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Intraoperative mechanical ventilation strategies for one-lung ventilation

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One-lung ventilation (OLV) has two major challenges: oxygenation and lung protection. The former is mainly because the ventilation of one lung is stopped while the perfusion continues; the latter is mainly because the whole ventilation is applied to only one lung. Recommendations for maintaining the oxygenation and methods of lung protection can contradict each other (such as high vs. low inspiratory oxygen fraction (FiO_2), high vs. low tidal volume (TV), etc.). In light of the (very few) randomized clinical trials, this review focuses on a recent strategy for OLV, which includes a possible decrease in FiO_2, lower TVs, positive end-expiratory pressure (PEEP) to the dependent lung, continuous positive airway pressure (CPAP) to the non-dependent lung and recruitment manoeuvres. Other applications such as anaesthetic choice and fluid management can affect the success of ventilatory strategy; new developments have changed the classical approach in this respect.

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One-lung ventilation (OLV) is a unique ventilation method whereby one lung is excluded from ventilation while the perfusion to the non-ventilated lung is continued.

The historical classification of 'absolute' and 'relative' indications is now considered rather confusing and inappropriate: a 'relative' indication is not just a 'surgical comfort' but also a confirmation of the decrease in intra- and post-operative complications. In addition, any 'relative' indication may unpredictably become an 'absolute' indication during the operation. The current classification of indications of OLV includes indications for 'lung separation' and 'lung isolation' [1].

Historically, the guidelines for OLV are primarily aimed at preventing and treating hypoxaemia, which was considered to be the most important, if not the only, problem during OLV. Hypoxaemia is still an important challenge to OLV for several reasons. However, a growing number of studies have shown that lung injury (acute lung injury (ALI)) associated with/induced by OLV is also an important problem [2]. Therefore, an 'optimal' ventilation strategy should overcome these two challenges: maintaining adequate gas exchange and protecting the lung.

Unfortunately, the number of 'randomized clinical trials' (RCT) examining intraoperative mechanical ventilation strategies for OLV is still not sufficient to provide adequate evidence. In a recent meta-analysis on the incidence of mortality and morbidity related to post-operative ALI in patients who have undergone abdominal or thoracic surgery, only four studies with exclusively thoracic operations could be included [3]. This review attempts to focus on mechanical ventilation strategies during OLV using both 'oxygenation' and 'lung protection'.

Hypoxaemia during OLV

During OLV, the ventilation of one lung is interrupted, while the perfusion persists. Hypoxaemia is caused not only by the increased intrapulmonary shunt (Q_s/Q_t) from the blood flow to the non-ventilated lung but also by the hypoventilation in the dependent lung as a result of derecruitment of the alveoli. Several mechanisms (above all, 'hypoxic pulmonary vasoconstriction (HPV)') cause a decrease of blood flow to the non-ventilated lung, resulting in a decreased Q_s/Q_t. For anaesthesia and intensive care, knowledge of the basic (patho)physiology of HPV is essential [4,5]. Yet, the inhibition of HPV is not the only cause of hypoxaemia during OLV [6]; any application causing a diversion of blood flow to the non-ventilated lung (e.g., high airway pressures in the ventilated lung) can lead, even without any impact of HPV, to hypoxaemia.

Matching of the ventilation and perfusion ($V-Q$) play a crucial role, with changes after anaesthesia induction (and also during OLV) leading to a $V-Q$ mismatch [7]. It has been shown that the lateral decubitus position was associated with better oxygenation compared with the supine position [8], and that the relative position of the ventilated versus the non-ventilated lung markedly affects arterial oxygenation during OLV [9]. Although many OLV procedures are performed successfully in the lateral decubitus position, the number of OLV procedures performed in the supine position is increasing (double-lung transplantation, minimally invasive coronary artery surgery, etc.).

Although several studies and practical experience support the classical knowledge that gravity is most important determinant of the distribution of both ventilation and perfusion, some studies have shown that anatomical differences can also play a role. An 'onion-like' layering of perfusion with reduced flow at the periphery of the lung and higher flow toward the hilum was demonstrated [10].

Table 1
Historical recommendation for OLV (to avoid hypoxaemia) (modified from Ref. [35]).

- FiO_2: 1.0
- High TV (e.g., 10 mL/kg)
- $PaCO_2 = 40$ mmHg (if necessary, increase respiratory rate)
- If severe hypoxaemia occurs, CPAP to non-dependent lung
- PEEP, only if severe hypoxaemia occurs, should be $\leq$ CPAP
- Use intravenous anaesthetics to prevent HPV