

MANAGEMENT OF INTRAOPERATIVE HYPOXEMIA DURING THORACIC SURGERY

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The lateral decubitus position and pathophysiological changes during one lung ventilation

Hypoxaemia is an adverse but ineluctable consequence of OLV, and it is defined by a decrease in arterial hemoglobin oxygen saturation to less than 90%. The lateral decubitus position provides optimal access for most operations on the lungs. Opening the chest the lower, dependent lung is ventilated, whereas the upper, non-dependent lung tends to collapse. Unfortunately, this position may significantly alter the normal pulmonary ventilation/perfusion relationships, causing the development of hypoxaemia. Other considerations that impair normal oxygenation includes oxygen storage, dissociation of oxygen from haemoglobin, and factors that reduce the effect of hypoxic pulmonary vasoconstriction (HPV).

Ventilation-perfusion mismatching

When a patient who lies on the back and breathes spontaneously assumes the lateral decubitus position, ventilation/perfusion matching is preserved because both ventilation and perfusion are greater in dependent than that in the non-dependent lung. Mismatching of ventilation and perfusion occurs when the patient is paralysed. In this situation, positive pressure ventilation favors the upper non-dependent lung in the lateral position, whereas perfusion remains greater in the dependent lung. This increases the volume of dead space which leads to hypercapnea. Despite HPV, collapsed lung may be perfused to a certain degree. As consequence occurs a substantial increase of shunt in the patient which leads to hypoxemia. Due to HPV clinically ob-

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served shunt fraction is lower than roughly half of the cardiac output that normally flows through each lung.

Clinical approach to management hypoxemia during One-Lung Ventilation

Thoracic anesthesia practice in the past few years implemented the concept of protective OLV in order to reduce the incidence of postoperative acute lung injury (1). The investigations emphasizes that the impact of protective OLV on intraoperative hypoxemia remains controversial (2, 3). It seems that hypercapnea as part of a protective ventilation strategy improves HPV and has a favorable effect on oxygenation (4). The square pressure waveform of pressure-control ventilation (PCV) theoretically should provide more uniform lung aeration and recruitment. Initial studies compared PCV and volume-control ventilation during OLV and concluded that both oxygenation and shunt fraction are improved with PCV(5), but subsequent investigations failed to highlight benefit of PCV during OLV (6-8).

Data shows that the lateral decubitus position improves oxygenation during OLV, under the influence of gravity pulmonary blood flow redistributes in such manner that divertes roughly 10% of CO to the dependent lung (9). On the other hand, Yatabe et al. found better $\text{PaO}_2/\text{FiO}_2$ ratios in patients undergoing esophagectomy in prone position (10). This finding may be explained by the superior V/Q matching in the prone position (11) and the lack of compression of the ventilated lung by mediastinal structures (12). Additionally, supine positioning during some thoracoscopic procedures also tends to increase the risk of hypoxemia during OLV (13). However, recent investigations in animal model suggest that anatomic pulmonary vascular factors in terms of pulmonary blood flow distribution are more important than gravity itself (14).

Overcoming hypoxia during OLV

Good Ventilation Strategy in the Dependent Lung

The implementation of alveolar recruitment maneuver to the ventilated lung is one of the most efficient way to treat hypoxemia during OLV (15). Alveolar recruitment increases the area of ventilated lung parenchyma, resulting in improved gas exchange and arterial oxygenation. Furthermore, data showed beneficial effect of the alveolar recruitment maneuver in major pulmonary resection, encourageing the reduction of intrapulmonary shunt and dead space. The proposed mechanism improves arterial hypoxemia during one-lung ventilation OLV (16, 17). Of particular note is that before-mentioned strategy may cause hemodynamic instability with a significant decrease

in left ventricular preload, CO and arterial blood pressure (18, 19), and also barotrauma (20), and translocation of proinflammatory cytokines from the alveolar space into the systemic circulation (21). Lung recruitment on the dependent lung may be beneficial in improving arterial oxygenation during OLV, but still this effect can be transient (22).

Oxygen Administration to the Nondependent Lung

When a patient undergoing one-lung ventilation develops hypoxia, intermittent two-lung ventilation and continuous positive airway pressure (CPAP) to the non-dependent lung should be applied. Regardless of the mechanism, it should be noted that this interrupts surgery, such as video-assisted thoracoscopic surgery (VATS) by deteriorating the view of the surgeon. Protection of surgical exposure arises as a goal, therefore modifications of the standard CPAP technique including novel method of selective insufflations of oxygen into a bronchopulmonary segment distant from the site of surgery (23) or intermittent small-volume oxygen insufflations may be a possible solution (24). When severe desaturation occurs, clamping the pulmonary artery may improve oxygenation. This strategy appears to be controversial since it causes the decrease of CO and systemic oxygen delivery. Ishikawa et al. proved that administration of an inotropic agent concomitant with lung compression lessens the decreases in CO and systemic oxygen delivery, but still maintains the beneficial impact of lung compression on arterial oxygen saturation (25).

High-frequency jet ventilation and high-frequency percussive ventilation also appear as a successful treatment modality of hypoxemia during OLV without impeding surgical exposure (26, 27).

Medications

Elhakim et al. concluded that epidural dexmedetomidine limits the decrease in PaO₂ during OLV with no influence on systemic or pulmonary hemodynamic parameters (28). This effect of dexmedetomidine may be accomplished by nitric oxide dependent vasorelaxation mediated by endothelial α 2-adrenoceptor activation (29). Another approach based on aerosolized epoprostenol, showed beneficial effect on arterial oxygenation and also decrease mean pulmonary artery pressure in patients with acute respiratory distress syndrome, probably via dilation of the pulmonary vascular bed in ventilated regions and flow redistribution from shunt areas (30). Despite limited data, it is suggested that epoprostenol may attenuate critical desaturation during OLV (31). In either case larger clinical trials are required, in order to establish its safety and efficacy profile during OLV.

Choice of anesthesia for thoracic surgery and effects of anesthetics on HPV

Numerous studies concluded that HPV is probably the most important intraoperative phenomenon in reducing shunt during OLV. In the presence of decreased alveolar partial pressure of oxygen (between 4 and 8 kPa) this effect occurs. A variety of factors (anesthetic agent, CO, alveolar oxygen tension, mixed venous oxygen tension, acid/base imbalance, temperature changes, lung manipulation, vasodilators) can modulate the volume of HPV in the non-dependent lung. The inhalation anesthetics and many of the intravenous drugs used in anesthesia have been studied for their effects on HPV. Investigations on animals proved that the volatile anesthetics deteriorate HPV and increase intrapulmonary shunt fraction or attenuate arterial oxygen tension in a dose-dependent manner (32, 33), whereas propofol doesn't influence on HPV. However, clinical trials have shown contradictory data related to the effect of a given anesthetic agent on oxygenation (34-38).

Prediction of hypoxemia

Capnometry

A numerous factor may be helpful in predicting oxygenation during OLV, such as the percentage of nondependent lung perfusion. On the other hand, capnometry might be used to estimate the balance of blood flow to both lungs and to predict the occurrence of hypoxemia during OLV. Prediction of hypoxemia allows anesthesiologists to consider applying continuous positive airway pressure (CPAP) to the nondependent lung and positive end-expiratory pressure (PEEP) to the dependent lung at a very early stage in OLV. Two recent studies presented by Fukuoka et al. and Yamamoto and coworkers found a significant linear relationship between ETCO_2 and the P/F ratio after starting OLV (38, 39).

Tissue oxygenation

Noninvasive determination of tissue oxygenation during OLV can be mediated only by using cerebral oximetry. Data showed that the majority of patients who underwent thoracic surgery with OLV have decreased levels of cerebral tissue oxygen saturation obtained by noninvasive cerebral oxygen monitoring (40). Further researches should be focused on the influence of OLV on the end-organs and organ systems. As imperative also arises the development of new techniques for non invasive organ monitoring.

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