Postoperative pulmonary complications (PPCs)

Postoperative pulmonary complications (PPCs) include a wide array of respiratory conditions that include from bronchospasm, atelectasis or pneumonia to the Acute Respiratory Distress Syndrome (ARDS). Depending on the definitions and severity included, the incidence of PPCs has been reported from 6% to 80%\(^1\)\(^-\)\(^5\). Independently of this heterogeneity, there are consistent reports that PPCs adversely influence postoperative course with morbidity and mortality\(^1\),\(^6\), mainly within the first postoperative week\(^7\),\(^9\). In adults, some estimates suggest >1 million PPCs/year in the US, with 46,200 related deaths and 4.8 million additional hospitalization days\(^6\). The association between perioperative respiratory events and excess hospital length of stay and costs has also been observed in the pediatric population\(^10\).

ARDS is the most studied PPC due to its severity (mortality around 40%)\(^11\), with multiple animal models and human studies that have helped understand and develop the concepts of volutrauma, barotrauma, biotrauma and atelectrauma\(^12\). The postoperative incidence of ARDS depends on multiple factors, but is overall low in the general population (7.5% in high-risk patients, including those undergoing emergency, cardiac, or major vascular surgery)\(^13\). More recently, other PPCs (i.e. pneumonia) are taking more relevance because of their significantly larger frequency.

The increasingly recognized effect of ARDS but also more frequent but ‘milder PPCs on outcomes has led to an increase in the number of studies and publications focused on PPCs, most of them retrospective\(^14\),\(^15\). A few exceptions include prospective studies primarily directed to understand the effect of intraoperative ventilation on PPC development\(^16\),\(^17\) or meta-analyses utilizing original patient data\(^18\),\(^20\).

A group of adult anesthesiologists and critical care physicians from large academic institutions in the United States have recently created the Perioperative Research Network (PRN). I will present some of the results from our multicenter prospective observational study aiming to characterize PPC in ASA 3 patients after non-cardiothoracic surgery, and their individual impact on mortality and hospital resources utilization. Our findings in mild but frequent PPCs suggest that future interventions to reduce these could lead to improved surgical outcomes.

Risk factors for PPC development

Several efforts have been developed to identify patients at high risk for PPC\(^1\),\(^2\),\(^7\),\(^13\),\(^15\),\(^21\)-\(^23\) with differences between them on PPC scope and definitions and targeted surgical population. An example is the Ariscat score\(^1\), often used to stratify the risk of PPCs in clinical studies. A recent
external validation\textsuperscript{24} has observed some heterogeneity on the predictive performance of the Ariscat score, which could reflect differences in geographical perioperative patient care.

Table 1 shows a summary of different risk factors for PPC development observed in different studies\textsuperscript{25}, classified as factors related to patient’s characteristics, preoperative, surgery or anesthetic management. For practical purposes, risk factors for PPCs can be classified as non-modifiable factors (age, abdominal or emergency surgery) or modifiable factors (preoperative oxygenation or anemia, administered intraoperative fluid volume, maybe procedure duration).

**Intraoperative ventilation and PPCs**

Interventions to reduce PPCs include intraoperative ICU-like mechanical ventilation strategies,\textsuperscript{9,14,19,26} which have been adopted over the past decade by U.S. academic centers\textsuperscript{27,28}.

**Tidal volume.** There is an increased interest in adapting mechanical ventilation strategies that shown proven results in critically ill patients reducing the risk of ARDS over a decade ago\textsuperscript{29} into the surgical population\textsuperscript{9,14,17}, with the goal of preventing ventilator-induced lung injury (VILI). Large tidal volumes, particularly >10mL/kg of predicted body weight (PBW) have also been associated with ARDS and other negative outcomes in surgical patients. These large tidal volumes are still sometimes found in surgical patients\textsuperscript{30-32}. However, a trend to use lower intraoperative tidal volumes in adult surgical patients is slowly but progressively happening\textsuperscript{27,33}. The use of predicted body weight, based on gender and height exclusively, is needed for appropriate tidal volume calculation. Gender female, short height (<165cm) and obesity (body mass index, BMI, \(\geq 30\)) have been found risk factors for (likely unintentional) large tidal volume use\textsuperscript{31,33}. Awareness of these risk factors may help achieving the widespread agreement to avoid tidal volumes >10 mL/kg PBW in adults.

Information about tidal volume in the pediatric surgical population is much more scarce and inconclusive. A systematic review of several observational studies found no association between clinical outcomes with low tidal volume ventilation in children\textsuperscript{34}. Most authors recommend maintaining the tidal volumes in children, with or without ARDS, under 10 mL/PBW (measured proximal to the endotracheal tube in children \(<10-15\ \text{kg}\)\textsuperscript{34-37}). However, the basis of these recommendations is primarily an extrapolation from the adult clinical studies and literature on pediatric animal models.

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**Table 1. Risk factors for PPCs (from Guldner et al., Anesthesiology 2015)\textsuperscript{22.}**

<table>
<thead>
<tr>
<th>Patient Characteristics</th>
<th>Preoperative Testing</th>
<th>Surgery</th>
<th>Anesthetic Management</th>
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<tbody>
<tr>
<td>Age</td>
<td>Low albumin</td>
<td>Open thoracic surgery</td>
<td>General anesthesia</td>
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<tr>
<td>Male sex</td>
<td>Low SpO(_2) ((\leq 95%))</td>
<td>Cardiac surgery</td>
<td>High respiratory driving pressure ((\geq 13\ \text{cm H}_2\text{O}))</td>
</tr>
<tr>
<td>ASA class (\geq 3)</td>
<td>Anemia (Hb &lt;10g/dl)</td>
<td>Open upper abdominal surgery</td>
<td>High inspiratory oxygen fraction</td>
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<tr>
<td>Previous respiratory infection</td>
<td></td>
<td>Major vascular surgery</td>
<td>High volume of crystalloid administration</td>
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<tr>
<td>Functional dependency</td>
<td></td>
<td>Neurosurgery</td>
<td></td>
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<tr>
<td>Congestive heart failure</td>
<td></td>
<td>Urology</td>
<td></td>
</tr>
<tr>
<td>COPD</td>
<td></td>
<td>Duration of surgery &gt;2 h</td>
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<tr>
<td>Smoking</td>
<td></td>
<td>Emergent surgery</td>
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<tr>
<td>Renal failure</td>
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<tr>
<td>Gastroesophageal reflux disease</td>
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<td>Weight loss</td>
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</table>

Respiratory driving pressure is defined as inspiratory plateau airway pressure minus positive end-expiratory pressure. ASA = American Society of Anesthesiologists; COPD = chronic obstructive pulmonary disease; Hb = hemoglobin concentration; SpO\(_2\) = oxygen saturation as measured by pulse oximetry.
Positive End-Expiratory Pressure (PEEP). The recommendations for PEEP management to prevent PPCs are more controversial, compared to those for tidal volumes or even for PEEP strategies in critically ill patients. Moderate or high PEEP levels are common in the ICU\textsuperscript{29}. While some studies suggest PPCs reduction in surgical patients receiving moderate PEEP levels in addition to lower tidal volumes\textsuperscript{9,16,26}, the recent PROVHILO study found these to increase the risk of PPCs\textsuperscript{17}. There have been recommendations for using of low PEEP levels because of the risk of hypotension\textsuperscript{25}, these levels are less frequently used in recent years\textsuperscript{27,33} and these suggestions are still under debate\textsuperscript{49,38}.

Some experts suggest the use of some level of PEEP to prevent atelectasis in pediatric surgical patients, but the optimum level is unknown\textsuperscript{35}.

Airway pressure. There is a widespread agreement in both the adult and pediatric populations to maintain peak inspiratory pressures below 30 cmH\textsubscript{2}O\textsuperscript{29,35}. There is a recent interest in the driving pressure, defined as the airway pressure change over the course of a respiratory cycle (usually calculated as end-inspiratory plateau pressure minus PEEP). A recent meta-analysis suggests the benefit of minimizing the driving pressure during intraoperative ventilation to prevent PPCs and improve outcomes\textsuperscript{20}, but prospective confirmation is still needed.

Inspiratory fraction of oxygen (FiO\textsubscript{2}). The use of high oxygen concentrations may worsen some clinical outcomes, in newborns but also in adults after cardiac arrest, or stroke\textsuperscript{39-41}, and even in ventilated patients\textsuperscript{42} although others have not confirmed this phenomenon\textsuperscript{43-45}. Despite attempts to further understand the effect of FiO\textsubscript{2} during surgery on PPC development to develop evidence-based recommendations this is still unclear\textsuperscript{46}. Selecting the minimum FiO\textsubscript{2} that assures an adequate oxygenation but avoids hyperoxia seems prudent.

Dr. Kneyber\textsuperscript{35} published recently a very comprehensive review on the latest recommendations for intraoperative ventilation in the pediatric surgical population. Their practice key points are shown in Table 2.

### Table 2. Latest recommendations for intraoperative ventilation in the pediatric surgical population, published recently by Kneyber\textsuperscript{35}.

<table>
<thead>
<tr>
<th>Practice points</th>
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<tbody>
<tr>
<td>● The set tidal volume should be within the range of 6–10 mL/kg, but the optimal tidal volume depends upon the disease severity of the lung.</td>
</tr>
<tr>
<td>● Inspiratory pressures should be limited: delta pressures are expected to be &lt; 10 cmH\textsubscript{2}O in patients with healthy lungs. For patients with lung injury, this is unclear, but inspiratory pressures should be kept less &lt;28–30 cmH\textsubscript{2}O in patients with lung injury.</td>
</tr>
<tr>
<td>● A certain level of positive end-expiratory pressure is necessary to prevent atelectasis, although the optimal level is unknown.</td>
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<tr>
<td>● The tidal volume should be measured near the endotracheal tube in children weighing &lt;10 –15 kg.</td>
</tr>
<tr>
<td>● The preferred mode of ventilation may be pressure control to achieve the optimal tidal volume.</td>
</tr>
</tbody>
</table>

Summary.

PPCs are common and associated with worse patient outcomes (including mortality) and increased healthcare utilization and costs, even those considered mild (i.e. atelectasis) and often considered less relevant. Interventions designed to reduce PPC should be multifactorial and multidisciplinary, especially in those patients at high risk, and include preoperative optimization of anemia and oxygenation, adequate intraoperative ventilation and fluid management,
minimizing blood loss and transfusion of blood products, and an increased awareness and efforts to diagnose PPCs and establish treatment early and aggressively. The information currently available to understand the effect of intraoperative ventilation on PPC in the pediatric surgical population is scarce. More information should be pursued for practical guidelines to be developed.

References


