these risks. Some of these interventions still have a conflicting evidence base. Therefore, it is important to continue research into PCC in order to provide a truly evidence-based approach to management in this field around the globe. Until this time however, lessons learned from other areas, such as pre-habilitation and smoking cessation in lung cancer patients, and ARDS management in critical care patients, can be applied to all major surgery to try and provide the best clinical care to all patient populations.

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