REVIEW ARTICLE

One lung anesthesia

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ABSTRACT

Thoracic anesthesia with one lung ventilation is challenging. The anesthetist is faced with demands of establishing proper isolation of one lung from the other in order to facilitate good surgical exposure and prevent intraoperative complications. Due to advances in one lung ventilation (OLV) strategies and equipment, complex intrathoracic procedures are being performed with success. During one-lung ventilation, mismatch of perfusion leads to an increase in shunt and dead space. Hypoxemia is an inevitable adverse consequence of OLV. Prompt management is required. This may particularly occur with high airway pressure caused by malpositioned double lumen tube or endobronchial blocker causing incomplete lung ventilation and/or airway obstruction. Other causes may be bronchospasm, air trapping with dynamic hyperinflation pneumothorax of the ventilated lung and coughing due to inadequate muscle relaxation. One lung induced acute lung injury (ALI) must be recognized.

Acute lung injury (ALI) is a major cause of overall mortality after thoracic surgery. Protective ventilation strategies have been identified and recommended by researchers for implementation during OLV. This includes small tidal volumes based on ideal body weight, reducing the fraction of inspired oxygen (FiO_2), use of positive end-expiratory pressure (PEEP) to the ventilated lung, and low peak and plateau airway pressures.

One-lung ventilation has to be managed from the start before beginning OLV till the end of OLV (in order to prevent complications like ALI). Extreme care is required during re-expansion of the lung towards the end of OLV. Noninvasive ventilation may be used during this period to improve oxygenation.

Keywords: One-lung ventilation, hypoxemia, Anesthesia and thoracic surgery, lung protective ventilation, endobroncheal devices

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INTRODUCTION

Thoracic surgery is greatly facilitated with isolation of one lung from the other or by causing selective atelectasis of the lung requiring surgery (One-lung ventilation / anesthesia)[1].

Due to advances in one-lung ventilation complex intrathoracic procedures could be performed with success. This is particularly true for video-assisted thoracoscopic surgeries (VATS)[2].

In the last decade, the management of OLV has been influenced by two major changes – first, the recognition of one lung ventilation induced acute lung injury (ALI), which is a major cause of post lung-resection death, and video assisted thoracoscopic surgeries as it is critical to have good surgical exposure for the success of surgery[2].

Hypoxemia has become less frequent due to advancement like better lung isolation and ventilation strategies and newer anesthetic agents.

In a review article on ventilator management of one-lung ventilation, Rocca et al identified that despite of the fact more comorbidities existed for intermediate to major thoracic surgical procedures, the operative mortality remained unchanged over a period of time[3].

The mortality causes have shifted from cardiac and surgical towards infections and acute lung injury (ALI) syndrome. The incidence of post thoractomy ALI has not decreased over the last twenty years. It still remains between 2-4%[3,4].

HISTORY

In 1931, Gale and Waters described an anesthetic technique for selective one-lung ventilation. They aimed to open the thorax and surgically manipulate the lungs. They used a single light tube and inserted into the right or left main stem bronchus[5].

Following this, various lung separation techniques have been proposed to make it safer[6].

Only the simplest intrathroacic operations were safe or feasible till 1930s. The methods for securing the airway, isolating the lungs and selectively ventilating either or both lungs have contributed to present situation[3].

MANAGEMENT OF OLV

Indications to Contraindications

Thoracic anesthesia includes a variety of diagnostic and therapeutic procedures involving the lungs, airways and other intrathoracic structures. Two techniques are fundamental to anesthetic management for the majority of thoracic procedures: (a) lung isolation to facilitate surgical access within the thorax, and (b) management of one – lung anesthesia[7,8,9].

Techniques on lung isolation are basically designed to facilitate one-lung ventilation (OLV) in patients undergoing cardiac, thoracic, mediastinal, vascular, oesophageal, or orthopedic procedures involving the chest cavity[10].

There is indication of lung isolation from each other when collapse of one lung confers a critical benefit to the surgical performance e.g., pneumonectomy, upper lobectomy, repair of thoracic aortic aneurysms, examination of pleural space. Lung isolation is also used to protect the lung from soiling by the contralateral lung in such cases as bronchopleural fistula, pulmonary haemorrhage and whole-lung lavage. Lung isolation also provides differential patterns of ventilation in unilateral reperfusion injury cases e.g., after lung transplantation, pulmonary thromboendarterectomy or unilateral lung trauma[1]. No true contraindication to lung isolation has been identified excepting inadequate lung function to support OLV.

Predictors of Hypoxemia during OLV - include right-sided surgery, low PaO_2 during two lung ventilation preferential perfusion to the operative lung, supine position, vasodilator use, excessive volatile anesthesia (>>1MAC), sepsis and lung function abnormalities[11].

EXECUTION OF OLV

Lung isolation can be achieved by three methods:[7,8,12] (1) Placing a right or left endobronchial double lumen tube (DLT)[13], (2) Placing a single lumen endotracheal tube in conjunction with a bronchial blocker (Arndt, Cohen, balloon-tipped luminal catheters) or utilizing a commercially available endotracheal tube with a built-in blocker (Univent)[9,14,15], and (3) Placing a single lumen tube in the right or left main bronchus. DLT and bronchial blockers have been shown to be clinically equivalent in the provision of OLV[16,17]. Lung isolation can also be done through a tracheotomy tube and is the most commonly done with a bronchial blocker[8].

Double Lumen Tube (DLT): Physiology Principles

Double lumen tubes are designed to isolate ventilation. They have the added benefit over other techniques of facilitating deflation and suctioning, and administering continuous positive airway pressure (CPAP) to the deflated lung. The DLT consists of (a) a tracheal and bronchial lumens, (b) cuffs on both lumens, and (c) right or left sidedness. Because of the anatomical differences in the bifurcation of tracheobronchial tree, right and left DLTs are slightly different in their endobronchial lumen design. Right DLTs have a side opening (Murphy's eye) close to the tip and surrounded by the cuff so that it can be positioned at the right upper lobe origin to assure its ventilation; the cuff of a left DLT may inadvertently block the right main bronchus[7,18].

Proper placement of DLT can be technically challenging due to its larger diameter, requirement of positioning into a specific mainstream bronchus and complications like rupture of DLT cuff to potential life threatening disruption of tracheobronchial tree[19]. In the event of a suspected (or unsuspected) difficult airway, it is better to place a single lumen tube and isolate the lung with a bronchial blocker. But in case DLT is necessary, a single lumen tube can be placed and a tube exchanger can be used to switch to a DLT.

The Robert-shaw is the most commonly used DLT. However, disposable plastic DLTs have replaced older red rubber Carlens, White and Robert-Shaw tubes. Sizes available range from 32F to 41F from various manufacturers and refer o the outer diameter[20]. Disagreement exists on the method of selection for the most appropriate size of DLT.

Some studies suggest choosing the largest tube that fits in order to decrease the chance of migration and obstruction, which can result in hypoxemia, lung isolation failure, increased airway resistance, difficulty of passing a fiberoptic scope or tracheal obstruction[20,21,22]. Other propose inserting a smaller than conventional size to decrease trauma with insertion. One study demonstrated that choosing a smaller size did not influence the incidence of hypoxemia, need for repositioning or success of lung isolation[23]. Other studies suggest that measurement of the tracheal size from available CT or MRI imaging films can be used as a guide to choose DLT size[24]. Tracheal width can be measured from patient's chest X-ray and the size of left bronchus may then be estimated[20]. Some recommended use of complex mathematical formulas for selecting the appropriate size of DLT[25,26]. In general, most male adults take a size 37F or 39F and most female adults take a size 35F or 37F[7,21,27,28]. Lung collapse and OLV for left sided thoracic surgery can be achieved by either a left or right DLT[19,29]. If a left pneumonectomy is planned, the left DLT can be withdrawn back to the trachea before the bronchus is stapled. Right sided double-lumen tube placement is more challenging because of the early branching of the right upper lobe and proper positioning of the opening for ventilation (Murphy's eye) of the endobronchial lumen at its origin[30]. But Campos et al concluded after comparison that Rt-DLT presented no increased risk of complications for Lt-sided thoracic surgery.

Insertion

The tip of the tube is inserted just through the vocal cords and then immediately rotated 90° in the direction of the bronchus that one is aiming to intubate[12].

Confirming Position

- One technique of determining proper positioning DLT is auscultation of the lungs and manual ventilation while the tracheal and bronchial lumens are selectively clamped and unclamped. Breath sounds should be absent distally when clamping the desired lumen (tracheal, bronchial)[31,32].
- **Fiberoptic bronchoscopy** is considered the Gold Standard for confirming proper positioning of DLT[23,33,34,35,36].
- Purohit et al identified in their review that the positioning of the lung isolation device could also be confirmed by ultrasonography of the chest with the intercostals approach[37].

Campos et al (2008) concluded in a prospective randomized trial that the experience of Anesthesiologist and his knowledge of endoscopic bronchial anatomy played a major role in successful placement of lung isolation devices[38]. Ng et al also concluded that the anesthetist must acquire additional training on the placement of lung isolation devices[35].

Dunlop (1939) concluded in his review that, "Many agents and divergent methods are in common use for major thoracic operations and various centers. It is impossible to say what is best. The one thing that impresses is that, as yet, the experience of the anesthetist, his knowledge of the pathology presents in each case and of the difficulties which may arise and his preparedness to cope with them are the most important factors"[39].

PHYSIOLOGY OF ONE LUNG VENTILATION

The functional residual capacity decreases as a consequence of loss of muscle tone in the chest wall and diaphragm after the induction of anesthesia. During two lung ventilation, the dependent lung compliance is reduced that shifts most of the tidal volume towards upper lung. Due to gravity, the pulmonary perfusion goes to the dependent lung.

After the lung is isolated, ventilation gets restricted to the dependent lung and any residual perfusion to the nondependent lung becomes true shunt flow[1,40].

Blood flow is decreased to the non-ventilated lung due to hypoxic pulmonary vasoconstriction (HPV) but it is still being perfused leading to a decrease in arterial oxygen tension (PaO_2). The PaO_2 may get further decreased by anesthetic agents during OLV due to inhibition of HPV in the non-ventilated lung[1].

Hypoxemia during OLV is basically due to obligatory shunt through the collapsed lung. The major determinant of degree of venous admixture is this distribution of perfusion. As the right lung receives a larger proportion of cardiac output (55% vs 45% to the left). Gravity in lateral decubitus position, retraction of the lung, hypoxic pulmonary vasoconstriction and surgical stimulation are the factors helping to reduce perfusion to the nondependent lung[1,11,41-46].

Hypoxemia (i.e., arterial oxygenation <90%) caused by OLV can be understood by considerating oxygen storage, dissociation of oxygen from haemoglobin ventilation/perfusion relationship and factors that reduce the effect of hypoxic pulmonary vasoconstriction. There is reduction in arterial oxygen partial pressure during OLV along with permissive hypercarbia and respiratory acidosis. These changes cause rapid dissociation of oxygen from haemoglobin (Bohr effect)[47].

Hypoxic pulmonary vasoconstriction is a potent physiological process that helps to reduce blood flow to poorly ventilation / perfusion mismatch. Decrease in the alveolar partial pressure of oxygen (PaO_2) results in rapid vasoconstriction with an initial plateau at fifteen minutes following lung isolation. After about four hours of lung isolation, maximal vasoconstriction is reached and this reduces shunt flow by 40%[1,44,48,49].

Inhibition of hypoxic pulmonary vasoconstriction was seen with older inhalational anesthetics like halothane and nitrous oxide in a dose dependent fashion, but not with the newer agents like desflurane and sevoflurane[1,6,45,50-54].

Hypoxic pulmonary vasoconstriction is also influenced by systemic and pulmonary vasodilators, acid / base imbalance[1,46,49].

COMPLICATIONS

Hypoxemia – affected from 9% to 27% of patients undergoing one-lung ventilation. It is influenced by several factors[6]. In earlier days of thoracic anesthesia hypoxemia was seen in about 40% of cases with Carlen's DLT and manual ventilation[55].

Over the years this complication has reduced significantly due to better tube designs, improvement in lung isolation and with newer volatile anesthetics having lesser effects on hypoxic pulmonary vasoconstriction. Although hypoxemia as low as 1% have been reported[21] patients and is a serious clinical concern[11].

Failure in proper lung isolation is a major cause of hypoxemia. Hence there is strong recommendation of confirmation, placement and/ or displacement during positioning with fiberoptic bronchoscopy[33-36].

Acute Lung Injury (ALI) – is diagnosed as an acute reduction in PaO_2/FiO_2 ratio to <300 and bilateral pulmonary infiltrates on chest radiography in the absence of left heart failure[2]. ALI is a sequalae of different pathogenic triggers and shows a biphasic distribution: (a) primary form triggered within three days by perioperative factors, (b) delayed form triggered by postoperative complication (3-10 days post-operative)[56]

Risk factors for primary ALI in thoracic surgery are: (a) peak inspiratory pressure >40 cm H_2O, (b) plateau pressure >29 cm H_2O, (c) long duration of OLV, (d) excessive fluid administration, (e) pneumonectomy, (f) alcohol abuse, and severe pulmonary dysfunction[44,57]. The delayed form is due to a sequence of deleterious events leading to alveolar and capillary injury.

Diffuse alveolar damage is due to barotraumas (direct high pressure on lungs), repetivitive opening and closing of alveoli (atelectotrauma), lung over-distension (volutrauma), cytokines and local inflammatory mediators (biotrauma). Due to its high (25-40%) mortality rate, ALI is a major cause of overall thoracic surgical mortality[60].

MONITORING

In procedures carrying significant risk of haemorrhage, haemodynamic instability, fluid shifts and complicated surgeries an arterial line access (apart from standard monitoring) will not only enable haemodynamic monitoring, but also arterial blood gas analysis to assess oxygenation and adequacy of ventilation. In OLV, there is increased end tidal and arterial pressure carbon dioxide ($ETCO_2$-$PaCO_2$) gradient. Continuous spirometry is important to appreciate: (a) changes in lung compliance because of recruitment / derecruitment, (b) to confirm any air leaks and air trapping.

Trans Oesophageal echocardiography TEE may be helpful in perioperative period to assess any right heart dysfunction. This can get aggravated because of increase in pulmonary vascular resistance due to initiation of OLV and clamping of pulmonary artery vessels[2].

Carassiti et al studied the pressures exerted by different endobronchial devices and concluded that patients undergoing one lung ventilation may be frail. Hence monitoring of pressure exerted by the tracheal and bronchial cuffs on the endobronchial device used is extremely important. This is beneficial to guide the anesthetist to do optimal inflation of the cuff to minimize bronchial mucosal damage[61].

ANESTHESIA REGIMEN

In an update published in 2013 of a Cochrane Review (earlier published in the Cochrane Library issue 2, 2008) to evaluate the effectiveness and safety of intravenous versus inhalation anesthesia for one-lung ventilation. Modolo et al identified that they included randomized controlled trials of intravenous e.g., propofol versus inhalation (e.g., isoflurane, sevoflurane, desflurane) anesthesia for one lung ventilation "No evidence indicated that the drug used to maintain anesthesia during one lung ventilation affected patient outcomes"[62].

A recent mutlicenter randomized controlled trial by Beck-Schimmer B et al studied the effect of volatile versus intravenous anesthetic on major complications after lung surgery. They concluded that "No difference between two anesthesia regimens was evident"[63]. Lohser et al compared inhaled versus intravenous anesthetics and concluded that patients had less adverse events with sevoflurane[64].

Modolo et al in their review published in Cochrane Database Systematic Reviews, 2013 concluded that, "If researchers believe that the type of drug used to maintain anesthesia during one-lung ventilation is important, they should design randomized controlled trials with appropriate participant outcomes rather than report temporary fluctuation in physiological variables. Researchers should include outcomes that are important to participants when assessing the effects of anesthetic technique during one lung ventilation. These include adverse postoperative effects, death and intraopreative awareness"[62].

At the time of Induction of Anesthesia to Start of OLV

Protective lung ventilation guidelines are recommended for two lung ventilation without lung injury[65]. In order to prevent derecuritment during protective ventilation, application of positive end-expiratory of pressure (PEEP) with low (4-6 $ml.Kg^{-1}$) tital volume (Vt) based on ideal body weight (IBW) is recommended. Derecruitment occurs after induction particularly with high FiO_2 and bronchoscopy during the confirmation of placement of lung separation device[59]. Oxygenation and ventilation is improved during two lung ventilation with alveolar recruitment maneuvers (ARM)[66,67,58,59].

This alveolar recruitment if done before OLV, leads to improvement in compliance of lung. This is also minimizes tidal recruitment during one lung ventilation, which represents atelectotrauma (repetitive alveolar opening (closure) and is a causative factor of acute lung injury (ALI). The simplest form of ARM comprises of vital capacity maneuver with a breath hold at 30 cm H_2O for 10-40 secs. On modern anesthetic ventilators, these formal cycling ARMs are incorporated. Peak inspiratomy pressure to be increased stepwise and PEEP held for 5-10 breathes per step up to 40/20 cm H_2O[68].

Establishing and Maintaining OLV

In a cohort study, Licker et al compared patients undergoing lung surgeries from year 1998-2003 with those during 2003-3008. They identified that there was a decreased incidence of acute lung injury where protective lung ventilation was applied as a routine[57]. Protective lung ventilation (PLV) in their cohort consisted of low tidal volume (mean 5.3 $ml.Kg^{-1}$ of IBW compared with 7.1 $ml.Kg^{-1}$ of IBW) during OLV, PEEP, pressure controlled ventilation and recruitment maneuvers frequently.

Licker et al performed a secondary analysis of an observational cohort in 2009 and concluded that implementation of protective lung ventilation protocol intraoperatively on patients undergoing lung cancer surgery showed better respiratory outcomes postoperatively. There was significantly reduced ALI and atelectosis incidence, and reduced ICU requirements[60,69].

Yung et al compared 102 patients in a randomized trial, having elective lobectomy to protective ventilation or conventional ventilation ($F1O_2$ 1.0 Vt 10 $ml.Kg^{-1}$, volume control ventilation and PEEP. They found that there was significantly lower pulmonary dysfunction in lung protective group as compared to conventional (4% vs 22%)[70].

Positive End-Expiratory Pressure (PEEP)

Studies support the role of PEEP in protective ventilation for lung injury prevention, although optimal PEEP settings are controversial[67,69,71-73].

Ferrando et al in their study showed improved oxygenation and lung mechanics with setting of external PEEP so as to achieve optimal dynamic lung compliance. They used PEEP decrement trial after an ARM[74]. Patients would most likely benefit from PEEP if their pulmonary function is normal.

Auto PEEP

Auto PEEP develops when tidal volume cannot be evacuated during the allocated expiratory time. Factors that pre-dispose auto-PEEP generation (single or in combination) are: (a) respiratory mechanics of patient (e.g., COPD), (b) ventilator settings (short expiratory time), (c) resistance of artificial airways including ventilator tubings, heat and moisture exchanges and DLT[75].

Double lumen tubes (DLT used for OLV during thoracic anesthesia increases positive end-expiratory pressure (auto-PEEP) to a moderate extent[75,76].

Inspired Oxygen Fraction (FiO_2)

Ischemia reperfusion injury as a result of surgical manipulation and lung collapse initiates tissue hypoperfusion. This leads to oxygen toxicity during

OLV. Reperfusion leads to lung damage due to re-expansion. This is due to formation of reactive oxygen species (ROS).

Respiratory failure, cardiac arrhythmias, and pulmonary hypertension are seen in one lung ventilations exceeding 120 minutes. This is due to oxidate stress[77]. An FiO_2 of 0.4 provides adequate oxygenation in the lateral decubitues position[78].

Recruitment

Atelectasis must be avoided in the non operative lungs as the shunt fraction from lung isolation can get worsened. Oxygenation is improved with the application of alveolar recruitment at the beginning of or just before OLV. Improved oxygenation or lung compliance following an ARM show that an adequate level of PEEP was being used. An optimal level of ARM has not been established[2].

Peak / Plateau Pressure

Protective ventilation lowers peak and plateau pressures, thus decreasing the associated lung injury. Peak pressures >40 cmH_2O and plateau pressures >29 cmH_2O are associated with ALI[60].

Respiratory Rate/Permissive Hypercapnia

The respiratory rate (RR) should be slightly high at the beginning of OLV to avoid hypercapnia with protective Vt. Permissive hypercapnia is a part of lung protection strategy. This allows decreased ventilatory pressure and mechanical stress[2].

Pressure Controlled vs Volume Controlled Ventilation

Pressure control ventilation (PCV) is associated with lower ventilatory pressures. This gives minimal differences in the intrabronchial pressure. PCV has been preferred over volume control ventilation (VCV) for OLV. Some studies have failed to identify benefit of PCV[58,79,80].

PREVENTION OF HYPOXEMIA DURING OLV[11]

- *Improving Perioperative Lung Function* – to decrease postoperative pulmonary complications and to improve oxygenation.
- *Monitoring Lung Separation* – fiberoptic monitoring of DLTs required both after intubation and after patient positioning.
- *Good Ventilation Strategy in the Dependent Lung keeping in mind the following:*
  a) Impediment of the expansion of the dependent lung due to mediastinal weight, pressure of the abdominal organs and cephalad displacement of the diaphragm and by the pressure, and noncompliance of the thoracic wall. This leads to atelectasis and alveolar collapse of the dependent lung leading to HPV.
  b) Avoid atelectasis development and keep dependent lung open.
  c) Poor ventilation strategy may lead to ALI.
- *Oxygen Administration to the Nondependent Lun*g – used (with or without CPAP) to treat hypoxemia during OLV and also for prevention.
- *Modulation of Perfusio*n e.g. with Nitric oxide.
- *Type of Aneshesia* – all volatile anesthetics inhibit HPV in a dose dependent fashion. Type of anesthesia (inhalational vs total intravenous, epidural vs no epidural) by itself does not affect oxygenation during OLV.
- Haemoglobin Levels – factors leading to decreased oxygenation of venous blood are increased oxygen extraction and low haemoglobin levels.

One Lung Ventilation to Extubation

Re-expansion of the Operative Lung

Lung recruitment to be done at the end of OLV for:

a) Restoration of normal lung to re-establish pleural interface.
b) Minimize post-operative pneumothorax.
c) Optimize pulmonary function post-operatively.
d) Restoration of V/Q mismatching in order to improve oxygenation.

Selective lung re-expansion with low FiO_2 should be used when recruiting lung after prolonged collapse.

Lung re-expansion should be gradual to a lower plateau pressure in order to avoid ALI.

Lung re-expansion can worsen lung injury (ischemic re-perfusion injury) due to reactive oxygen species and oxidative stress[81].

Two Lung Ventilation: Post OLV to Emergence

Lung function is impaired postoperatively due to General Anesthesia, lung oedema, residual paralysis, manipulation, inflammation and residual atelactosis. At this particular time patients are at risk of lung injury. Patient should not be switched to unsupported spontaneous ventilation at this point, keeping in mind the high airflow resistance of DLT and changes of derecruitment. Hypoventilation and high FiO_2 will lead to atolactasis. Pressure support ventilation with PEEP may maintain optimal lung volumes at the time of emergence[2].

Post Extubation Period

Continuous positive airway pressure (CPAP) to be applied after emergence particularly, in high risk patients. Studies have identified that non-invasive ventilation has been shown the decrease mortality and need for re-intubation in cases of acute respiratory failure following lung resection[2].

RECOMMENDATIONS ON MANAGEMENT OF OLV[2]

1. Induction of Anesthesia to Start of OLV: (a) pre-oxygenate with 100% Oxygen and ventilate with FiO_2 of 1.0 prior to OLV, (b) alveolar recruitment maneuvers after intubation and initial bronchoscopy, (c) gently ramp up pressure to a plateau of 30 cmH_2O. Plateau to be maintained for 10 seconds or more, (d) low Vt (6-8 $ml.Kg^{-1}$ of IBW) during TLV, (e) PEEP 3-10 cm H_2O.
2. Establishing and Maintaining One-Lung Ventilation:
   - i) Tidal volume - Vt should be 4-6 $ml.Kg^{-1}$ of IBW.
   - ii) Positive End-Expiratory Pressure (PEEP) - set PEEP at 3-10 cm H_2O during OLV. Titrate to the highest lung compliance, or consider auto PEEP.
   - iii) Inspired Oxygen Fraction (FiO_2) - titrate FiO_2 to target SpO_2 of 92-96%.
   - iv) Recruitment: (a) do initial ARM following lung isolation, (b) gently ramp up pressure to a plateau of 30 cmH_2O. To be maintained for more than 10 seconds, (c) initiate ARM therapeutically when required. Follow with PEEP adjustment.
   - v) Peak/Plateau Pressure: (a) peak and plateau inspiratory pressures to be minimized during OLV (peak pressure <30 cmH_2O and plateau pressure <20 cmH_2O).
   - vi) Respiratory Rate/Permissive Hypercapnia: (a) respiratory rate be 12-16 breaths per minute, (b) $PaCO_2$ 40-60 mmHg, (c) routine 1:E ratio is 1:2, (d) for restrictive lung disease 1:E:1.1-2:1, (e) for obstructive lung disease 1:E – 1:14-1:6 in order to avoid intrinsic PEEP.
   - vii) Pressure Control vs Volume Control: use either VCV or PCV.
   - viii) Maintenance of anesthesia: maintain anesthesia with Sevoflurane or Desflurane.
   - ix) Management of Hypoxemia: (a) increase FiO_2, (b) confirm lung isolation, (c) ensure adequate cardiac output, (d) recruitment maneuvers to the ventilated lung, (e) if no improvement, apply continuous positive pressure (CPAP) to the operative lung or use intermittent TLV[82-85].
3. From OLV to Extubation: re-expansion of the operative lung: (a) perform unilateral re-expansion, (b) minimize recruitment pressure (30 cmH_2O without resection and 20 cmH_2O with lung resection), (c) recruitment pressure to be developed slowly and maintain until full re-expansion has occurred (30-60 secs), (d) FiO_2 to be minimized.
4. Two Lung Ventilation: Post-OLV to Emergence: (a) maintain protective lung ventilation post OLV (4-6 $ml.Kg^{-1}$ of IBW with PEEP (in lung resection); 6-8 $ml.Kg^{-1}$ of IBW with PEEP (without lung resection); FiO_2 to be titrated to target SpO_2 of 92-96%, (b) pressure support ventilation from chest closure until extubation.
5. Post Extubation Period: (a) in high risk patients post extubation oxygenation can be improved with CPAP, and (b) Noninvasive ventilation improves outcome in respiratory failure after lung resection.

CONCLUSION

Recent advances in thoracic anesthesia techniques and equipment have improved the outcomes. Recommendations on protective ventilation strategies have shown improved safety in the intra and post operative period. However, some disagreements still exist on the method of selection for the most appropriate size of DLT. No specific guidelines exist amongst the researchers. The patient outcomes have not been studied on the drugs used for maintaining anesthesia during one-lung ventilation (OLV).

Controversies still exist on the use of PCV vs VCV for OLV. Hence, larger multicentered randomized controlled trials should be designed to address the above concerns.

Conflict of interest: Nil

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