MANAGEMENT OF INTRAOPERATIVE HYPOXEMIA DURING THORACIC SURGERY

Radmilo J. Janković[1], Biljana Stošić[1]

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-

1 Department for Anesthesia and Intensive Care, School of Medicine, University of Niš, Serbia

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 PaO_2/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 aplied. 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 occures, clamping the pulmonary artery may improve oxygenation. This strategy appears to be contraversal 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 PaO_2 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.

REFERENCES:

1. Licker M, Diaper J, Villiger Y, et al. Impact of intraoperative lung-protective interventions in patients undergoing lung cancer surgery. Crit Care 2009; 13:R41.
2. Lohser J. Evidence-based management of one-lung ventilation. Anesthesiol Clin 2008; 26:241–72.
3. Theroux MC, Fisher AO, Horner LM, et al. Protective ventilation to reduce inflammatory injury from one lung ventilation in a piglet model. Pediatr Anaesth 2010; 20: 356–64.
4. Balanos GM, Talbot NP, Dorrington KL, Robbins PA. Human pulmonary vascular response to 4 h of hypercapnia and hypocapnia measured using Doppler echocardiography. J Appl Physiol 2003; 94:1543–51.
5. Tugrul M, Camci H, Karadeniz M, et al. Comparison of volume controlled withpressure controlled ventilation during one-lung anaesthesia. Br J Anaesth 1997; 79: 306–10.
6. Unzueta MC, Casas JI, Moral MV. Pressure-controlled versus volume-controlledventilation during one-lung ventilation for thoracic surgery. Anesth Analg 2007; 104:1029–33.
7. Pardos PC, Garutti I, Pineiro P, et al. Effects of ventilatory mode during onelung ventilation on intraoperative and postoperative arterial oxygenation in thoracic surgery. J Cardiothorac Vasc Anesth 2009; 23:770–4.
8. Choi YS, Shim JK, Na S, et al. Pressure- controlled versus volume- controlled ventilation during one-lung ventilation in the prone position for robot-assisted esophagectomy. Surg Endosc 2009; 23:2286–91.
9. Neustein SM, Eisenkraft JB, Cohen E. Chapter 40 Anesthesia for thoracic surgery. In Barash PG, Cullen BF, Stoelting RK, et al., editors. Clinical anesthesia. 6th ed. Lippincott Williams & Wilkins: Philadelphia; 2009. pp. 1032–72.
10. Yatabe T, Kitagawa H, Yamashita K, et al. Better postoperative oxygenation in thoracoscopic esophagectomy in prone positioning. J Anesth 2010; 24:803–6.
11. Nyren S, Radell P, Lindahl SG, et al. Lung ventilation and perfusion in prone and supine postures with reference to anesthetized and mechanically ventilated healthy volunteers. Anesthesiology 2010; 112:682–7.
12. Pelosi P, Croci M, Calappi E, et al. The prone positioning during general anesthesia minimally affects respiratory mechanics while improving functional residual capacity and increasing oxygen tension. Anesth Analg 1995; 80: 955–60.
13. Darlong LM. Video-assisted thoracic surgery for superior posterior mediastinal neurogenic tumour in the spine position. J Minim Access Surg 2009; 5:49–51.
14. Chang H, Lai-Fook SJ, Domino KB, et al. Spatial distribution of ventilation and perfusion in anesthetized dogs in the lateral postures. J Appl Physiol 2002; 92:745–2.
15. Tusman G, Bo¨hm SH, Sipmann FS, Maisch S. Lung recruitment improves the efficiency of ventilation and gas exchange during one-lung ventilation anesthesia. Anesth Analg 2004; 98:1604–09.
16. Tusman G, Bohm SH, Melkun F, et al. Alveolar recruitment strategy increases arterial oxygenation during one-lung ventilation. Ann Thorac Surg 2002; 73:1204-09.
17. Tusman G, Bohm SH, Sipmann FS, et al. Lung recruitment improves the efficiency of ventilation and gas exchange during onelung ventilation anesthesia. Anesth Analg 2004; 98: 1604-09.
18. Syring RS, Otto CM, Spivack RE, et al. Maintenance of end-expiratory recruitment with increased respiratory rate after saline-lavage lung injury. J Appl Physiol 2007; 102:331–9.
19. Garutti I, Martinez G, Cruz P, et al. The impact of lung recruitment on hemodynamics during one-lung ventilation. J Cardiothorac Vasc Anesth 2009; 23:506–8.
20. Meade MO, Cook DJ,Griffith LE, et al. A study of the physiologic responses to a lung recruitment maneuver in acute lung injury and acute respiratory distress syndrome. Respir Care 2008; 53: 1441–9.
21. Halbertsma FJ, Vaneker M, Pickkers P, et al. A single recruitment maneuver in ventilated critically ill children can translocate pulmonary cytokines into the circulation. J Crit Care 2010; 25: 10–15.
22. Lumb AB, Greenhill SJ, Simpson MP, Stewart J. Lung recruitment and positive airway pressure before extubation does not improve oxygenation in the postanaesthesia care unit: a randomized clinical trial. Br J Anaesth 2010; 104: 643–7.
23. Ku CM, Slinger P, Waddell TK. A novel method of treating hypoxemia during one-lung ventilation for thoracoscopic surgery. J Cardiothorac Vasc Anesth 2009; 23:850–2.
24. Russell WJ. Intermittent positive airway pressure to manage hypoxia during one-lung anaesthesia. Anaesth Intensive Care 2009; 37:432–4.
25. Ishikawa S, Shirasawa M, Fujisawa M, et al. Compressing the nondependent lung during one-lung ventilation improves arterial oxygenation, but impairs systemic oxygen delivery by decreasing cardiac output. J Anesth 2010; 24: 17–23.
26. Ender J, Brodowsky M, Falk V, et al. High-frequency jet ventilation as an alternative method compared

to conventional one-lung ventilation using double-lumen tubes: a study of 40 patients undergoing minimally invasive coronary artery bypass graft surgery. J Cardiothorac Vasc Anesth 2010; 24: 602–7.
27. Lucangelo U, Antonaglia V, Zin WA, et al. High-frequency percussive ventilation improves perioperatively clinical evolution in pulmonary resection. Crit Care Med 2009; 37:1663–9.
28. Elhakim M, Abdelhamid D, Abdelfattach H, et al. Effect of epidural dexmedetomidine on intraoperative awareness and postoperative pain after one lung ventilation. Acta Anaesthesiol Scand 2010; 54: 703–9.
29. Figueroa XF, Poblete MI, Boric MP, et al. Clonidine-induced nitric oxide dependent vasorelaxation mediated by endothelial α2-adrenoceptor activation. Br J Pharmacol 2001; 134: 957–68.
30. Walmrath D, Schneider T, Schermuly R, et al. Direct comparison of inhaled nitric oxide and aerosolized prostacyclin in acute respiratory distress syndrome. Am J Respir Crit Care Med 1996; 153: 991–6.
31. Raghunathan K, Connelly NR, Robbins LD, et al. Inhaled epoprostenol during one-lung ventilation. Ann Thorac Surg 2010; 89: 981–3.
32. Ishibe Y, Gui X, Uno H, et al. Effect of sevoflurane on hypoxic pulmonary vasoconstriction in the perfused rabbit lung. Anesthesiology 1993; 79: 1348-53.
33. Loer SA, Scheeren TW, Tarnow J. Desflurane inhibits hypoxic pulmonary vasoconstriction in isolated rabbit lungs. Anesthesiology 1995; 83: 552-6.
34. Reid CW, Slinger PD, Lenis S. A comparison of the effects of propofol-alfentanil versus isoflurane anesthesia on arterial oxygenation during one-lung ventilation. J Cardiothorac Vasc Anesth 1996; 10: 860-3.
35. Abe K, Shimizu T, Takashina M, et al. The effects of propofol, isoflurane, and sevoflurane on oxygenation and shunt fraction during one-lung ventilation. Anesth Analg 1998: 87: 1164-9.
36. Beck DH, Doepfmer UR, Sinemus C, et al: Effects of sevoflurane and propofol on pulmonary shunt fraction during one-lung ventilation for thoracic surgery. Br J Anaesth 2001; 86: 38-43.
37. Pruszkowski O, Dalibon N, Moutafis M, et al: Effects of propofol vs sevoflurane on arterial oxygenation during one-lung ventilation. Br J Anaesth 2007; 98: 539-44.
38. Fukuoka N, Iida H, Akamatsu S, et al. The association between the initial endtidal carbon dioxide difference and the lowest arterial oxygen tension value obtained during one-lung anesthesia with propofol or sevoflurane. J Cardiothorac Vasc Anesth 2009; 23: 775–9.
39. Yamamoto Y, Watanabe S, Kano T. Gradient of bronchial end-tidal CO2 during two-lung ventilation in lateral decubitus position is predictive of oxygenation disorder during subsequent one-lung ventilation. J Anesth 2009; 23: 192–7.
40. Hemmerling TM, Bluteau MC, Kazan R, Bracco D. Significant decrease of cerebral oxygen saturation during single-lung ventilation measured using absolute oxymetry. Br J Anaesth 2008; 101:870–5.