Original Article

Effectiveness of Ventilation of Nondependent Lung for a Brief Period in Improving Arterial Oxygenation during One-lung Ventilation: A Prospective Study

Abstract

Background: Hypoxemia is common during one-lung ventilation(OLV), predominantly due to transpulmonary shunt. None of the strategies tried showed consistent results. We evaluated the effectiveness of ventilating the operated, non-dependent lung (NDL) with small tidal volumes in improving the oxygenation during OLV. **Methods:** 30 ASA 1 and 2 patients undergoing elective, open thoracotomy were studied. After standard induction of anesthesia, lung seperation was acheived with left sided DLT. The ventilatory settings for two lung ventilation (TLV) were: FiO_2 of 0.5, tidal volume of 8-10ml/kg and respiratory rate of 10-12/min. After initiating OLV, the dependent lung alone was ventilated with the above settings for 15 minutes and an arterial blood gas (ABG) analysis was done. Then the NDL was ventilated with a separate ventilator, with FiO_2 of 1, tidal volume of 70 ml, I:E ratio of 1:10 and respiratory rate of 6/min for 15 minutes. The NDL ventilation was started early if the patients desaturated to <95%. ABG was done at 5 and 15 mins of NDL ventilation. We compared the PaO_2 values. **Results:** The mean PaO_2 decreased from 232.2 ± 67.2 mm of Hg (TLV-ABG1) to 91.2 ± 31.7 mm of Hg on OLV (OLV-ABG1). The ABG after 5 minutes and 15 minutes after institution of NDL ventilation during OLV showed a PaO2 of 145.7 ± 50.2 mm of Hg and 170.6 ± 50.4 mm of Hg which were significantly higher compared to the one lung ventilation values.

Keywords: *Hypoxemia, nondependant lung ventilation, one lung ventilation*

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Introduction

One lung ventilation (OLV) using double lumen tube (DLT) is a standard procedure for lung resections. OLV carries a risk of hypoxemia irrespective of the ventilatory strategy used. On occasions, hypoxia may turn life-threatening, requiring the institution of ventilatory measures that will require immediate, temporary cessation of surgery. Hypoxemia during OLV is multifactorial, but transpulmonary shunt caused by the perfusion of the collapsed, nonventilated lung is the predominant cause.[1] Ventilatory manipulations of the nondependent lung (NDL) are employed with a view to reduce the shunt in patients who become hypoxemic on OLV. Continuous positive airway pressure (CPAP) and intermittent reinflation are the most frequently used ventilatory manipulations of the NDL, both of which require inflation of the NDL.[2] Intermittent inflation/deflation of the NDL with oxygen has been done manually during OLV with improvement in saturation.[3] The primary aim of our prospective clinical study is to evaluate the effect of intermittent positive pressure ventilation of the NDL with small tidal volumes during one-lung ventilation (OLV) on oxygenation. The secondary aim is to study the extent of interference of this ventilatory strategy with the surgical field.

Methods

The study was approved by the Institutional Ethics Committee and written; informed consent was obtained from all the patients participating in the study. The optimal sample size was determined by calculating the statistical power. Thirty patients provide a power of 80% to detect a one-tailed difference of 30 mmHg in PaO_2 during OLV with an α error of 5% based on an expected standard deviation of 25 mmHg.

Eligible patients for the study were patients under 70 years of age, American Society of Anesthesiologists physical status 1 or 2, scheduled for elective lobectomy of the

How to cite this article: Chigurupati K, Raman SP, Pappu UK, Madathipat U. Effectiveness of ventilation of nondependent lung for a brief period in improving arterial oxygenation during one-lung ventilation: A prospective study. Ann Card Anaesth 2017;20:72-5.

Received: September, 2016. **Accepted:** December, 2016.

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Access this article online

Website: www.annals.in

DOI: 10.4103/0971-9784.197840

Quick Response Code:

lung through thoracotomy and an expected OLV time of at least 60 min.

All patients received a standardized anesthetic protocol. Patients were premedicated with 5.0 mg oral diazepam on the day of surgery. In the operating room, a large-bore intravenous (IV) cannula and radial arterial line were inserted. Patients were preoxygenated with 100% oxygen, and anesthesia was induced with propofol 1.5–2 mg/kg, fentanyl 5–10 mcg/kg IV, sevoflurane 0.5–0.8 minimum alveolar concentration. Pancuronium was used to facilitate tracheal intubation with appropriate sized left-sided double lumen tube (Mallinckrodt, Covidien, Boulder, CO, USA). Following DLT placement, the correct position of the DLT was confirmed by clinical means and by fiberoptic bronchoscope both in the supine and lateral positions. For all patients, an epidural catheter was placed between the 5th and 7th thoracic epidural space and epidural analgesia was provided with 5 ml of a combination of 0.125% bupivacaine and fentanyl 2 mcg/ml. Anesthesia was maintained with sevoflurane and intermittent doses of fentanyl.

Immediately after tracheal intubation, the lungs were ventilated with air-oxygen mixture at an inspired oxygen fraction (FiO_2) of 0.5 with Aestiva 5, Datex-Ohmeda ventilator (GE Healthcare/Datex-Ohmeda, Madison, WI, USA). The initial settings for two lung ventilation (TLV) were as follows: Tidal volume of 8–10 ml/kg, I:E ratio of 1:2 and respiratory rate of 10–12/min, without positive end-expiratory pressure (PEEP), till isolation of the lung. A blood sample was taken to analyze the arterial blood gas (ABG) after 30 min after ventilating both the lungs with the above setting (TLV-ABG1).

All the patients were operated on in the lateral decubitus position. OLV was initiated at the time of thoracotomy. The dependent lung was ventilated with a tidal volume of 6–8 ml/kg, I:E ratio of 1:2, respiratory rate of 12–14/min with an unchanged FiO_2 of 0.5 with the Aestiva 5 ventilator. Following thoracotomy, the collapse of the NDL was confirmed visually. The DLT lumen of the NDL was kept opened to the atmosphere during OLV. After 15 min of OLV an ABG sample (OLV-ABG1) was collected and thereafter the NDL was ventilated with a separate, Maquet Servo-i ventilator (Maquet Critical Care, Solna, Sweden). The settings on this ventilator were as follows, pressure regulated volume control mode (PRVC), tidal volume 70 ml, respiratory rate 6/min with an inspiratory to expiratory ratio of 1:10 and FiO_2 of 1.0. No PEEP was applied to the NDL. If the patient desaturated after initiating OLV (pulse oximeter saturation <95%), the blood gas samples were collected quickly, and the study protocol of ventilating the NDL was started early (without waiting for 15 min of OLV).

ABG was analyzed at 5 min and 15 min after initiating the nondependant lung ventilation (OLV-ABG2 and OLV-ABG3, respectively). The time taken for the saturation to raise to above 95% was noted in cases which desaturated after initiating OLV. The surgeon was asked to grade the lung collapse during NDL ventilation. The assessment was made on a scale of 1–10 based on the ease of surgical dissection. Scale of 10 would imply that the surgeon finds the collapse of the lung to be perfect in spite of the NDL ventilation and score of 1 implied that the NDL ventilation was making any surgical dissection impossible.

The rescue strategy for hypoxia-resistant to the study protocol was as follows: Confirmation of the appropriate position of DLT by fiberoptic bronchoscope and suctioning the lumens of the DLT. The FiO_2 of the dependent lung was increased to 1.0, and intermittent reinflations were done to the NDL. These cases were recorded as study failure.

All patients were to be extubated in the operating room.

The significance of the difference between blood gas values drawn at different times was tested with paired *t*-test. $P < 0.05$ was considered statistically significant.

Results

Thirty consecutive patients were enrolled in this study. The patient demographics, details of anesthesia and surgery are presented in Table 1. There were 16 men and 14 women in the study. Pulmonary function tests were not available in all patients. None had any significant cardiac illness. Right-sided lobectomy was done in 20 patients and left side in 10. Left-sided DLT was placed in all the cases. Table 2 shows the blood gas results taken at different times. PaO_2 was significantly less on OLV in all patients compared to TLV ($P < 0.001$) with the PaO_2 decreasing from 232.2 ± 67.2 mm Hg (TLV-ABG1) to 91.2 ± 31.7 mmHg on OLV (OLV-ABG1). 17 patients (56%) had a fall in pulse oximeter saturation below 95% of whom 8 patients (26%) had saturation below 90%. All patients had improvement in pulse oximeter saturation within the 1st min after initiating

Table 1: Demographic and surgical data

Patients	30
Male	16
Female	14
Age (year)	44.6±15.2
Weight (Kgs)	56.2±8.8
Height (cms)	161.1±6.7
Indication for surgery	
Primary lung carcinoma	18
Metastatic lung carcinoma	2
Adenoma of lung	4
Aspergilloma	4
Bronchectomy	2
Right lobectomy	20
Left lobectomy	10
Left sided Double lumen tube	30
Surgery duration (mins)	190±54.2
Duration of One lung ventilation (mins)	127.1±42.5

Table 2: Intraoperative blood gas values (expressed as mean±standard deviation)

Parameter	TLV-ABG1	OLV-ABG1	OLV-ABG2	OLV-ABG3
pH	7.38±0.06	7.38±0.07	7.34±0.06	7.37±0.05
PaO_2 (mmHg)	232.2±67.2	91.2±31.7	145.7±50.2	170.6±50.4
$PaCO_2$ (mmHg)	40.2±7.42	40.2±7.87	44.9±7.9	40.7±6.47
Hemoglobin (g/dl)	12.6±2.3	12.2±1.6	12.07±1.6	11.9±1.5

TLV-ABG1: On two lung ventilation, OLV-ABG1: 15 min after initiation of OLV, OLV-ABG2: 5 min after ventilating the collapsed lung, OLV-ABG3: 15 min after ventilating the collapsed lung, OLV: One lung ventilation, TLV: Two lung ventilation, AGB: Arterial blood gas

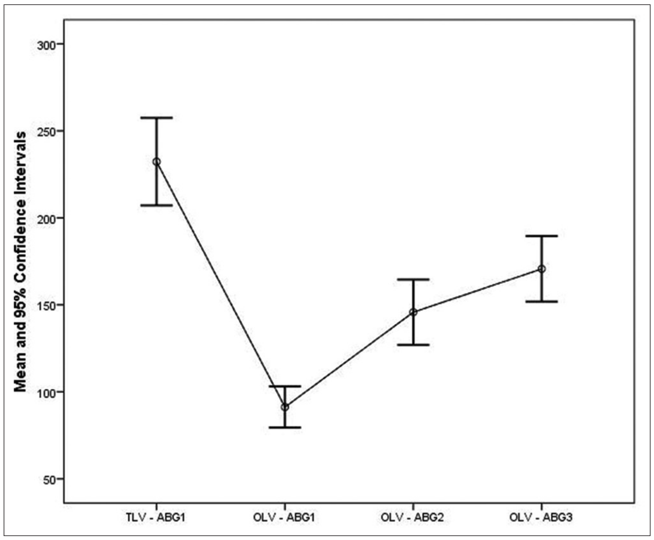

Figure 1: Graphical representation of PaO_2 at various stages of ventilation in mmHg

NDL ventilation. An average of 228 s was required for the saturation to improve above 95% in patients who desaturated during OLV. The average time to improvement in saturation was 260 s even in those who desaturated below 90%. The ABG after 5 min after the institution of NDL ventilation during OLV showed a PaO_2 of 145.7 ± 50.2 mmHg (OLV-ABG2) which was significantly higher ($P < 0.001$) than OLV-ABG1. The ABG after 15 min of NDL ventilation (OLV-ABG3) showed PaO_2 170.6 ± 50.4 and it was significantly better than OLV-ABG1 and OLV-ABG2 ($P < 0.001$) as shown in Figure 1. The mean peak pressure during NDL ventilation on PRVC mode was 10 cmH_2O. There were no significant changes in pH and $PaCO_2$. The surgeon satisfaction score was 10 in 28 patients and 8 in 2 patients, implying that the lung isolation was perfect and that the surgeon did not notice the NDL being ventilated.

Discussion

Hypoxemia is the most common problem encountered during OLV. Although all patients develop fall in PaO_2 during OLV, for many it may not progress to the extent of desaturation. Lung function cannot accurately predict the patients who may develop hypoxia during OLV. Patients with low forced expiratory volume at 1 s had better oxygenation during OLV than patients with normal lung function.[1] Perfusion to the diseased lung is another determinant of hypoxia during OLV. Thus, the individual patient's predilection to hypoxemia on OLV varies. This was the rationale for choosing patients as their own controls in our study.

Our study shows that a brief period of intermittent positive pressure ventilation of the NDL is effective in improving PaO_2 and saturation during OLV without interfering with the surgery. Continuing perfusion of the NDL while it is collapsed for OLV leads to shunt and hypoxemia. Russel reasons that the oxygen deficit due to the shunt during OLV is "quite modest." We have calculated the presumed oxygen deficit of patients in our study using the reasoning employed by Russel.[3] Our patients had a mean hemoglobin of 12 gm/dl. Assuming a cardiac output of 5 L/min and 100% saturation, the oxygen delivery (DO_2) is about 830 ml/min. If the patient desaturates to 85%, then the oxygen deficit will be about 120 ml/min. The ventilatory settings used for NDL in this trial, with tidal volume of 70 ml and ventilatory rate of 6/min at a FiO_2 of 1.0 would supply oxygen of about 420 ml/min, easily correcting this oxygen deficit.

The NDL was ventilated in PRVC mode,[4] a pressure controlled mode designed to provide the set target tidal volume at the lowest peak pressure. In none of the patients, the peak pressure during NDL exceeded 10 cmH_2O. The I:E ratio of 1:10 meant that the inflation period would be just less than a second with 9 s provided for each deflation. Ventilation of the NDL with 100% oxygen removes nitrogen in the NDL and allows for absorption atelectasis and a better collapse of the lung. This ensured that the ventilation of the NDL remained at a level that was not detectable by the surgeon and did not interfere with the surgical dissection.

Hypoxia during OLV may not progressively deteriorate and may, in fact, show some spontaneous improvement with time.[5] However, in the interest of patient safety, for patients who desaturate during OLV, remedial measures for treatment of hypoxemia are always indicated.

The continued ventilation of the NDL is not required for the entire duration of OLV for the treatment of hypoxia. In none of our patients, the saturation fell to <95% even after the discontinuation of NDL ventilation. Complete alveolar collapse, following cessation of NDL ventilation, can increase the vascular resistance of the lung and cause a decrease in the shunt, thus maintaining the oxygen saturation for a longer period. Besides, it is also known that hypoxic pulmonary vasoconstriction is potentiated by repeated lung collapse.[6]

Variety of ventilatory manipulations of NDL has been employed to decrease the shunt and improve the oxygen saturation during OLV. Russel employed intermittent, timed occlusion of a Pall BB25 Ultipor filter connected to an oxygen source attached to the NDL to provide oxygenation of the collapsed lung. His technique involved occlusion of this filter for 2 s and release for 8 s.[2] This technique requires manual control of the filter and care must be taken not to occlude the filter for too long otherwise the pressure from the oxygen source will lead to re-expansion of the collapsed lung. Using a separate ventilator for NDL ventilation, as we did in this study, provides for better control of the I:E ratio, oxygen pressure and volume of oxygen. CPAP of 2–5 cmH_2O has been found beneficial for improving hypoxia during OLV.[7] CPAP is effective only when it is instituted after inflation of the lung to 30 cmH_2O for 15 s. However, use of CPAP may interfere with surgical exposure and may not be effective in improving oxygenation in all patients. Ku *et al*. used selective segmental insufflation of oxygen into the nonoperated lobe of the NDL through a fiberoptic bronchoscope and found that it improved oxygen saturation. However, their method has not undergone trials to prove its effectiveness.[8] Simple insufflation of oxygen without CPAP is seldom sufficient to reliably improve PaO_2.[9] Intermittent re-expansion of the NDL is effective in improving saturation but has the disadvantage of impending surgery.[1] Use of PEEP to the dependent lung has been advocated as a means for improving dependent lung ventilation. However, not all patients benefit from PEEP, and some may even have worsening of the PaO_2. Understanding which patients benefit from PEEP requires an understanding of the individual patients lower inflection point on the static compliance curve. Patients likely to have improved PaO_2 with PEEP are those who have low-end expiratory pressure to begin with and application of PEEP elevates the end expiratory pressure to the lower inflection point. Clearly, the calculation of static compliance curve would be too cumbersome in every patient.[10]

The suitability of our technique to thoracoscopic surgery is yet to be tested.

Conclusion

Intermittent positive pressure ventilation of the NDL with small tidal volume is a simple and inexpensive technique which effectively minimizes the intrapulmonary shunt, reliably improving the PaO_2 without impeding surgical access. This can serve as an effective strategy to combat the problem of hypoxemia during OLV.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Karzai W, Schwarzkopf K. Hypoxemia during one-lung ventilation: Prediction, prevention, and treatment. Anesthesiology 2009;110:1402-11.
2. Yasuuji M, Kusunoki S, Hamada H, Kawamoto M. Intermittent reinflation is safe to maintain oxygenation without alteration of extravascular lung water during one-lung ventilation. J Clin Anesth 2014;26:177-83.
3. Russell WJ. Intermittent positive airway pressure to manage hypoxia during one-lung anaesthesia. Anaesth Intensive Care 2009;37:432-4.
4. Guldager H, Nielsen SL, Carl P, Soerensen MB. A comparison of volume control and pressure-regulated volume control ventilation in acute respiratory failure. Crit Care 1997;1:75-77.
5. Ishikawa S. Oxygenation may improve with time during one-lung ventilation. Anesth Analg 1999;89:258-9.
6. Pirlo AF, Benumof JL, Trousdale FR. Potentiation of lobar hypoxic pulmonary vasoconstriction by intermittent hypoxia in dogs. Anesthesiology 1981;55:226-30.
7. Hogue CW Jr. Effectiveness of low levels of nonventilated lung continuous positive airway pressure in improving arterial oxygenation during one-lung ventilation. Anesth Analg 1994;79:364-7.
8. 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.
9. Slimani J, Russell WJ, Jurisevic C. An evaluation of the relative efficacy of an open airway, an oxygen reservoir and continuous positive airway pressure 5 cmH2O on the non-ventilated lung. Anaesth Intensive Care 2004;32:756-60.
10. Slinger PD, Kruger M, McRae K, Winton T. Relation of the static compliance curve and positive end-expiratory pressure to oxygenation during one-lung ventilation. Anesthesiology 2001;95:1096-102.