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Review Article

Peri-operative pulmonary dysfunction and protection

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Summary

Pulmonary complications are a major cause of peri-operative morbidity and mortality, but have been researched less thoroughly than cardiac complications. It is important to try and predict which patients are at risk of peri-operative pulmonary complications and to intervene to reduce this risk. Anaesthetists are in a unique position to do this during the whole peri-operative period. Pre-operative training, smoking cessation and lung ventilation with tidal volumes of 6–8 $ml.kg^{-1}$ and low positive end-expiratory pressure probably reduce postoperative pulmonary complications.

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Introduction

Pulmonary complications are a major cause of peri-operative morbidity and mortality and increase hospital stay [1–5]. In the month after thoracic surgery, 1 in 20 patients die, mostly from pulmonary complications, which affect one in five thoracic patients [6]. Less is known about pulmonary complications than cardiac complications following non-cardiothoracic surgery, although there may be more pulmonary complications [2–4, 7]. In a retrospective cohort study of 45 000 patients undergoing colorectal surgery, one in five had pulmonary complications postoperatively, while 1 in 100 experienced cardiac complications [8]. The cost of pulmonary complications was over three times the cost of cardiac complications.

The results of large studies of postoperative pulmonary complications have been inconsistent [2, 3, 9, 10]. Pulmonary complications include a wide variety of conditions such as atelectasis, pneumonia, exacerbation of chronic lung disease, acute lung injury (ALI), acute respiratory distress syndrome (ARDS) and respiratory failure [2, 4, 5]. Approximately one in five patients who develop postoperative respiratory failure will die within 30 days [4]. Thus, it is important to try and predict which patients are at risk of pulmonary complications to prevent them happening. This review focuses mostly on non-cardiothoracic surgery, with occasional reference to cardiothoracic surgery.

Risk factors for peri-operative pulmonary complications

Patient characteristics and the type of surgery affect the rate and severity of postoperative pulmonary complications.

The patient characteristics most commonly associated with pulmonary complications include age, poor general health and functional status, comorbidities and drug abuse, including smoking [1, 2, 4, 5, 9, 11–13]. It is unclear whether the association with age is due to associated comorbidities, rather than age per se [1, 11].

The ASA physical status and serum albumin concentrations less than 30 $g.l^{-1}$ are associated with postoperative pulmonary complications [1, 2, 4, 9]. Comorbidities associated most with pulmonary complications include congestive heart failure, chronic obstructive pulmonary disease and renal insufficiency [1, 2, 5, 9, 11]. Alcohol consumption and smoking moderately increase the rate of pulmonary complication [1, 2, 4, 11]. Additional factors for respiratory failure after thoracic surgery include decreased preoperative respiratory function, the extent of lung resection and coronary artery disease [14]. Impaired spirometry before non-thoracic surgery is not associated with postoperative pulmonary complications [2, 7].

More recently, three associated pulmonary disorders have been found to increase pulmonary complications postoperatively, namely obstructive sleep apnoea, obesity hypoventilation syndrome and pulmonary hypertension [1, 4, 11, 13]. Postoperative hypoxia, aspiration pneumonia, tracheal re-intubation and hospital length of stay are increased in patients with obstructive sleep apnoea [13]. Chronic hypercapnia ($P_aCO_2 > 45$ mmHg), sleep disordered breathing and a BMI > 30 $kg.m^{-2}$ characterise obesity hypoventilation syndrome, which is associated with more postoperative complications than obstructive sleep apnoea, possibly because it is less often recognised as a problem [13]. Patients with pulmonary hypertension have high postoperative rates of respiratory failure, mechanical ventilation and prolonged length of stay in intensive care [13]. Uncomplicated obesity and controlled asthma do not increase pulmonary complications [1, 2, 4, 5, 11].

The duration and type of operation as well as the anaesthetic technique influence the rate of pulmonary complications [1, 2, 4, 5, 9, 11]. Pulmonary complications are more common after surgery that lasts more than 3 h [1]. Operations in the chest and abdomen increase pulmonary complications, due to diaphragmatic dysfunction, atelectasis and consequently inadequate ventilation [4, 5]. Pulmonary complications are also more common after neurosurgery, head and neck surgery and emergency surgery. Laparoscopy is not consistently associated with fewer pulmonary complications than laparotomy, unless the patient is obese [3, 4]. General anaesthesia predisposes to pulmonary complications, which might be partly attributed to associated neuromuscular blockade, particularly if it is inadequately reversed before tracheal extubation [2–4, 7, 15, 16].

Pre-operative interventions to reduce pulmonary complications

Postoperative pulmonary complications can be reduced by optimising the treatment of respiratory disease, particularly through pre-operative physiotherapy, rehabilitation and by stopping smoking [3, 7, 9]. Medications should be continued peri-operatively, including long-acting and short-acting inhaled bronchodilators and, if indicated, a course of steroids or antibiotics [1].

Pre-operative training, or 'prehabilitation' includes a comprehensive program of chest physiotherapy, physical exercise and nutrition. Pre-operative training decreases pulmonary complications after lung volume reduction surgery, lung transplantation and lung cancer surgery [9, 17–19]. Pre-operative training may not affect the rate of complications after other major surgical procedures [18, 20]. However, more specific preoperative lung expansion techniques, such as incentive spirometry, active breathing and forced expiration, halved the rates of postoperative pulmonary complications, including pneumonia, if performed for 20 min a day for at least two pre-operative weeks [4, 11, 21].

Stopping smoking just before surgery may increase the rate of pulmonary complications due to the combination of increased mucus production but less coughing [3]. Stopping smoking one month or more before surgery may decrease complications including ARDS, while wound healing may be improved [22, 23]. How long smoking should be stopped before surgery is still a matter of conjecture [9].

Intra-operative interventions to reduce pulmonary complications

Postoperative pulmonary complications may be reduced by 'lung protective' modes of mechanical ventilation, attention to fluid administration and adequate analgesia.

In patients with ARDS, a tidal volume of 12 $ml.kg^{-1}$ caused more deaths and morbidity than a

tidal volume of 6 $ml.kg^{-1}$, which is within the range of normal spontaneous tidal volumes [24]. Tidal volumes larger than 6–8 $ml.kg^{-1}$ and peak airway pressures more than 30 cmH_2O are associated with increased rates of ALI in mechanically ventilated patients, including those with previously healthy lungs (so-called ventilator-induced lung injury) [25, 26]. Acute lung injury is the most common diagnosis for postoperative ventilatory failure and is associated with mortality rates as high as 45% [27]. A recent meta-analysis of mechanical ventilation during general anaesthesia in a variety of surgical procedures suggests that, for patients with normal lungs, lower tidal volumes (6–8 $ml.kg^{-1}$ ideal body weight) and low levels of positive end expiratory pressure (< 6 cmH_2O) are optimal settings to decrease postoperative pulmonary complications. The studies included in this meta-analysis have often included recruitment manoeuvres with positive end-expiratory pressure. Although recruitment appears to be beneficial, it is not possible to recommend a specific recruitment strategy due to the differences in the manoeuvers used in the different studies [28].

Higher volumes of intra-operative fluid are associated with higher rates of peri-operative ALI and ARDS [27, 29]. In cardiothoracic surgery, fluid overload is thought to contribute to pulmonary endothelial damage, compounding that caused by the inflammatory reaction to mechanical ventilation and cardiopulmonary bypass, leading to pulmonary oedema [30–33]. A recent meta-analysis reported that higher volumes of intravenous fluid caused higher rates of pneumonia and pulmonary oedema and longer hospital stays after major surgery [34]. The contrasting concern is that fluid restriction might compromise perfusion to organs and the surgical site, including colorectal anastomoses [32]. The current recommendation is to titrate fluid infusions individually to specific cardiovascular measurements, such as stroke volume, cardiac output and fluid responsiveness as indicated by pulse pressure and stroke volume variation [32].

Neuraxial analgesia reduces the rate of postoperative pulmonary complications by one half after otherwise painful abdominal, oesophageal, aortic and cardiac operations [11], although one review concluded that this evidence was not consistent [3]. Control of thoracotomy pain with thoracic epidural analgesia reduces postoperative ventilatory dysfunction and complications. Thoracic epidural anaesthesia can also reduce myocardial oxygen demand, which might be important in patients with coronary artery disease [35]. Regional anaesthesia might be used without general anaesthesia for other patients at increased risk of postoperative pulmonary complications, for instance patients with obstructive sleep apnoea [13, 36]. The benefit of this must be balanced against the potential for complications associated with specific regional techniques, such as the risk of pneumothorax, phrenic nerve and diaphragmatic paralysis in certain brachial plexus blocks. This would be of particular concern in patients with pre-existing lung disease.

Postoperative interventions to reduce pulmonary complications

Postoperative techniques to expand the lungs can halve pulmonary complications, especially after upper abdominal and thoracic surgery [1–4, 7]. These techniques include chest physiotherapy, continuous positive airway pressure and incentive spirometry. Chest physiotherapy includes deep breathing, assisted cough, postural drainage, percussion, vibration, suctioning and ambulation. Continuous airway pressure is particularly useful in patients with obstructive sleep apnoea and patients unable to participate in incentive spirometry or deep breathing exercises, but can be an uncomfortable and expensive way of increasing tidal volumes in these patients. Incentive spirometry, on the other hand, is an easy and inexpensive way to encourage deep breathing.

Other interventions

Volatile anaesthetics may protect lung function by modulating the inflammatory response through inhibition of pro-inflammatory mediators. Volatile anaesthetics protect the lungs as well as the heart against ischaemia and reperfusion injury [37–40]. Inflammation following one-lung ventilation is less after volatile anaesthesia compared with propofol anaesthesia and volatile agents might also reduce the composite rate of adverse effects [41, 42].

Adequate gas exchange can be achieved by slow ventilation with a tidal volume of 3 $ml.kg^{-1}$ if

supported by extracorporeal gas exchange devices, which are being used more in critically ill patients. A tidal volume of 3 $ml.kg^{-1}$ induces less inflammation than 6 $ml.kg^{-1}$ and might improve outcomes [43–45].

Conclusions

Postoperative patients commonly experience a pulmonary complication, which prolongs hospital stay and can directly or indirectly contribute to mortality. Anaesthetists are in the unique position to identify patients at increased risk pre-operatively. Anaesthetists can plan and institute peri-operative interventions to reduce the rate of pulmonary complications, even in healthy patients. Many promising interventions have yet to prove that they reduce adverse pulmonary events. It is therefore important to continue research to determine which interventions are valuable and which are not. In the meantime, anaesthetists might help patients before surgery through pre-operative training and smoking cessation and peri-operatively by ventilating the lungs with tidal volumes of 6–8 $ml.kg^{-1}$ and low levels of positive end expiratory pressure (< 6 cmH_2O).

Competing interests

No external funding and no competing interests declared.

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