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Comparative Evaluation of One-Lung Versus Two-Lung Ventilation on Arterial Blood Gas Parameters, Surgical Exposure, and Postoperative Inflammatory Response in Patients Undergoing Thoracoscopic (VATS) Esophagectomy.

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Abstract

Background: Video-assisted thoracoscopic esophagectomy (VATS) is widely used for the management of esophageal cancer due to reduced surgical trauma and improved recovery. However, the optimal ventilation strategy during the thoracic phase remains controversial. One-lung ventilation (OLV) provides excellent surgical exposure but is associated with hypoxemia and ventilation–perfusion mismatch. Two-lung ventilation (TLV) with artificial pneumothorax has emerged as an alternative approach. ***Aim:*** To comparatively evaluate the effects of one-lung ventilation and two-lung ventilation on arterial blood gas parameters, surgical exposure, and postoperative inflammatory response in patients undergoing VATS esophagectomy. ***Methods:*** This prospective observational study included 82 patients undergoing VATS esophagectomy, divided into two groups: OLV (n = 41) and TLV (n = 41). Intraoperative arterial blood gas parameters (PaO_2, $PaCO_2$, and P/F ratio) were recorded. Surgical exposure was assessed intraoperatively, and postoperative inflammatory markers including temperature, heart rate, total leukocyte count, and C-reactive protein were evaluated. Statistical analysis was performed using appropriate parametric and non-parametric tests, with $p < 0.05$ considered significant. ***Results:*** The TLV group demonstrated significantly higher PaO_2 and P/F ratios compared to the OLV group ($p < 0.001$), indicating better oxygenation. $PaCO_2$ levels were significantly higher in the OLV group ($p < 0.001$). Surgical exposure was comparable between the two groups ($p > 0.05$). Postoperative inflammatory markers, including temperature, heart rate, TLC, and CRP, were significantly higher in the TLV group ($p < 0.05$). ***Conclusion:*** Although associated with increased postoperative inflammatory response, TLV remains a safe and effective alternative ventilation strategy in VATS esophagectomy.

Keywords: One-lung ventilation. Two-lung ventilation. VATS esophagectomy.

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INTRODUCTION

Esophageal cancer is a significant global health problem and remains one of the leading causes of cancer-related mortality worldwide. Surgical resection, particularly esophagectomy, continues to be the cornerstone of curative treatment in patients with resectable disease. Despite advancements in surgical techniques and perioperative care, esophagectomy is still associated with considerable morbidity, with postoperative pulmonary complications being one of the most common and serious concerns affecting patient recovery and outcomes. The evolution of minimally invasive surgical approaches, especially video-assisted thoracoscopic surgery (VATS), has transformed the management of esophageal cancer by reducing surgical trauma, improving postoperative recovery, and shortening hospital stay.[1]

However, VATS esophagectomy presents unique anesthetic and physiological challenges. One of the most critical intraoperative considerations is the choice of ventilation strategy during the thoracic phase of surgery. Lung isolation is typically achieved using a double-lumen endotracheal tube or bronchial blocker. Although OLV facilitates optimal visualization, it leads to significant alterations in respiratory physiology, including ventilation–perfusion mismatch, increased intrapulmonary shunt, and reduced arterial oxygenation due to continued perfusion of the non-ventilated lung. Additionally, OLV has been associated with mechanical stress, alveolar injury, and inflammatory responses, which may contribute to postoperative pulmonary complications.[2]

In recent years, two-lung ventilation (TLV) with artificial carbon dioxide pneumothorax has emerged as a promising alternative to OLV during VATS esophagectomy. This technique allows continuous ventilation of both lungs while maintaining adequate surgical exposure through controlled lung compression induced by pneumothorax. TLV may help preserve more physiological ventilation–perfusion relationships, improve oxygenation, and potentially reduce lung injury. Furthermore, studies have demonstrated that TLV provides stable respiratory mechanics, maintains adequate gas exchange, and offers comparable surgical exposure, especially when combined with prone positioning.[3]

Apart from intraoperative oxygenation, the postoperative inflammatory response plays a crucial role in determining patient outcomes. Surgical trauma, lung manipulation, and ventilation strategies significantly influence systemic inflammatory markers such as C-reactive protein (CRP) and total leukocyte count. Increased inflammatory response has been linked with higher rates of complications and delayed recovery. Therefore, identifying a ventilation strategy that optimizes oxygenation while minimizing inflammatory response is of clinical importance.

AIM

To comparatively evaluate the effects of one-lung ventilation and two-lung ventilation on arterial blood gas parameters, surgical exposure, and postoperative inflammatory response in patients undergoing VATS esophagectomy.

OBJECTIVES

1. To compare intraoperative arterial blood gas parameters (PaO_2, $PaCO_2$, and P/F ratio) between OLV and TLV groups.
2. To evaluate the adequacy of surgical exposure in both ventilation strategies.
3. To assess postoperative inflammatory response using clinical and laboratory parameters.

MATERIALS AND METHODS

Source of Data

The data for the present study were collected from patients undergoing video-assisted thoracoscopic esophagectomy at a tertiary care teaching hospital. Clinical, intraoperative, and laboratory data were obtained from patient records, anesthesia charts, and hospital laboratory reports.

Study Design

The study was designed as a prospective observational comparative study.

Study Location

The study was conducted in the Department of Anaesthesiology in collaboration with the Department of Surgical Oncology at a tertiary care center.

Study Duration

The study was carried out over a period of 18–24 months, including patient recruitment, intraoperative monitoring, postoperative follow-up, and data analysis.

Sample Size

A total of 82 patients were included in the study:

- OLV Group = 41 patients
- TLV Group = 41 patients

Inclusion Criteria

- Patients aged ≥18 years
- Patients undergoing elective VATS esophagectomy
- ASA physical status I–III
- Patients who provided informed written consent

Exclusion Criteria

- Patients with severe pulmonary disease (e.g., COPD, restrictive lung disease)
- Patients with significant cardiac comorbidities
- Patients requiring emergency surgery
- Patients with incomplete data
- Patients who refused consent

Procedure and Methodology

After obtaining informed consent, all patients underwent preoperative evaluation including history, clinical examination, and relevant investigations. Patients were allocated into two groups based on the ventilation strategy used intraoperatively:

- OLV Group: Lung isolation was achieved using bronchial blocker.
- TLV Group: Patients were ventilated using a single-lumen tube with both lungs ventilated, and surgical exposure was achieved using CO_2 pneumothorax.

All thoracoscopic procedures were performed in the PRONE POSITION during the thoracic phase of VATS esophagectomy. In the TLV group, artificial CO_2 pneumothorax in prone position was used to facilitate surgical exposure while maintaining two-lung ventilation.

Standard general anesthesia protocols were followed in all patients. Intraoperative monitoring included ECG, pulse oximetry, invasive arterial blood pressure, and capnography. Arterial blood gas (ABG) analysis was performed at predefined intervals to measure PaO_2, $PaCO_2$, and calculate the P/F ratio. Surgical exposure was assessed by the operating surgeon using a standardized grading system.

Postoperatively, patients were monitored for inflammatory response parameters such as body temperature, heart rate, total leukocyte count, and C-reactive protein levels.

Sample Processing

Arterial blood samples were collected intraoperatively under aseptic conditions and analyzed immediately using an automated blood gas analyzer. Postoperative blood samples for inflammatory markers were processed in the central laboratory using standard biochemical methods.

Statistical Methods

Data were entered into Microsoft Excel and analyzed using statistical software (SPSS version 28.0).

- Continuous variables were expressed as mean ± standard deviation
- Categorical variables were expressed as frequency and percentage
- Independent t-test was used for comparison of continuous variables
- Chi-square test was used for categorical variables
- A p-value <0.05 was considered statistically significant

Data Collection

Data were collected using a structured proforma that included:

- Demographic details (age, gender, BMI)
- Preoperative clinical parameters
- Intraoperative ABG values (PaO_2, $PaCO_2$, P/F ratio)
- Surgical exposure grading
- Postoperative inflammatory parameters

All data were recorded systematically and verified for accuracy before analysis.

RESULTS

TABLE 1: Baseline Characteristics

Variable	OLV (n=41) Mean±SD / n(%)	TLV (n=41) Mean±SD / n(%)	Test	95% CI (Mean Diff)	p-value
Age (years)	56.8 ± 9.4	55.9 ± 8.8	t = 0.43	-2.8 to 4.6	0.66
Gender (Male)	29 (70.7%)	27 (65.9%)	χ^2 = 0.21		0.64
BMI (kg/m²)	23.7 ± 3.1	24.1 ± 2.8	t = -0.61	-1.7 to 0.9	0.54
FEV1 (%)	82.5 ± 6.8	83.1 ± 7.2	t = -0.37	-3.6 to 2.4	0.71
ASA II (%)	25 (61.0%)	24 (58.5%)	χ^2 = 0.05		0.82

The baseline characteristics of patients in the OLV and TLV groups were comparable. The mean age in the OLV group was 56.8 ± 9.4 years, while in the TLV group it was 55.9 ± 8.8 years, with no statistically significant difference (p = 0.66). The proportion of male patients was similar between the groups, with 70.7% in the OLV group and 65.9% in the TLV group (p = 0.64). The mean BMI was 23.7 ± 3.1 kg/m² in the OLV group and 24.1 ± 2.8 kg/m² in the TLV group, which was also not statistically significant (p = 0.54). Pulmonary function as assessed by FEV1 (%) showed comparable values

(82.5 ± 6.8 vs. 83.1 ± 7.2; p = 0.71). Similarly, the distribution of ASA II status was nearly equal in both groups (61.0% vs. 58.5%; p = 0.82).

TABLE 2: Intraoperative ABG Parameters

Parameter	OLV Mean±SD	TLV Mean±SD	Test	95% CI (Mean Diff)	p-value
PaO_2 (mmHg)	158.4 ± 22.6	186.7 ± 24.8	t = -5.26	-39.4 to -17.2	**<0.001***
$PaCO_2$ (mmHg)	46.2 ± 5.3	41.8 ± 4.9	t = 3.87	2.1 to 6.5	**<0.001***
P/F Ratio	296.5 ± 38.2	348.9 ± 42.5	t = -5.89	-69.5 to -34.1	**<0.001***

The comparison of intraoperative arterial blood gas parameters revealed significant differences between the two groups. The mean PaO_2 was significantly higher in the TLV group (186.7 ± 24.8 mmHg) compared to the OLV group (158.4 ± 22.6 mmHg), indicating better oxygenation with TLV ($p < 0.001$). The P/F ratio was also significantly higher in the TLV group (348.9 ± 42.5) than in the OLV group (296.5 ± 38.2), further confirming improved oxygenation status ($p < 0.001$). In contrast, the mean $PaCO_2$ was significantly higher in the OLV group (46.2 ± 5.3 mmHg) compared to the TLV group (41.8 ± 4.9 mmHg), suggesting relatively higher carbon dioxide retention during one-lung ventilation ($p < 0.001$).

TABLE 3: Surgical Exposure Comparison

Surgical Exposure Grade	OLV n (%)	TLV n (%)	Test	95% CI (OR)	p-value
Excellent	32 (78.0%)	30 (73.2%)	$\chi^2 = 0.28$	0.45–2.21	0.59
Adequate	9 (22.0%)	11 (26.8%)			

The adequacy of surgical exposure was comparable between the two groups. Excellent surgical exposure was achieved in 78.0% of patients in the OLV group and 73.2% in the TLV group, while adequate exposure was noted in 22.0% and 26.8% of patients, respectively. The difference between the groups was not statistically significant ($\chi^2 = 0.28$, $p = 0.59$).

TABLE 4: Postoperative Inflammatory Response

Parameter	OLV Mean±SD	TLV Mean±SD	Test	95% CI (Mean Diff)	p-value
Temperature (°C)	37.6 ± 0.4	38.1 ± 0.5	t = -5.01	-0.7 to -0.3	**<0.001***
Heart Rate (bpm)	88.4 ± 8.2	94.7 ± 9.1	t = -3.29	-10.1 to -2.3	**0.002***
TLC ($\times 10^3/\mu L$)	10.8 ± 2.1	13.4 ± 2.5	t = -5.09	-3.6 to -1.6	**<0.001***
CRP (mg/L)	38.5 ± 8.7	52.3 ± 10.4	t = -6.52	-18.0 to -9.6	**<0.001***

Postoperative inflammatory parameters showed significant differences between the two groups. The mean postoperative temperature was significantly higher in the TLV group (38.1 ± 0.5°C) compared to the OLV group (37.6 ± 0.4°C) ($p < 0.001$). Similarly, the mean heart rate was higher in the TLV group (94.7 ± 9.1 bpm) than in the OLV group (88.4 ± 8.2 bpm), which was statistically significant ($p = 0.002$). Laboratory markers also demonstrated elevated inflammatory response in the TLV group, with higher total leukocyte count (13.4 ± 2.5 vs. 10.8 ± 2.1 $\times 10^3/\mu L$; $p < 0.001$) and CRP levels (52.3 ± 10.4 vs. 38.5 ± 8.7 mg/L; $p < 0.001$).

DISCUSSION

In the present study, baseline variables were comparable between OLV and TLV groups. Mean age, gender distribution, BMI, FEV1 and ASA II status showed no statistically significant difference, indicating that both groups were well matched before comparison. This is important because differences in oxygenation, surgical exposure and inflammatory response can therefore be more confidently attributed to the ventilation strategy rather than baseline patient characteristics. Similar baseline comparability was reported by Daghmouri MA et al. (2022)[1] and Akimoto M et al. (2025)[2], who also compared TLV with artificial pneumothorax against conventional OLV in thoracoscopic esophagectomy and found no major baseline imbalance between study groups.

Intraoperative ABG parameters showed significantly better oxygenation in the TLV group. Mean PaO_2 was higher in TLV than OLV (186.7 ± 24.8 vs. 158.4 ± 22.6 mmHg, $p<0.001$), and the P/F ratio was also significantly higher in TLV (348.9 ± 42.5 vs. 296.5 ± 38.2, $p<0.001$). These findings support the physiological advantage of ventilating both lungs during VATS esophagectomy. In OLV, collapse of the one lung produces ventilation–perfusion mismatch and intrapulmonary shunt, leading to lower oxygenation. During one-lung ventilation, Hypoxic Pulmonary Vasoconstriction (HPV) acts as an important physiological protective mechanism that diverts blood flow away from the non-ventilated hypoxic lung toward the ventilated lung, thereby reducing intrapulmonary shunting and helping maintain arterial oxygenation. However, HPV is often incomplete and may be influenced by anesthetic agents, patient positioning, carbon dioxide levels, and surgical manipulation. As a result, significant ventilation–perfusion mismatch and hypoxemia may still occur during OLV despite

the compensatory HPV response. In contrast, TLV preserves ventilation in both lungs and minimizes dependence on HPV for maintenance of oxygenation. Benumof JL.(1985)[18]

Mohammed SO et al. (2024)[3] similarly reported better intraoperative oxygenation and oxygen saturation in patients receiving TLV with artificial pneumothorax. Deng HY et al. (2022)[4] also found TLV with CO_2 pneumothorax feasible and safe in minimally invasive McKeown esophagectomy. Furthermore, Nomura S et al. (2020)[5] emphasized that OLV can cause hypoxemia and ventilator-induced lung injury, while TLV with artificial pneumothorax is increasingly used in minimally invasive esophagectomy.

In the present study, $PaCO_2$ was significantly higher in the OLV group than the TLV group (46.2 ± 5.3 vs. 41.8 ± 4.9 mmHg, $p<0.001$). This may be due to reduced ventilated lung volume and altered respiratory mechanics during OLV. Although mild hypercapnia may also occur during CO_2 pneumothorax, controlled TLV can maintain more stable ventilation when insufflation pressure is carefully regulated. Yang Y et al. (2024)[6] reported that ventilatory strategies influence gas exchange significantly during thoracoscopic procedures, including effects on $PaCO_2$ and shunt fraction. Additionally, Lianyong J et al. (2024)[7] further supported that TLV-based approaches can be safely applied without compromising intraoperative respiratory stability.

Surgical exposure was comparable between the groups, with excellent exposure in 78.0% of OLV patients and 73.2% of TLV patients, and no significant difference ($p=0.59$). This suggests that TLV with artificial pneumothorax did not compromise the operative field. Coppola S et al. (2025)[8] similarly observed that surgical exposure was adequate in both TLV and OLV groups, with no increase in perioperative morbidity. Schittek HT et al. (2025)[9] & Gao J et al. (2025)[10] also reported that single-lumen tube ventilation with artificial pneumothorax provided adequate surgical exposure without increasing intraoperative or postoperative complications. Furthermore, Li MY et al. (2020)[11], Solanki RN et al. (2025)[12] & Otsubo D et al. (2017)[13] showed that different lung isolation and ventilatory techniques produce comparable lung collapse and surgical exposure, supporting the concept that satisfactory exposure can be achieved using different ventilation approaches.

Postoperative inflammatory response was significantly higher in the TLV group in the present study, with higher temperature, heart rate, TLC and CRP levels. This finding may reflect the effect of surgical stress, CO_2 pneumothorax, operative manipulation, or perioperative inflammatory activation rather than ventilation strategy alone. Yatabe T et al. (2013)[14] & Dapri G et al. (2008)[15] demonstrated that intraoperative ventilatory strategies influence postoperative inflammatory and physiological responses. Additionally, Tanigawa Y et al. (2021)[16] & Cai L et al. (2017)[17] highlighted that artificial pneumothorax can affect operative and physiological parameters, including inflammatory response.

CONCLUSION

The present study demonstrated that two-lung ventilation (TLV) with artificial pneumothorax provides significantly better intraoperative oxygenation compared to conventional one-lung ventilation (OLV), as evidenced by higher PaO_2 and P/F ratios. In contrast, OLV was associated with relatively higher $PaCO_2$ levels, indicating altered gas exchange dynamics during single lung ventilation. Despite these physiological differences, both ventilation strategies offered comparable surgical exposure, confirming that TLV does not compromise operative field visibility during thoracoscopic esophagectomy.

However, postoperative inflammatory markers, including temperature, heart rate, total leukocyte count, and C-reactive protein levels, were significantly higher in the TLV group. This suggests a heightened inflammatory response, possibly related to CO_2 pneumothorax and surgical stress, although no immediate adverse clinical outcomes were observed.

Overall, TLV appears to be a safe and effective alternative to OLV in VATS esophagectomy, offering superior oxygenation and adequate surgical exposure. Its use may be particularly beneficial in patients at risk of hypoxemia during OLV. Nevertheless, the clinical significance of the increased inflammatory response requires further evaluation through larger studies.

LIMITATIONS OF THE STUDY

1. The study had a relatively small sample size (n = 82), which may limit generalizability.
2. It was a single-center study, reducing external validity across different clinical settings.
3. The observational design may introduce selection bias.
4. Randomization was not performed, which may affect internal validity.
5. Long-term postoperative outcomes and complications were not assessed.
6. Inflammatory markers were limited to routine parameters (CRP, TLC) without cytokine profiling.

7. Effects of different anesthetic agents on outcomes were not separately analyzed.
8. Variability in surgical technique and surgeon experience was not controlled.
9. Duration and pressure of CO_2 pneumothorax were not standardized for all patients.
10. Postoperative pulmonary complications were not extensively evaluated.

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