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Perioperative modifications of respiratory function

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Postoperative pulmonary complications contribute considerably to morbidity and mortality, especially after major thoracic or abdominal surgery. Clinically relevant pulmonary complications include the exacerbation of underlying chronic lung disease, bronchospasm, atelectasis, pneumonia and respiratory failure with prolonged mechanical ventilation. Risk factors for postoperative pulmonary complications include patient-related risk factors (e.g., chronic obstructive pulmonary disease (COPD), tobacco smoking and increasing age) as well as procedure-related risk factors (e.g., site of surgery, duration of surgery and general vs. regional anaesthesia). Careful history taking and a thorough physical examination may be the most sensitive ways to identify at-risk patients. Pulmonary function tests are not suitable as a general screen to assess risk of postoperative pulmonary complications. Strategies to reduce the risk of postoperative pulmonary complications include smoking cessation, inspiratory muscle training, optimising nutritional status and intra-operative strategies. Postoperative care should include lung expansion manoeuvres and adequate pain control.

Significance of perioperative pulmonary complications

Postoperative pulmonary complications are as common as cardiac complications for patients undergoing non-cardiothoracic surgery[1–5]; in addition, they are equally clinically important in terms of

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morbidity, mortality and length of stay.[2,3] Indeed, one study reported that postoperative pulmonary complications may prolong the hospital stay by up to 2 weeks.[6] Pulmonary complications may also be more likely than cardiac complications to predict 'long-term' mortality after surgery, particularly among older patients.[7]

However, compared with postoperative cardiac complications, far less research has been done on prevention. As an example of the patient profile, studies that have derived predictive equations for cardiac risk are prominent,[8,9] but few that predict pulmonary risk[10] are commonly known or discussed.

Pulmonary complications following surgery can be considered as 'general' or 'specific': general complications relate to complications of surgery or anaesthesia under any circumstances (e.g., atelectasis, infection, bronchospasm, pulmonary embolus, exacerbation of underlying chronic illness, respiratory failure requiring ventilation and acute respiratory distress syndrome (ARDS)). On the other hand, specific cardiothoracic complications occur as a result of local lesions in the thorax (e.g., phrenic nerve palsy – particularly problematic in small children, pleural effusion, bronchopleural fistula, sternal wound infection and empyema).

The incidence of postoperative pulmonary complications is high and is associated with substantial morbidity and mortality and prolonged hospital stay; this may be especially true following major thoracic or abdominal surgery. The reported incidence varies from 2% to 19%,[11] and the variability is likely due in part to differences in surveillance, practice and different definitions, as well as differences in the true incidence. Kroenke et al. found that the incidence of postoperative pulmonary complications increased with increasing American Society of Anesthesiology (ASA) classification: 10%, 28% and 46% in ASA class II, III and IV, respectively,[12] with rates of up to 40% following cardiothoracic surgery.[13] It is probable that 'preoperative' evaluation of pulmonary status is a critical step in managing patients with lung disease, who are undergoing elective surgery.

Causes of perioperative pulmonary complications

Risk factors for postoperative pulmonary complications include patient-related risk factors (e.g., chronic obstructive pulmonary disease (COPD), increased age, tobacco use, poor nutritional status and the presence of pulmonary hypertension) and intra-operative or procedure-related risk factors (e.g., site of surgery, general vs. regional anaesthesia, emergency surgery and longer duration of surgery).

Some studies suggest that impaired sensorium, abnormal findings on chest examination, alcohol use and the presence of recent weight loss increase the risk for postoperative pulmonary complications to a certain extent.[14] Since the first report in 1944,[15] smoking has consistently been shown to increase the risk – even among those without chronic lung disease.[16]

The Goldman cardiac-risk index includes factors from the patient's history, the physical examination and laboratory data,[9] and predicts the development of pulmonary – as well as cardiac – complications.[6,17] In addition, the ASA classification, which was developed to evaluate the risk of 'overall' perioperative mortality, is strongly predictive of postoperative pulmonary complications.[18,19] Studies suggesting an increased risk of pulmonary complications with older age have not generally controlled for co-existing conditions, and the relationship may be stronger for co-existing conditions than for chronologic age. Among co-existing diseases, the presence of COPD appears to be especially predictive, with increasing severity of COPD associated with increasing incidence of complications.[20]

Procedure-related risk factors may be as important as patient-related risk factors in estimating complication risk. These include surgical site, duration of surgery, anaesthetic technique and the need for emergency surgery.

Surgical site appears to be the most important procedure-related predictor of pulmonary risk, with upper abdominal and thoracic surgery carrying the greatest risk (10–40%).[16,21] By contrast, postoperative complications are rare after operations outside the thorax or abdomen. The duration of operation appears to be important also, with procedures lasting more than 3 h particularly associated with a high complication risk.[22,23]

The nature of the anaesthesia may also be significant in this regard. Most studies have reported a lower incidence of pulmonary complications following epidural or spinal anaesthesia (vs. general anaesthesia) although the results are mixed,[24] and this is a controversial area. Although regional anaesthesia, such as an axillary nerve block, carries a lower risk than either spinal or general anaesthesia for overall pulmonary complication rate, some regional techniques such as an interscalene nerve block are associated with specific although rare risks (e.g., pneumothorax and phrenic nerve paresis), which can certainly have an impact in terms of postoperative pulmonary status.

Preoperative lung function testing and preoperative optimisation

Careful history taking and a thorough physical examination may be the most sensitive ways to identify at-risk patients. The medical history should document any smoking history and recognised occupational exposures, seeking evidence of respiratory symptoms, limited exercise capacity, pre-existing lung disease (especially focussing on undiagnosed COPD) and recent respiratory infections. The physical examination should screen for cardiopulmonary disorders. Decreased breath sounds, dullness to percussion, wheezes, rhonchi and a prolonged expiratory phase predict an increase in the risk of pulmonary complications.[25]

The best assessment of respiratory function comes from a history of the patient's quality of life.[26] It is useful to think of respiratory function in three related areas: respiratory mechanics, gas exchange and cardio-respiratory interaction. Respiratory mechanics can be assessed using spirometry, measurement of peak expiratory flow rate and more extensive measurement of respiratory mechanics. Gas exchange, sometimes considered to be an 'integrated' assessment of pulmonary parenchymal function, is assessed using the diffusion capacity of the lung for carbon monoxide (i.e., DL_{CO}) or sampling for arterial blood gases. Blood gas measurement provides assessment of oxygenation (usually related to adequacy of pulmonary parenchymal function) and hypercapnia (reflecting an integrated ability to maintain adequate alveolar ventilation, i.e., neural drive, muscle strength, hyperinflation and alveolar area).

The DL_{CO} correlates with the total functional surface area of the alveolar–capillary interface: it theoretically reflects a composite of the capillary–alveolar surface (less area, lower DL_{CO}), the distance between the alveolus and the capillary blood (greater distance, higher DL_{CO}) and is decreased by recent smoking (carbon monoxide bound to haemoglobin reduces gradient for CO diffusion from alveoli, thereby reducing DL_{CO}) and anaemia (which also reduces diffusion gradient).

The traditional test to estimate cardiopulmonary reserve is stair climbing. Formal laboratory exercise testing with maximal oxygen consumption (VO_{2max}) may be a gold standard for assessment of cardiopulmonary function, and represents an integrated assessment of global and regional oxygen transport. The ability to climb less than two standard flights of stairs (i.e., significant global compromise) is associated with very high complication risk. Climbing five flights of stairs approximates a VO_{2max} value of more than 20 ml kg^{-1} min^{-1} and less than one flight, a VO_{2max} of less than 10 ml kg min.[27] Of course, in any such formal testing, the clinician needs to sensibly review the patient and take into account the presence of concomitant disease to place such assessment into context.

Few studies have rigorously evaluated the accuracy of preoperative or operative variables to predict complications in patients undergoing non-thoracic surgery,[11] although prediction may be more accurate for elective non-cardiothoracic versus cardiothoracic surgery. McAlister et al. enrolled 272 patients, who were referred for preoperative consultation prior to non-thoracic surgery.[28] The mean age was 62 years and 40% were male. A total of 22 patients (8%) suffered at least one post-operative pulmonary complication. Of these, six patients required ventilatory support, nine had postoperative pneumonia and seven developed atelectasis requiring bronchoscopic intervention. Six factors were found to be significantly associated with pulmonary complications after surgery, while several other variables commonly cited to increase risk (e.g., male sex, recent upper respiratory tract infection and history of chronic productive cough) were not associated with adverse outcome.[28] The six factors were hypercapnoea of 45 mmHg or more, a maximal laryngeal height of 4 cm or less (the distance between the top of the thyroid cartilage and the suprasternal notch at the end of expiration indicating tracheal descent in COPD), a forced expiratory time of 9 s or more, smoking of 40 pack-years or more and a body mass index of 30 or more. In this study, these preoperative factors were statistically significant predictors of pulmonary complications.

Although spirometry aids in the diagnosis of obstructive lung disease, it does not translate into an effective risk prediction instrument for individual patients. Consensus does exist regarding the value of spirometry before lung resection, as well as in determining safety of coronary artery bypass surgery.

However, its value before extrathoracic surgery remains unproven. Pulmonary function testing should be performed selectively in patients undergoing other surgical procedures.[28]

The perioperative complications of a specific high-risk group of smokers with preoperatively determined significant airway obstruction (forced expiratory volume in 1 s (FEV_1) < 40%), undergoing abdominal surgery, were studied by Warner et al.[29] Although bronchospasm was more likely to develop in these patients compared with a group without airway obstruction, outcome including the need for prolonged endotracheal intubation and intensive care stay was not worse, and the overall complication rate was less than 5%.[29] In an accompanying editorial[30] to that article,[29] Kimball pointed out that altered actions of the care team based on knowledge of such tests could be the reason for a relatively favourable outcome in this group of high-risk patients.[30] Thus, the lack of blinding and prospective study can cloud the issue, as in so many perioperative predictive assessments.

Clinicians frequently obtain chest radiographs as part of a routine preoperative evaluation. In a review, Archer et al. found that while 10% of preoperative chest radiographs were abnormal only 1.3% showed unexpected abnormalities and only 0.1% influenced management.[31] The evidence suggests that clinicians may predict most abnormal preoperative chest radiographs by history and physical examination and that this test only rarely provides unexpected information that influences preoperative management. A low serum albumin level ($<35\ \mathrm{g\,l^{-1}}$) has been shown to be an important predictor of postoperative pulmonary complications.[14] Gibbs et al. reported that a low serum albumin level was also the most important predictor of 30-day perioperative morbidity and mortality,[32] but it is not clear what the clinician should do when faced with a positive predictive test that has no obvious therapeutic or preventive link.

Screening pulmonary function tests (i.e., spirometry with or without measurement of the DL_{CO}) accurately identifies patients who are not likely to survive major lung resection.[27,33] The preoperative evaluation of patients with lung cancer involves determining the type and extent of the tumour as well as the patient's cardiopulmonary reserve so as to estimate the maximum chance for survival. In 2003, the American College of Chest Physicians published guidelines on the diagnosis and management of lung cancer,[27] which are summarised as follows:

1. Age is not a contraindication for lung resection surgery.
2. Preoperative cardiac evaluation according to established guidelines is needed.
3. Spirometry should be performed in patients being considered for resection; if FEV_1 >80% predicted or >2 l, the patient is suitable for pneumonectomy without further evaluation; if the FEV_1 is >1.5 l, the patient is suitable for lobectomy without further evaluation.
4. Patients with evidence of interstitial lung disease on radiographs or undue dyspnoea on exertion should have DL_{CO} measured even though FEV_1 may be adequate.
5. If either the FEV_1 or DL_{CO} is <80% predicted, postoperative lung function should be predicted on the basis of additional testing.
6. Exercise testing is indicated preoperatively in patients with a percentage predicted postoperative FEV_1 <40% predicted or DL_{CO} <40% predicted.

Numerous studies have tried to predict the patients in whom postoperative pulmonary complications will develop after undergoing thoracotomy. The European Thoracic Surgery Database project analysed 3426 patients retrospectively for risk factors associated with in-hospital death.[34] Although only 66 patients (2%) died, the degree of dyspnoea, ASA score, class of procedure and age were all independently associated with in-hospital death. Other studies have found that increased preoperative levels of fibrinogen and lactate dehydrogenase are associated with increased perioperative mortality.[35,36] The extent of the tumour, the duration of surgery, the presence of heart disease and older age are all associated with increased mortality.[37]

Preoperative pulmonary function testing, when used to predict postoperative lung function, is subject to a great deal of uncertainty. First, the quality of spirometry itself is often questionable. The results of a survey in primary care practice revealed alarming issues of quality and non-reproducibility of such tests.[38] Furthermore, Bolliger and Perruchoud described significant differences between preoperative predicted and postoperative measured spirometric values.[39] In their investigation, conventional preoperative lung function testing overestimated the functional loss after lung resection[39]; similar findings were also reported by Larsen et al.[40] Finally, clinical findings were found to be generally more predictive of pulmonary complications than spirometric results in the few studies that have evaluated both factors.[20,41] However, no prospective, randomised trials have addressed this question.

Preparation of patients with lung disease for surgery

Risk-reduction strategies include smoking cessation, inspiratory muscle training, optimising nutritional status, intra-operative strategies (e.g., muscle-sparing surgery, minimally invasive options and regional analgesia) as well as postoperative incentive spirometry and continuous positive airway pressure (CPAP).

Preoperative smoking cessation

In a prospective study of preoperative smoking cessation, men undergoing hip- or knee-replacement surgery were randomly assigned to usual care or weekly meetings (where they received advice about smoking cessation, as well as nicotine replacement for 6–8 weeks before surgery and lasting until 10 days after surgery). Of the 56 patients in the intervention group, 36 stopped smoking and 14 reduced smoking before surgery. The overall complications were lower in the intervention group (18% vs. 52%) primarily due to fewer wound complications and urinary tract infections; an important caveat here is the gap between the observed outcome differences and plausible mechanisms to explain them. The only pulmonary outcome, postoperative ventilatory support, occurred in one patient in each group. Trends favoured shorter mean hospital stay and fewer cardiac complications in the intervention group but these were not statistically significant.[42] A previous study showed paradoxically 'higher' postoperative pulmonary complications for smokers who stopped or reduced smoking within 2 months of non-cardiothoracic surgery.[43] Such a finding is theoretically possible as smoking cessation may transiently increase mucus production due to improved mucociliary activity while at the same time reduce coughing due to less bronchial irritation; in such a scenario, short-term risk could be increased.

Preoperative corticosteroids and bronchodilators

Silvanus et al. found fewer instances of bronchospasm during intubation in patients with bronchial hyperreactivity who were not previously on bronchodilators when they were pre-treated daily for 5 days with albuterol and methylprednisolone.[44] Whether this benefit extends to patients who use bronchodilators in the long term has not been assessed. A short course of perioperative corticosteroids does not increase the incidence of infection or other postoperative complications in patients with asthma.[45,46] International guidelines for the treatment of COPD suggest the use of inhaled bronchodilators, beta-2 agonists and anticholinergics as the mainstay of symptomatic therapy.[47,48] However, only a minority of COPD patients are treated in accordance with those guidelines.[49] It seems rational to optimise therapy for COPD preoperatively.

Anaesthetic and analgesic techniques

Regional atelectasis occurs after induction of anaesthesia, persists postoperatively and is compounded by disruption of respiratory muscles, limited respiratory movement due to pain and disruption of neurally mediated diaphragmatic functions after manipulation of abdominal viscera.[43]

One trial found no difference in the rates of postoperative pulmonary complications between intermediate-acting (atracurium and vecuronium) and long-acting (pancuronium) neuromuscular blocking agents in patients undergoing elective abdominal, gynaecological or orthopaedic surgery.[50] However, the incidence of residual neuromuscular block was higher among patients receiving pancuronium. Patients with residual block after pancuronium were three times more likely to develop postoperative pulmonary complications than those without residual block, and this was not observed in patients who developed residual block with the intermediate-acting agents. Therefore, long-acting neuromuscular blockers (perhaps, specifically pancuronium) may lead to higher rates of prolonged neuromuscular block and indirectly increase pulmonary risk compared with shorter-acting agents.

Neuraxial blockade reduces the stress response to surgery and may improve recovery and prevent complications.[51] Postoperative epidural analgesia may reduce respiratory muscle dysfunction and pain-related hypoventilation. One meta-analysis combined 141 trials (total of 9559 patients) comparing general anaesthesia and neuraxial blockade for a variety of surgical procedures.[52] The authors compared patients receiving neuraxial blockade (with or without general anaesthesia) versus those receiving only general anaesthesia. Neuraxial blockade reduced overall mortality, pneumonia and respiratory failure.[52] However, this is controversial, and other studies have not confirmed this benefit.[53,54] Postoperative epidural and patient-controlled intravenous analgesia both seem better than on-demand delivery of opioids in preventing postoperative pulmonary complications.[55,56]

Laparoscopic versus open procedures

Many trials have compared laparoscopic and open procedures but few have reported post-operative pulmonary complication rates. A number of trials found statistically greater compromise in forced vital capacity (FVC) and FEV_1 at 24 and 48 h postoperatively with open cholecystectomy.[57,58] One trial assessed the frequency and severity of atelectasis (diagnosed by postoperative chest radiographs) in patients who were randomised to either laparoscopic cholecystectomy or open cholecystectomy.[59] Chest X-rays were assessed by radiologists blinded to the type of procedure, and atelectasis occurred significantly less often following the laparoscopic procedure.[59] Abraham et al. carried out a meta-analysis of laparoscopic versus open resection of colorectal cancer.[60] The overall mortality did not differ. Risk was consistently less with laparoscopic operations, primarily due to fewer wound complications. Regarding pulmonary complications, a non-statistically significant trend favoured laparoscopic resection.[60]

Smetana reviewed data on preoperative pulmonary evaluation and presented an overview on risk-reduction strategies.[61] The most important predictor of pulmonary complications was the site of operation. The complication rate of upper abdominal and thoracic incisions was reported to be 10–40% of all cases, compared with 0.3–0.4% in laparoscopic cholecystectomy.[61]

Nasogastric decompression after abdominal surgery

Routine decompression after abdominal surgery has been thought to speed up bowel recovery and decrease the risk of aspiration. Selective use of nasogastric tubes refers to use only for postoperative nausea or vomiting, inability to tolerate oral intake or symptomatic abdominal distension. A meta-analysis of studies comparing routine versus selective nasogastric decompression has been carried out.[62] The authors identified 28 eligible trials of routine versus selective nasogastric decompression. Patients who were randomly assigned to selective decompression had fewer postoperative pulmonary complications, and the benefit approached statistical significance. Selective decompression also resulted in earlier bowel recovery.[62]

Lung expansion modalities

Decreased lung volumes and atelectasis due to anaesthesia and surgery may be the first events in a cascade leading to postoperative pulmonary complications. Whether prophylactic lung expansion is beneficial is uncertain. Techniques include incentive spirometry, deep breathing exercises, chest physiotherapy, intermittent positive pressure breathing and continuous positive pressure breathing. One systematic review focussed on upper abdominal surgery and identified 14 randomised trials.[63] Across all lung expansion modalities, a trend favoured fewer postoperative pulmonary complications compared with controls. In a more recent trial, 204 patients undergoing intra-abdominal vascular surgery were randomly assigned to supplemental oxygen to maintain arterial oxygen saturation greater than 95% or to nasal CPAP for 12 h after surgery.[64] Severe hypoxaemia ($PaO_2 < 70$ mmHg at

$FiO_2 > 0.7$) occurred less often, and additional trends favoured less pneumonia and re-intubation in the CPAP group. For patients having abdominal surgery, the evidence suggests that any type of lung expansion intervention is better than no prophylaxis. In particular, incentive spirometry is simple, inexpensive and provides objective goals for and monitoring of patient performance.

Nutritional support

One multisite trial randomly assigned 395 patients undergoing laparotomy or non-cardiac thoracotomy to perioperative total parenteral nutrition (TPN) or no TPN. The overall rates of major complications and 90-day mortality were similar between the groups. TPN was associated with non-statistically significant trends towards higher rates of pneumonia and empyema but significantly lower rates of non-infectious complications.[65] In another trial, 317 malnourished patients were randomly assigned to TPN or total enteral nutrition (TEN).[66] Rates of overall complications and infectious complications were statistically significantly lower with TEN but rates of pneumonia or the combined outcome of pneumonia and respiratory failure did not differ.

Immunonutrition refers to enteral feedings with additional ingredients aimed at enhancement of the immune system and preventing infection. In another trial, 305 patients undergoing elective resection of gastrointestinal cancer were randomly assigned to: (a) an enteral solution enriched with arginine, omega-3 fatty acids and ribonucleic acids preoperatively (5 days before surgery); or (b) this combination perioperatively (5 days before surgery plus jejunal tube feeding within 12 h of surgery); or (c) to a control group.[67] The overall infection rates were significantly lower with immunonutrition but rates of pneumonia did not differ.

Assessment of risk

Preoperative risk assessment: The predictive value of different lung function tests for postoperative pulmonary complications has been variable. There have been no randomised controlled trials to compare clinical and various functional parameters.

In a few non-randomised trials, spirometry was inferior to clinical assessment including chest radiography. Pulmonary function tests are not suitable as a general screen to assess risk of post-operative pulmonary complications, but are important in patients undergoing lung resection surgery. Risk stratification is effective in patients undergoing lung resection and lung-volume-reduction surgeries; however, such a strategy is lacking in patients undergoing other surgeries.

Clinical scoring systems to assess overall co-morbidity, such as ASA classification and the Goldman cardiac risk index, may be the best predictors of complications. The American College of Physicians published guidelines on clinical and laboratory predictors of perioperative pulmonary risk before non-cardiothoracic surgery,[14] as follows:

- *Recommendation 1*: All patients undergoing non-cardiothoracic surgery should be evaluated for the presence of the following significant risk factors for postoperative pulmonary complications to receive pre- and postoperative interventions to reduce pulmonary risk: COPD, age older than 60 years, ASA class of II or greater, functionally dependent and congestive heart failure.
- *Recommendation 2*: Patients undergoing the following procedures are at higher risk for post-operative pulmonary complications: prolonged surgery (>3 h), abdominal surgery, thoracic surgery, neurosurgery, head and neck surgery, vascular surgery, aortic aneurysm repair, emergency surgery and general anaesthesia.
- *Recommendation 3*: A low serum albumin level ($<35\ g\,l^{-1}$) is a powerful marker of increased risk for postoperative pulmonary complications.
- *Recommendation 4*: All patients who, after preoperative evaluation, are found to be at higher risk for postoperative pulmonary complications should receive the following postoperative procedures: deep breathing exercises or incentive spirometry and selective use of a nasogastric tube.
- *Recommendation 5*: Preoperative spirometry and chest radiography should not be used routinely for predicting risk for postoperative pulmonary complications.

Table 1
Perioperative modification of respiratory disease.

Pre-operative
Recognise high risk patients (Chronic obstructive pulmonary disease, cigarette smokers, ASA > II, impaired sensorium, nutrition status)
Encourage cessation of smoking for at least 8 weeks
Optimally treat COPD according to guidelines
Administer antibiotics and delay surgery if respiratory infection is present
Patient education regarding lung expansion
Intra-operative
Limit surgery to less than 3 h
Use regional anaesthesia techniques
Avoid pancuronium
Use laparoscopic surgery if possible
Post-operative
Good pain control (epidural and patient controlled analgesia (PCA)
Use lung expansion techniques
Use continuous positive airway pressure

- *Recommendation 6*: The following procedures should not be used solely for reducing postoperative pulmonary complications: (1) right-heart catheterisation and (2) TPN or TEN (for patients who are malnourished or have low serum albumin levels).

However, the global application of risk factor prediction is problematic. First, risk factor profiles often work well for populations, but seldom for individual patients. Too many variables, which are potentially interrelated, are involved, and for groups, the systems target averages – not individuals. Until further clinical trials are carried out to determine equations to assess the risk of pulmonary complications, all patients should probably be treated using a broad risk-reduction strategy. This should involve preoperative recognition and optimisation of high-risk patients, intra-operative strategies to reduce the risk and postoperative care, including lung-expansion manoeuvres and pain control (Table 1).

Conclusion

Preoperative pulmonary evaluation is based primarily on a careful history taking and physical examination. Pulmonary function testing should be viewed as a management tool for selected at-risk patients and not a general screen to assess the risk of perioperative pulmonary complications. Pulmonary function testing is of course mandatory in lung resection surgery. Optimising lung function preoperatively seems to be a reasonable strategy. This consists of smoking cessation, optimal treatment of underlying disease and patient education. Reduction of intra-operative risk factors should be done in high-risk patients to decrease the risk of perioperative pulmonary complications. Postoperatively, patients should receive good pain control and attention must be paid to lung-expansion techniques. CPAP may be used in higher-risk patients. Although postoperative pulmonary complications contribute considerably to morbidity and mortality, further clinical studies need to be done to determine which patients develop these complications and how they can be avoided before they develop.

Practice points

- Postoperative pulmonary complications are as important as cardiac complications in terms of morbidity, mortality and length of stay.
- Careful history taking and a thorough physical examination are needed to identify at-risk patients.
- Known high-risk patients should be treated using a broad risk-reduction strategy. This includes optimisation preoperatively, intra-operative strategies to reduce the risk and postoperative care, including lung expansion and pain control.

Research agenda

- Further studies are needed to evaluate the accuracy of preoperative or operative variables to determine equations to predict the risk of pulmonary complications.
- Prospective randomised trials are needed to assess the value of pulmonary function testing.
- Further research is needed to assess how high-risk patients can be treated to prevent the development of pulmonary complications.

Conflict of interest statement

None.

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