Review Article

Post-operative pulmonary complications after non-cardiothoracic surgery

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ABSTRACT

Post-operative pulmonary complications (PPCs) occur in 5–10% of patients undergoing non-thoracic surgery and in 22% of high risk patients. PPCs are broadly defined as conditions affecting the respiratory tract that can adversely influence clinical course of the patient after surgery. Prior risk stratification, risk reduction strategies, performing short duration and/or minimally invasive surgery and use of anaesthetic technique of combined regional with general anaesthesia can reduce the incidence of PPCs. Atelectasis is the main cause of PPCs. Atelectasis can be prevented or treated by adequate analgesia, incentive spirometry (IS), deep breathing exercises, continuous positive airway pressure, mobilisation of secretions and early ambulation. Pre-operative treatment of IS is more effective. The main reason for post-operative pneumonia is aspiration along the channels formed by longitudinal folds in the high volume, low pressure polyvinyl chloride cuffs of the endotracheal tubes. Use of tapered cuff, polyurethane cuffs and selective rather than the routine use of nasogastric tube can decrease chances of aspiration. Acute lung injury is the most serious PPC which may prove fatal.

Key words: Acute lung injury, aspiration, atelectasis, non-thoracic surgery, post-operative pneumonia, post-operative pulmonary complications, risk factors

INTRODUCTION

Post-operative pulmonary complications (PPCs) occur in 5–10% of patients undergoing non-thoracic surgery and in 22% of high risk patients. Even in minor surgeries, the incidence can be 1–2%. As many as one in four deaths occurring within a week of surgery is related to pulmonary complications, thus making it the second most common serious morbidity after cardiovascular event.[1] There is a wide variation in the incidence of PPCs from 2% to 40%.[2] This is mainly due to lack of uniformity about the inclusion of medical conditions as PPCs.

Definition

There are various definitions available in the literature:

1. Respiratory complications that occur within 48–72 h following surgery[3]
2. Conditions affecting the respiratory tract that can adversely influence clinical course of the patient after surgery[4]
3. Any pulmonary abnormality occurring in the post-operative period that produces identifiable disease or dysfunction that is clinically significant and adversely affects the clinical course.

There is a wide spectrum of pulmonary complications which are as follows:

- Atelectasis-resulting in post-operative hypoxaemia (commonest complication)
- Pneumonia, bronchitis
- Bronchospasm
- Exacerbation of previous lung disease
- Pulmonary collapse due to mucus plugging of the airways
- Respiratory failure with ventilatory support >48 h

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- Acute lung injury (ALI) including aspiration pneumonitis, transfusion-related ALI (TRALI) and acute respiratory distress syndrome (ARDS)
- Pulmonary embolism.

The PPCs can be classified into four grades:[5,6]

Grade 1: Any deviation from normal post-operative course without the need of pharmacological treatment or surgical, endoscopic and radiological intervention. For example, atelectasis requiring spirometry or physiotherapy

Grade 2: Requiring specific pharmacological treatment. For example, pneumonia requiring antibiotics in the ward and bronchospasm requiring bronchodilators

Grade 3: Requiring surgical, endoscopic or radiological intervention. For example, bronchoscopic suction to clear the blocked airway and chest tube placement for pneumothorax/pleural effusion
(Grades 2 and 3 require non-invasive ventilation [NIV] support and/or pharmacological treatment, e.g., bronchodilators, diuretics, etc.)

Grade 4: Life-threatening condition requiring intensive care unit (ICU) admission (single/multiple organ failure requiring ICU admission, mechanical ventilation, etc.)

Grade 4a: Single organ dysfunction - lung failure requiring intubation and ventilation

Grade 4b: Same with additional other organ dysfunction.

The peculiarity of the pulmonary complications is that they are preventable or modifiable to a considerable extent. There are various pre-operative risk factors associated with PPCs [Tables 1 and 2]. Hence, (a) Risk reduction strategies can be planned from pre-operative period itself, (b) appropriate surgical and anaesthetic technique can be chosen after thorough discussion with the surgeon and the patient and weighing the risks and benefits, (c) post-operative meticulous management can prevent progression to severe complications.

Table 1: Pre-operative risk factors

Patient-related risk factors

Risk factor	Relevance to complication
Age >65 years	Independent risk predictor[7-9]
	Unmodifiable risk factor[10]
Positive cough test	Recurrent cough after 1st cough[9]
Smoking	Higher incidence of complications[6,7,10]
	Only if associated with COPD[9]
	Disagreement about the period of abstinence[8]
	Desirable to quit smoking even close to surgery[11,12]
COPD	Most important risk factor[7,8,11]
	Pre-operative preparation decreases the complications considerably[8]
Bronchial asthma	Well-controlled asthmatics (symptom free patient with FEV_1 >80%) not a risk factor[11]
Obesity	Outcome studies do not show relation but pre-operative preparation is desirable[11]
General health	ASA >2, albumin <3.5 g%, poor functional status and reduced exercise capacity - risk factors[8]
Obstructive sleep apnoea	Higher risk of post-operative hypoxaemia, hypercarbia, aspiration pneumonia and ARDS[11]

COPD – Chronic obstructive pulmonary disease; ASA – American Society of Anesthesiologists; ARDS – Acute respiratory distress syndrome; FEV_1 – Forced expiratory volume in 1 s

Table 2: Procedure-related risk factors

Risk factor	Relevance to complication
Duration of surgery	Independent risk predictor[9-12]
Type of anaesthesia	RA decreases risk of complications but verdict unclear
	Combined technique (GA with neuraxial block) preferable[11]
	Long acting NMBs during GA - risk factor
Site of surgery	Neck, thorax, upper abdominal surgeries, neurological surgery and abdominal aortic aneurysm surgery[8]
	Distance of incision from diaphragm inversely proportional to the incidence of complications
	Upper abdominal surgeries complications increase by a factor of 1.5[13]
Type of surgery	Laparoscopy - fewer complications than open (important to remember effect of increased IAP on atelectasis)
	Emergency surgery - higher complications versus planned[11]
Blood transfusion	Independent risk predictor
	TRALI - specific PPC associated with transfusion[7]
NGT	Presence associated with VAP and PP selective rather than routine NGT placement advocated[14-16]
Mechanical ventilation >48 h	Risk predictor of VALI[7]

RA – Regional anaesthesia; GA – General anaesthesia; NMBs – Neuromuscular blockers; IAP – Intra-abdominal pressure; TRALI – Transfusion-related acute lung injury; PPC – Post-operative pulmonary complication; VAP – Ventilator-associated pneumonia; PP – Post-operative pneumonia; NGT – Nasogastric tube; VALI – Ventilator-associated lung injury

POST-OPERATIVE HYPOXAEMIA

There are many reasons for the development of post-operative hypoxaemia in the immediate post-operative period. Residual depressant effect of the anaesthetic agents resulting in hypoventilation, airway obstruction, depressed CO_2 responsiveness of the respiratory centre, residual neuromuscular blocking agent (NMBA) action, and splinting of diaphragm due to pain, especially in the upper abdominal surgeries are few of the causes. As a result of pain in the immediate post-operative period, the patient tends

to under-ventilate, avoiding deep breathing, there is an inadequate cough with the retention of secretions, all leading to increased chances of infection. Postoperatively, there is spinal reflex inhibition of the phrenic nerve due to nociceptive inputs to ventral and ventrolateral horns of the spinal cord,[17] further affecting the diaphragm function. The importance of pain relief need not be overemphasised. Besides analgesia, proper monitoring, oxygen therapy to maintain adequate saturation, ensuring unobstructed airway and respiratory support in the form of continuous positive airway pressure (CPAP)/NIV till adequate spontaneous respiration is established will correct this hypoxaemia.

Besides all the causes of hypoxaemia mentioned above, the most important cause is atelectasis.

Atelectasis

Atelectasis is induced intraoperatively due to various factors such as induction of general anaesthesia with the effect of general anaesthetics, neuromuscular (N-M) blocker induced muscle paralysis, recumbent position, increased intra-abdominal pressure (like in laparoscopies), various operative positions such as Trendelenburg's position. The most affected part of the lungs is the basal segments. In one study, in patients with normal lungs, 90% were developed atelectasis in the most dependent segments after intubation.[8,18] The atelectasis can exceed 15–20%. The degree of atelectasis can be even more in obese patients. In the case of abdominal surgeries, the atelectasis can persist for several weeks postoperatively.

Atelectasis can be classified into three groups:[18]

A. Compressive atelectasis (mentioned above)
B. Absorption atelectasis

Greater the FiO_2 after induction, faster the collapse. Pre-oxygenation before induction and oxygenation with 100% O_2 at the end of surgery and endotracheal suctioning at the time of extubation by direct application of negative pressure contribute to the atelectasis. To prevent atelectasis due to these causes, following measures are advocated intraoperatively.[5]

Early recruitment manoeuvre after securing the airway, inspiratory pressure of 40 cm of H_2O for 8–10 s, which is known as vital capacity (VC) manoeuvre:

1. Reduction in FiO_2 <60% to keep SaO_2 >96%
2. Gentle recruitment manoeuvre before extubation
3. Avoiding hyper oxygenation with 100% O_2 at the time of extubation. 50–70% O_2 is considered enough (this is possible only with air, O_2 mixture and not while using N_2O where danger of diffusion hypoxia mandates the use of 100% O_2 for last 10 min)
4. CPAP during pre-oxygenation in obese patients
5. Use of positive end-expiratory pressure (PEEP) and alveolar recruitment strategy, that is, stepwise increase of PEEP and inspiratory pressure, e.g., 0/10, 5/15, 10/20, and 15/25 cm of H_2O in 8–10 respiratory cycles.

In obese patients undergoing laparoscopic bariatric surgery, VC manoeuvre should be maintained for 8 s followed by 10 cm of H_2O PEEP.[5]

C. The third reason for atelectasis is the loss of surfactant. This prevents reopening the collapsed alveoli. In the perioperative period, surfactant production decreases. Chronic alcohol abuse is associated with decreased surfactant production.[19] Atelectasis impedes surfactant function making the lung prone to collapse even after reopening.

POST-OPERATIVE MEASURES TO PREVENT ATELECTASIS

1. Good post-operative analgesia: Prevents under ventilation and manoeuvres to open collapsed alveoli, such as incentive spirometry (IS) and deep breathing exercises (DBEs), can be instituted more effectively. The institution of analgesia also helps in alleviating the neuroendocrine stress response which can further lead to PPC and organ dysfunction. Both techniques viz., epidural analgesia and patient-controlled analgesia technique have been shown to be superior to on-demand analgesics.[15]
2. IS, this remains as an attractive technique because it is less labour-intensive, more economical and patient-driven.[15]
3. DBEs, a deep breath hold for 3–5 s, has been shown to significantly improve the oxygen tension
4. CPAP, this is independent of patient effort that being the biggest advantage of the technique. As this is a costly technique, it should be reserved for patients who are unable to perform IS/DBE.[15] All lung expansion techniques, that is, IS, DBE, and lung hyperinflation have been

shown to be equally effective in reducing PPCs. In those cases where the patients are trained preoperatively, the results are better,[15] hence in high risk patients, pre-operative training is highly recommended. Lawrence *et al*. have given a robust evidence after studying the data over 25 years (1980–2005) that lung expansion manoeuvres are very effective in decreasing the PPCs

5. Early mobilisation and ambulation.

POST-OPERATIVE PNEUMONIA

The atelectatic area acts as a nidus for infection and patient may suffer from post-operative pneumonia (PP). Usually, development of pneumonia tends to occur in the first five post-operative days. The patient may present with fever, leucocytosis, increased secretions and pulmonary infiltrates on the radiograph. The patient develops hypoxaemia and eventually may develop respiratory distress.[7] In a meta-analysis, Smetna has enumerated the following risk factors for PP after non-cardiothoracic surgery-smoking, CCF, age >70 years, American Society of Anesthesiologists class >2, pre-existing COPD and high risk surgeries.[7,12]

Usually, the reason for PP and even ventilator-associated pneumonitis (VAP) is the aspiration of subglottic secretions containing bacteria. These colonise in the respiratory tract. VAP may be preceded by VAT (ventilator-associated tracheo-bronchitis) which progresses to VAP. The risk factors for aspiration are:

- Type of endotracheal tube
- Mechanical ventilation without PEEP
- Presence of nasogastric tube (NGT)
- Gastroesophageal reflux disease (GERD).

It must be noted that in the immediate post-operative period for a period of 2 h, the protective reflexes are depressed and the patient can aspirate. The upper oesophageal sphincter remains depressed. This is more likely to occur with advanced age and the use of long acting muscle relaxants.[20]

It is observed that the usual high volume, low pressure (HVLP) cuffs develop longitudinal folds forming small channels in the polyvinyl chloride (PVC) cuff, permitting transit of secretions in the tracheal lumen.[21] This causes, aspiration, a distinct possibility even in intubated patients who can aspirate intraoperatively (especially during long duration surgical procedures) or in the ICUs when the patient is on the ventilator. A lot of work is being done on the cuff design. Tapered cuffs are more effective in achieving tracheal seal than the cylindrical cuffs.[22] Whereas the polyurethane cuff is also shown to be effective in preventing fold formation.[23] These authors have also shown that the cross sectional area ratio of the cuff to trachea is important. When it exceeds 1.5:1, it facilitates development of longitudinal folds. Both these studies are *in vitro* studies. Zanella *et al*.[22] have come out with a new idea of wrapping the HVLP cuff with a low protein latex rubber supported by gel lubrication between the two layers to ensure an even surface without folds. A new cuff less tube has been designed, which is a low pressure sealing system, consisting of 12–20 toroidal layers of thin polyurethane film termed gills. This tube is oval, making a better fit at the glottic level.[23]

Another method to decrease aspiration is continuous suction of the subglottic secretions. To achieve this, special tubes are designed having a separate dorsal lumen ending proximal to the cuff. Using this technique, the incidence of VAP is shown to go down considerably.[20,23] In a meta-analysis of 5 studies, approximately, 50% reduction in VAP was shown to occur in patients on ventilator for 72 h using this technique. After this study, the centre for disease control, The American Association of Respiratory Care, The American Association of Critical Care Nurses and American Thoracic Society have endorsed this technique.[15]

Presence of nasogastric tube

The NGT renders the cardiac sphincter incompetent; hence in anaesthetic management of full stomach patients, if it is passed to empty the stomach contents, it should be withdrawn in the oesophagus above the cardia during induction. As the NGT favours the silent aspiration favouring PP/VAP, the routine placement of NGT in the post-operative period and in the ICU should be discouraged and selective placement of NGT should be advocated.[15,16]

To avoid regurgitation and aspiration when the NGT is in place, a nasogastric balloon tube has been designed. The balloon, when inflated, lies at the cardia, preventing any reflux.[18]

Intra-operative and post-operative measures to reduce VAP and PP[18]

1. Limiting the duration of surgery

Rate of VAP and PP is time-related. Longer the duration of surgical procedure, greater the risk of aspiration. Surgical procedure lasting >2 h increases the risk four-fold. Similarly longer duration of mechanical ventilation in the ICU increases the risk. Hence early resumption of spontaneous breathing and weaning from ventilator is important
2. Level of sedation in the ICU is important
3. Avoidance of the usage of long acting NMBAs
4. Lubrication of the PVC cuff
5. Intervals of cuff pressure <20 cm H_2O during the first 8 ventilation days significantly increase the risk of PP. Intracuff pressure of 24 cm of H_2O is considered as a safe lower limit
6. Prophylactically 5-8 cm of H_2O PEEP should be applied
7. Aspiration of subglottic secretions
8. Use of special tubes
9. Avoidance of NGT when possible.

ACUTE LUNG INJURY

The respiratory failure associated with ALI and/ ARDS is one of the most important contributors to post-operative mortality.

Definition

The ALI is a hypoxaemic respiratory failure caused by diffuse lung injury which is characterised by decreased lung compliance and non-cardiogenic pulmonary oedema, resulting from widespread capillary leakage. Increased microvascular permeability with increased protein in the oedema fluid is the hallmark of ALI irrespective of the cause. There are bilateral pulmonary infiltrates which may progress to whiteout making it indistinguishable from ARDS. The PCWP is <18 mm Hg. When the PaO_2/FiO_2 ratio is <300 mm Hg, it is ALI and when it is <200 mm Hg, it is ARDS (American European Consensus Conference).[19]

The ALI can be of two types:
1. Primary – Here, the clinical presentation is in the immediate post-operative period and it is due to the systemic inflammatory response induced by surgical insult
2. Secondary - The secondary ALI presents 3–12 days after surgery when it is triggered by post-operative complications such as sepsis, pulmonary embolism, aspiration of gastric contents, pneumonia or transfusion. The severity and presentation of ALI secondary to aspiration depends on the quantity of aspirated fluid and pH (Mendelson's syndrome).

When the causative agent of ALI is transfusion of blood/blood products, it is termed as TRALI.

By definition, TRALI is acute onset of respiratory distress and non-cardiogenic pulmonary oedema developing during or within 6 h of transfusion.[24]

In atypical cases, TRALI can become symptomatic much later.

There are two types of TRALI:
A. Immune TRALI
B. Non-immune TRALI

Immune transfusion-related acute lung injury

Trigger in the transfused blood is granulocyte binding auto antibodies. (HLA class 1 and 2 or HNA-1 and HNA-3a).[25] It is a severe reaction which may need ventilatory support, is not uncommonly fatal, 6–9% is the fatality rate.

Non-immune transfusion-related acute lung injury

In this type, the trigger is neutrophil priming substance such as biologically active lipids in stored blood. It has a more benign course and may require only oxygen support.[24]

PATHOPHYSIOLOGY OF TRANSFUSION-RELATED ACUTE LUNG INJURY

There is complement activation, neutrophil-mediated endothelial damage and capillary leak. Moreover, there is a massive release of protease resulting in an increase of pulmonary capillary permeability and pulmonary oedema.[26] The aim of treatment is to block or reduce detrimental effects of platelet activation. Successful use of tranexamic acid, a cascade blocker, has been reported in a severe case of TRALI in a 16-year-old girl with craniofacial injuries requiring multiple blood transfusions.[27] Besides this, the treatment of TRALI is usually supportive with mild variety needing only oxygen supplementation. The severe form may need ventilatory management.[25]

MECHANICAL VENTILATION AND ACUTE LUNG INJURY

The mechanical ventilation is incriminated in producing ventilation-induced lung injury (VILI) or ventilation-associated lung injury. The factors

favouring VILI are high tidal volumes resulting in cyclic stretching of alveoli and exposure to higher FiO_2. The tissue damage leads to a local inflammatory reaction in the lungs with production of radical oxygen intermediates and other inflammatory markers causing disruption of alveolocapillary membrane and pulmonary oedema. Hence, protective lung ventilation strategy should be used which consists of:

a. Low tidal volumes of 6–8 ml/kg
b. PEEP 5–8 cm of H_2O
c. Use of lowest FiO_2 providing satisfactory peripheral saturation (SaO_2 > 90%) to prevent oxidative damage and prevent absorption atelectasis.[19]

Whether short term mechanical ventilation during surgery can significantly affect the healthy lungs producing VILI is not very clear, but in anaesthetised patients with healthy lungs, RCTs have been carried out to study the impact of protective ventilatory settings on the markers of inflammation (systemic and pulmonary), oxygenation and PPCs.[5] The result was as follows - in case of minor/moderate surgical procedures, no difference was found between traditional and protective ventilatory settings, but in high risk surgical procedures lasting for >5 h, protective ventilatory strategy resulted in reduced expression of alveolar/systemic inflammatory markers, better respiratory mechanical properties, stable or improved oxygenation indices and better post-operative clinical outcome.[5]

All these preliminary studies suggest that use of protective ventilation strategy should be used in all surgeries.

PREDISPOSING FACTORS TO ACUTE LUNG INJURY

Pre-operative COPD, severe diabetes mellitus, GERD and alcohol abuse are strong predictors of post-operative lung injury. Genetic factors also have been implicated in the development of ALI.[19]

A new scoring system namely surgical lung injury prediction score or lung injury prediction score (LIPS) has been established, wherein preoperatively the patients can be stratified as low, intermediate and high risk. The calculation work sheet is available online.[28] When the score is >3.5, there is a high risk of ALI.[26,29,30] The LIPS score has got an excellent negative predictive value, but PPV (positive predictive value) is limited.[31] Recently, a new biomarker level has been shown to be elevated in patients who went on to develop ALI. Higher plasma angiopoietin 2 (an endothelial growth factor) levels, angiopoietin 2/angiopoietin 1 ratio and IL-8 (a cytokine and marker of inflammation) levels have been associated with increased pulmonary leak index, severity of ALI and mortality.[31]

PREVENTIVE STRATEGIES AGAINST ACUTE LUNG INJURY

The various measures to prevent acute lung injury are:[19]

1. Avoidance of alcohol
2. Improving nutritional status
3. Improving patients' functional respiratory performance
4. Pre-operative physiotherapy to provide adequate lung expansion and reduce atelectasis
5. Pre-operative inspiratory muscle training
6. Optimisation of medical therapy
7. Intra- and post-operative rapid correction of hypoxaemia
8. Use of bronchodilator and removal of airway secretions
9. Manoeuvres to improve respiratory functions, early mobilisation, stimulation of active cough, inspiratory exercises and pre-operative NIV to improve respiratory reserve.

PULMONARY EMBOLISM

This complication is a serious post-operative complication known to occur more commonly in patients posted for orthopaedic surgery, malignancy surgery, obesity surgery, or intercurrent surgery in obese patients, old age patients and all patients prone to develop deep vein thrombosis (DVT). DVT is so common in post-operative patients that almost 1% of post-surgical patients die of fatal pulmonary embolism.[7] Since the pathophysiology of this complication is more related to the cardiovascular system, this complication is not included in this review.

SUMMARY

This review discusses the PPCs after non-cardio thoracic surgery ranging from hypoxaemia in the post-operative period which can be treated with simple oxygen therapy to severe complications such as ALI which may prove fatal. If the risk factors are identified preoperatively, proper anaesthetic planning can reduce the incidence of complications. Limiting the duration of surgery to <3 h, using a minimally

invasive surgery and using regional techniques can decrease the incidence of complications. Lung expansion techniques should be instituted from pre-operative period. Use of proper analgesia, selective use of NGT, protective ventilatory technique in the case of prolonged surgery and ventilatory management and early ambulation go a long way in reducing the complications. Use of tapered cuff polyurethane tubes is advocated. Proper lubrication of cuff and aspiration of subglottic secretions decrease the chances of aspiration.

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