Apnea-induced hemoglobin desaturation during one-lung vs two-lung ventilation

Anis Baraka MD FRCA,
Marie Aouad MD,
Samar Taha MD,
Mohamad El-Khatib PhD,
Nadine Kawkabani MD,
Antoine Soueidi MD

Purpose: To compare the rate of apnea-induced hemoglobin desaturation during one-lung ventilation (OLV) vs two-lung ventilation (TLV) in patients undergoing thoracic surgery.

Methods: Six patients undergoing thoracotomy or thoracoscopy were included. Each patient served as his/her own control. The lungs were ventilated with oxygen 100% using TLV, followed after 20-30 min by OLV and the resultant PaO₂ was measured. Apnea was then induced following the two techniques of ventilation, and the times for every 1% decrease in hemoglobin saturation from 100% to 95%, as monitored by pulse oximetry, were recorded. The times for every 1% decrease in the saturation were compared in the two groups.

Results: The mean PaO₂ value following TLV (445 ± 99 mmHg) was higher than the mean PaO₂ following OLV (156 ± 18 mmHg). Also, the mean time for subsequent apnea induced hemoglobin desaturation from SpO₂ 100% to 95% following TLV was twice the time of desaturation following OLV (6.3 ± 1.2 min vs 3.2 ± 0.5 min, $P < 0.05$).

Conclusion: Hemoglobin desaturation occurs more rapidly during apnea following OLV than TLV. The rapid desaturation may be attributed to the decrease of FRC, associated with an increased transpulmonary shunting. The results suggest that two-lung ventilation with oxygen 100% provides a greater safety margin than one-lung ventilation with oxygen 100% whenever ventilation is interrupted.

Objectif : Comparer la vitesse de désaturation de l'hémoglobine induite par l'apnée pendant la ventilation unilatérale (VUL) vs bilatérale (VBL) chez des patients qui subissent une intervention chirurgicale thoracique.

Méthode : Six patients devant subir une thoracotomie ou une thoracoscopie ont participé à l'étude. Chaque patient était son propre témoin. La VBL a été réalisée avec 100 % d'oxygène et a été suivie, 20-30 min après, par la VUL. On a mesuré la PaO₂ qui en a résulté. L'apnée a été ensuite induite selon les deux techniques de ventilation et le temps nécessaire à la diminution de chaque 1 % de saturation de l'hémoglobine, de 100 % à 95 % démontrée par l'oxymétrie pulsée, a été enregistrée. On a fait une comparaison intergroupe du temps de chaque baisse de 1 %.

Résultats : La valeur moyenne de la PaO₂ à la suite de la VBL (445 ± 99 mmHg) a été plus élevée que la PaO₂ moyenne qui a suivi la VUL (156 ± 18 mmHg). De plus, le temps moyen nécessaire à la désaturation subséquente de l'hémoglobine, induite par l'apnée, passant d'une SpO₂ de 100 % à 95 %, à la suite d'une VBL a été deux fois plus long que le temps de désaturation après la VUL (6,3 ± 1,2 min vs 3,2 ± 0,5 min, $P < 0,05$).

Conclusion : La désaturation de l'hémoglobine survient plus rapidement pendant l'apnée qui suit une VUL qu'une VBL. La désaturation rapide peut relever de la baisse de la CRF, associée à une augmentation du shunt transpulmonaire. Les résultats suggèrent que la ventilation bilatérale avec 100 % d'oxygène fournit une plus grande marge de sécurité que la ventilation unilatérale de même nature chaque fois que la ventilation est interrompue.

From the Department of Anesthesiology, American University of Beirut, Beirut, Lebanon.

Address correspondence to: Anis Baraka MD FRCA. Fax: 961-1744-464; E-mail: abaraka@aub.edu.lb

Accepted for publication October 7, 1999

ONE-LUNG ventilation (OLV) during thoracotomy or thoracoscopy creates an obligatory right-to-left, transpulmonary shunt through the non-ventilated lung, with a consequent increase in the alveolar-to-arterial oxygen tension gradient and decrease of the PaO_2 .¹ In addition, collapse of the non-ventilated lung decreases the functional residual capacity (FRC), which is the main oxygen store in the body.² The decrease of the available oxygen store during OLV may decrease the safety margin, with a consequent rapid hemoglobin desaturation whenever ventilation of the dependent lung is compromised or interrupted. The decreased safety margin during OLV may be predicted from the basic physiologic principles; however, quantification of its extent has never been reported.

The present report compares, in patients undergoing thoracotomy or thoracoscopy, the rate of hemoglobin desaturation when apnea was induced during one-lung ventilation *vs* two-lung ventilation. Each patient served as his/her own control.

Method

The study was approved by the institutional review board, and informed consent was obtained from each patient. Six patients undergoing thoracotomy or thoracoscopy were included in the study (Table I). Prior to induction of anesthesia, the preoperative baseline oxygen saturation (SpO_2) values breathing room air were 97-100%. Following induction of anesthesia with propofol, fentanyl, lidocaine and vecuronium, the trachea was intubated with a Robertshaw double-lumen tube. Anesthesia was then maintained with isoflurane

1-2% in oxygen 100%. The patients were monitored by ECG, noninvasive arterial blood pressure, end-tidal capnography and pulse oximetry.

Before surgery commenced, both lungs were ventilated for five minutes with a tidal volume of 10 ml·kg⁻¹, at a respiratory rate of 12 bpm, using isoflurane 1-2% in 10 L·min⁻¹ oxygen 100% delivered by a carbon dioxide absorption circuit. The anesthetic concentration was kept constant during the measurement periods. At the end of the five minutes, arterial oxygen tension (PaO_2) was measured by Radiometer ABL300, Acid-Base Laboratory (Copenhagen). The anesthesia circuit was subsequently disconnected from the double-lumen tube, and both lumens were then open to ambient air, while hemoglobin oxygen saturation (SpO_2) was continuously monitored by pulse oximetry (Hewlett Packard, SPO_2 /PLETH M1020A). Apnea was allowed until SpO_2 decreased to 95%; the times for every 1% decrease in the SpO_2 were recorded. As soon as the SpO_2 decreased to 95%, the double-lumen tube was reconnected to the anesthesia circuit, and the two lungs were ventilated.

After 20-30 min, ventilation of the non-dependent lung was stopped, the lumen of the double-lumen tube on this side was opened to room air. Following thoracotomy or thoracoscopy, collapse of the non-dependent lung was confirmed. The dependent lung was then ventilated with the same tidal volume and respiratory rate using isoflurane in 10 L·min⁻¹ oxygen 100% for five minutes, followed by arterial PO_2 analysis. The anesthesia circuit was subsequently disconnected from the double-lumen tube, and again apnea was allowed until SpO_2 decreased to 95%. The times

TABLE I

	Age	Weight	Surgical Procedure	Site of Surgery
Patient 1	78	84 kg	Right upper lobectomy (lung cancer)	Right lateral thoracotomy
Patient 2	30	57.5 kg	Excision of parasternal sarcoma	Left lateral thoracotomy
Patient 3	54	62 kg	Left upper lobectomy (lung cancer)	Left lateral thoracotomy
Patient 4	50	81 kg	Left upper lobectomy (lung cancer)	Left lateral thoracotomy
Patient 5	30	55 kg	Evacuation of left hydatid cyst	Left lateral thoracoscopy
Patient 6	35	60 kg	Evacuation of right hydatid cyst	Right lateral thoracoscopy

Age (yr), weight (kg), site of surgery and the surgical procedures of the six patients

TABLE II

SpO_2	99%	98%	97%	96%	95%
Two-Lung ventilation	5.1 ± 0.8	5.5 ± 0.9	5.8 ± 1.1	6.1 ± 1.1	6.3 ± 1.2
One-Lung ventilation	1.8 ± 0.7*	2.3 ± 0.4*	2.6 ± 0.3*	2.9 ± 0.4*	3.2 ± 0.5*

Time (min) to hemoglobin desaturation of 95% in the two-lung *vs* the one-lung ventilation technique.

* $P < 0.05$ Two-lung ventilation *vs* One-lung ventilation.

FIGURE A diagram comparing the mean time to apnea-induced hemoglobin desaturation from SpO_2 100% down to 95% following two-lung vs one-lung ventilation.

for every 1% decrease in SpO_2 were recorded. The mean times to reach SpO_2 of 99%, 98%, 97%, 96% and 95% during apnea following one-lung preoxygenation were compared with the corresponding values following two-lung preoxygenation.

Data are reported as mean $\pm$ standard deviation. The paired *t* test was used to compare the data obtained during OLV and TLV. Statistical significance was considered at $P < 0.05$.

Results

The mean initial PaO_2 value during two-lung ventilation with oxygen 100% was higher (445 ± 99 mmHg) than the mean PaO_2 during one lung ventilation (156 ± 18 mmHg).

The mean times from the onset of apnea until SpO_2 reached 95% are presented in Table II. The time for apnea-induced hemoglobin desaturation from 100% to 95% was longer ($P < 0.05$) during two-lung than one-lung ventilation (6.3 ± 1.2 min vs 3.2 ± 0.5 min). As shown in Figure, the difference in the rate of hemoglobin desaturation between the two ventilatory techniques was primarily due to the different desaturation time from an SpO_2 of 100% to 99% (TLV: 5.1 ± 0.8 min vs OLV: 1.8 ± 0.7 min, $P < 0.05$), while the hemoglobin desaturation time between 99% and 95% was not different (TLV: 1.2 ± 0.5 min vs OLV: 1.4 ± 0.6 min).

Discussion

The present report demonstrated in a group of patients undergoing thoracic surgery that two-lung ventilation with oxygen 100% results in higher PaO_2 values than that achieved by one-lung ventilation. Also, the rate of

hemoglobin desaturation during the subsequent apnea is slower following TLV than after OLV.

Breathing oxygen 100% causes a substantial increase in total oxygen stores.²⁻⁴ Most of the additional oxygen is accommodated in the alveolar gas in the FRC where 80% of it may be withdrawn without causing the PaO_2 to decrease below the normal value.² Beyond this point, the oxygen reserve becomes limited, and apnea or hypoventilation can result in rapid hemoglobin desaturation.⁵

Switching from two-lung to one-lung ventilation and collapse of the non-ventilated lung reduce the FRC, with a subsequent decrease of the oxygen store in the lung. The time of apnea-induced hemoglobin desaturation following one-lung ventilation with oxygen 100% is nearly half the time of desaturation following two-lung preoxygenation. Thus, the decrease in the time of desaturation may be attributed to the decrease of the oxygen store secondary to switching from two-lung to one-lung ventilation. The rate of hemoglobin desaturation may be further exaggerated by the associated shunt:⁵ OLV creates an obligatory right-to-left transpulmonary shunt.¹ Because of the hypoxic pulmonary vasoconstriction in the non-ventilated collapsed lung, the shunt through the non-ventilated lung is usually 20 to 30% of the cardiac output as opposed to the 40 to 50% shunt that might be expected.¹

The main difference in the rate of apnea-induced hemoglobin desaturation following OLV vs TLV is observed between 100% saturation and 99% saturation. This range of desaturation falls on the flat part of the hemoglobin dissociation curve, and may be attributed predominantly to the different oxygen stores in the FRC, as well as to the different PaO_2 levels provided by preoxygenation. When the oxygen reserve is depleted, hemoglobin desaturation is rapid following both techniques of ventilation.

In conclusion, two-lung ventilation with oxygen 100% provides a greater safety margin than one-lung ventilation with oxygen 100%, should a period of apnea occur. The rapid rate of apnea-induced hemoglobin desaturation during OLV may be attributed to the decreased oxygen store in the FRC, associated with an increased transpulmonary shunting.

References

- 1 Benumof JL. Physiology of one-lung ventilation. In: Benumof JL (Ed.). *Anesthesia for Thoracic Surgery*, 2nd ed. Philadelphia: W.B. Saunders Company, 1995: 131-2.
- 2 Nunn JF. Oxygen stores and the steady state. In: Nunn JF (Ed.). *Applied Respiratory Physiology*, 3rd ed. Cambridge: Butterworths & Co. Ltd., 1987: 271-3.

- 3 *Hamilton W, Eastwood D.* A study of denitrogenation with some inhalation anesthetic systems. *Anesthesiology* 1955; 16: 861–7.
- 4 *Berthoud M, Read DH, Norman J.* Preoxygenation - how long? *Anaesthesia* 1983; 38: 96–102.
- 5 *Farmery AD, Roe PG* A model to describe the rate of oxyhaemoglobin desaturation during apnoea. *Br J Anaesth* 1996; 76: 284–91.