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RESEARCH ARTICLE

Comparison of intraoperative oxygenation and perioperative outcomes between thoracoscopic and open thoracic surgery during one-lung ventilation

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Abstract

Objective: To compare intraoperative oxygenation and early perioperative outcomes between patients undergoing thoracoscopic and open thoracic surgery with one-lung ventilation, using peripheral oxygen saturation 30 minutes after initiation of one-lung ventilation as the primary outcome.

Methods: In this single-center retrospective study, 42 adults undergoing elective thoracic surgery with one-lung ventilation in 2025 were classified according to the planned surgical approach as thoracotomy (n = 29) or thoracoscopy (n = 13). Three converted procedures remained in the thoracoscopy group. Secondary outcomes included intraoperative PaO_2/FiO_2 ratio, calculated shunt fraction, hypoxemia, ventilatory settings, one-lung ventilation duration, postoperative gas exchange, duration of postoperative mechanical ventilation, and intensive care unit stay. Secondary analyses were considered exploratory.

Results: Baseline characteristics were similar, whereas major thoracic procedures were more frequent in the thoracotomy group (58.6% vs. 15.4%, p = 0.017). During one-lung ventilation, peripheral oxygen saturation was higher in the thoracoscopy group (98% [IQR 94–100] vs. 90% [IQR 89–95], p = 0.011; Hodges–Lehmann estimate 5 percentage points, bootstrap 95% CI 1–8). One-lung ventilation lasted longer in the thoracotomy group (130 [IQR 115–180] vs. 60 [IQR 50–140] minutes, p = 0.038; Hodges–Lehmann estimate 50 minutes, bootstrap 95% CI 0–80). Other intraoperative and early outcomes were similar.

Conclusions: For the primary outcome, thoracoscopy was associated with higher peripheral oxygen saturation during one-lung ventilation. Among exploratory secondary outcomes, open thoracotomy was associated with longer one-lung ventilation. The imbalance in procedural complexity and attenuation of the saturation difference after exclusion of conversions indicate that these associations should not be interpreted as causal.

Keywords: thoracoscopy, thoracotomy, one-lung ventilation, intraoperative oxygenation, perioperative outcomes

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Introduction

Thoracotomy remains an established surgical approach for the diagnosis and treatment of thoracic diseases. However, the incision and rib spreading required for open surgery may cause substantial chest-wall trauma and are associated with postoperative pain and pulmonary, pleural, and cardiovascular complications. Postoperative pulmonary complications, including atelectasis, pneumonia, respiratory failure, and acute respiratory distress syndrome, are important contributors to morbidity after thoracic surgery (1–5).

Video-assisted thoracoscopic surgery (VATS) is a minimally invasive alternative to open thoracotomy. By reducing the extent of the incision and chest-wall trauma, thoracoscopic surgery may be associated with less postoperative pain, fewer wound complications, and shorter recovery and hospital stay in appropriately selected patients (1,2,6–11).

Both approaches frequently require one-lung ventilation (OLV) to provide surgical exposure and isolate the operative lung. Lung separation is usually achieved with a double-lumen endotracheal tube or a bronchial blocker (1,10,12).

During OLV, perfusion of the non-ventilated lung creates an intrapulmonary shunt and may reduce arterial oxygenation. Hypoxic pulmonary vasoconstriction partly limits this effect by diverting blood flow toward the ventilated lung. At the same time, the dependent lung is exposed to increased mechanical stress and may be vulnerable to ventilator-induced lung injury (1,4,12).

Consequently, OLV requires a balance between adequate oxygenation and lung protection. Relevant complications include hypoxemia, volutrauma, barotrauma, atelectrauma, hyperoxia-related injury, and inflammatory lung injury. Placement of a double-lumen tube may also cause airway trauma or malposition (4,5,12,13).

Although thoracoscopic and open procedures differ in surgical invasiveness, both are performed under the physiological constraints of OLV. Evidence directly comparing

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intraoperative oxygenation and ventilatory requirements according to the surgical approach remains limited and may be influenced by differences in patient selection and procedural complexity.

The primary objective of this study was to compare peripheral oxygen saturation measured 30 minutes after initiation of one-lung ventilation between patients undergoing thoracoscopic and open thoracic surgery. Secondary objectives were to compare other intraoperative oxygenation indices, ventilatory parameters, duration of one-lung ventilation, postoperative gas exchange, and early perioperative outcomes.

Methods

We conducted a retrospective, single-center observational study at the Târgu Mureș Emergency County Clinical Hospital. Adult patients who underwent elective thoracic surgery with OLV between January and December 2025 were considered for inclusion. The study was approved by the Institutional Ethics Committee under decision No. Ad. 3880/16.03.2026 and was conducted in accordance with the Declaration of Helsinki. All participants had provided written informed consent for the use of their medical data and biological samples for scientific purposes.

Patients were classified into two groups according to the initially planned surgical approach:

- the open thoracotomy group (n = 29);
- the thoracoscopic surgery group (n = 13).

Three procedures initially planned as thoracoscopic required conversion to thoracotomy. These patients were retained in the thoracoscopy group according to the initially planned approach. Patients were excluded when the surgical approach or key intraoperative outcome variables could not be determined, when major intraoperative hemodynamic instability precluded the planned monitoring protocol, or when surgery was performed as an emergency procedure. Variables with sporadic missing values were analyzed using available cases.

Clinical, anesthetic, ventilatory, and laboratory data were collected retrospectively from medical records, anesthesia charts, and laboratory reports.

The primary outcome was peripheral oxygen saturation (SpO_2) recorded at the standardized intraoperative assessment 30 minutes after initiation of one-lung ventilation. Secondary outcomes were intraoperative hypoxemia, PaO_2/FiO_2 ratio, calculated shunt fraction (Qs/Qt), FiO_2, PEEP, peak inspiratory pressure, tidal volume, tidal volume normalized to predicted body weight, $PaCO_2$, duration of one-lung ventilation, total surgical time, postoperative PaO_2/FiO_2 ratio and Qs/Qt, duration of postoperative mechanical ventilation, and intensive care unit length of stay. Because this was a retrospective study, secondary outcomes were interpreted as exploratory.

The analyzed variables were grouped as follows:

- preoperative and procedural variables: age, sex, body mass index, ASA physical status, peripheral oxygen saturation, procedure category, and conversion from thoracoscopy to thoracotomy;
- oxygenation variables: arterial blood gas samples obtained 30 minutes after initiation of one-lung ventilation were used for intraoperative gas-exchange assessment. The PaO_2/FiO_2 ratio was calculated as arterial oxygen partial pressure divided by the inspired oxygen fraction at sampling. Peripheral oxygen saturation at the same assessment point, calculated shunt fraction (Qs/Qt), postoperative PaO_2/FiO_2 ratio, and postoperative Qs/Qt were analyzed. Hypoxemia was defined as $SpO_2 < 90\%$ at the intraoperative assessment point;
- intraoperative ventilatory variables: fraction of inspired oxygen (FiO_2), positive end-expiratory pressure (PEEP), peak inspiratory pressure (Ppeak), tidal volume (VT), VT normalized to predicted body weight (VT/PBW), and arterial partial pressure of carbon dioxide ($PaCO_2$). Predicted body weight was calculated as $50 + 0.91 \times$ (height in cm – 152.4) for men and $45.5 + 0.91 \times$ (height in cm – 152.4) for women;
- early perioperative outcomes: duration of one-lung ventilation, total surgical time, duration of postoperative mechanical ventilation, and intensive care unit length of stay.

All patients underwent general anesthesia with lung isolation and one-lung ventilation according to the institutional thoracic anesthesia protocol. Lung isolation was achieved with a double-lumen endotracheal tube, and correct positioning was confirmed by fiberoptic bronchoscopy. During OLV, protective ventilation was applied with a tidal volume of 6 mL/kg of predicted body weight and a positive end-expiratory pressure of 5 cmH_2O. FiO_2 was adjusted according to oxygenation status, targeting an SpO_2 of 92–94% whenever possible. The available retrospective records did not consistently specify a single mandatory ventilation mode or whether recruitment maneuvers were performed; these aspects were determined by the attending anesthesiologist according to the clinical situation and could not be analyzed systematically. When impaired oxygenation was suspected, double-lumen tube position was reassessed bronchoscopically as clinically indicated.

Statistical analyses were performed using SPSS IBM V.23 for Windows. Data distribution was assessed using the Shapiro–Wilk test. Continuous variables were summarized as mean ± standard deviation when approximately normally distributed and as median with interquartile range otherwise. Between-group comparisons were performed using the Student t-test or Mann–Whitney U test, as appropriate. Sex, major procedure frequency, and hypoxemia frequency were compared using Fisher's exact test, and the distribution of ASA physical status was compared using the Fisher–Freeman–Halton exact test. Major procedures were defined as anatomical pulmonary resection (lobectomy, bilobectomy, or pneumonectomy) or esophagectomy. For the primary outcome and the exploratory OLV-duration comparison, effect sizes were expressed as Hodges–Lehmann location-shift estimates with bootstrap 95% confidence intervals based on 50,000 resamples. A sensitivity analysis excluded the three procedures converted from thoracoscopy to thoracotomy. Analyses were based on available cases for variables with missing observations. Statistical significance was set at $p < 0.05$ for the primary comparison. No formal correction for multiple comparisons was applied; therefore, p-values for secondary outcomes were interpreted as hypothesis-generating.

Results

The study included 42 patients: 29 in the thoracotomy group and 13 in the thoracoscopic surgery group. Three of the 13 procedures initially planned as thoracoscopic required conversion to thoracotomy (23.1%). No statistically significant differences were detected in age, sex distribution, body mass index, ASA physical status, or preoperative peripheral oxygen saturation. Major thoracic procedures were more frequent in the thoracotomy group than in the thoracoscopy group (17/29 [58.6%] vs. 2/13 [15.4%], p = 0.017) (Table I). Body mass index and preoperative SpO_2 were available for 12 of the 13 patients in the thoracoscopy group and for all 29 patients in the thoracotomy group.

During OLV, peripheral oxygen saturation was higher in the thoracoscopy group than in the thoracotomy group (median 98% [IQR 94–100] vs. 90% [IQR 89–95], p = 0.011). The Hodges–Lehmann location-shift estimate was 5 percentage points (bootstrap 95% CI 1–8). Hypoxemia at the intraoperative assessment point occurred in 1/13 patients (7.7%) in the thoracoscopy group and 10/29 patients (34.5%) in the thoracotomy group (p = 0.127). Intraoperative PaO_2/FiO_2 ratio and calculated Qs/Qt did not differ significantly. Postoperative PaO_2/FiO_2 ratio and Qs/Qt were also similar between groups (Table II). Postoperative oxygenation data were available for 11 patients in the thoracoscopy group and 27 patients in the thoracotomy group.

The recorded intraoperative ventilatory variables did not differ significantly between groups. FiO_2, PEEP, peak inspiratory pressure, absolute tidal volume, VT/PBW, and $PaCO_2$ were comparable between the thoracoscopic and thoracotomy groups (Table III).

Table I. Baseline characteristics of study groups

Parameter	Thoracoscopy (n = 13)	Thoracotomy (n = 29)	p-value
Age (years), median [IQR]	59 [50–67]	66 [56–69]	0.327
Female sex, n (%)	7 (53.8)	10 (34.5)	0.314
BMI (kg/m^2), median [IQR]	24.0 [21.5–27.4]	24.7 [23.0–27.7]	0.465
ASA II/III/IV, n	5/6/2	11/15/3	0.900
Preoperative SpO_2 (%), median [IQR]	99 [98.8–100]	100 [98–100]	1.000
Major thoracic procedure, n (%)	2 (15.4)	17 (58.6)	0.017

Data are median [IQR] or n (%). IQR = interquartile range; BMI = body mass index; ASA = American Society of Anesthesiologists physical status; SpO_2 = peripheral oxygen saturation.

Table II. Baseline characteristics of study groups

Parameter	Thoracoscopy (n = 13)	Thoracotomy (n = 29)	p-value
SpO_2 during OLV (%), median [IQR]	98 [94–100]	90 [89–95]	0.011
SpO_2 < 90% during OLV, n (%)	1 (7.7)	10 (34.5)	0.127
Intraoperative PaO_2/FiO_2 ratio, median [IQR]	138 [92–190]	100 [71–164]	0.265
Intraoperative Qs/Qt (%), median [IQR]	35.0 [29.7–41.8]	39.7 [30.7–47.3]	0.456
Postoperative PaO_2/FiO_2 ratio, median [IQR]	319 [232.5–366]	305 [189.5–384]	0.699
Postoperative Qs/Qt (%), median [IQR]	22.2 [14.6–24.7]	22.1 [14.6–26.3]	0.872

Data are median [IQR] or n (%). Intraoperative Qs/Qt was available for 12 patients in the thoracoscopy group and 27 in the thoracotomy group. OLV = one-lung ventilation; SpO_2 = peripheral oxygen saturation; PaO_2 = arterial partial pressure of oxygen; FiO_2 = fraction of inspired oxygen; Qs/Qt = calculated shunt fraction.

Table III. Intraoperative ventilatory variables

Parameter	Thoracoscopy (n = 13)	Thoracotomy (n = 29)	p-value
FiO_2 (%), median [IQR]	100 [95–100]	100 [100–100]	0.489
PEEP (cmH_2O), median [IQR]	5 [5–5]	5 [5–6]	0.095
Ppeak (cmH_2O), mean ± SD	22.00 ± 5.53	20.31 ± 6.30	0.445
VT (mL), mean ± SD	329.09 ± 62.36	336.92 ± 62.97	0.731
VT/PBW (mL/kg), median [IQR]	5.90 [5.23–6.35]	5.48 [4.50–6.10]	0.427
$PaCO_2$ (mmHg), mean ± SD	46.34 ± 8.10	50.20 ± 12.15	0.303

PEEP was available for 11 patients in the thoracoscopy group and 27 in the thoracotomy group; Ppeak and absolute VT were available for 11 and 26 patients, respectively. VT/PBW was available for 10 and 26 patients, respectively. IQR = interquartile range; SD = standard deviation; FiO_2 = fraction of inspired oxygen; PEEP = positive end-expiratory pressure; Ppeak = peak inspiratory pressure; VT = tidal volume; PBW = predicted body weight; $PaCO_2$ = arterial partial pressure of carbon dioxide.

The duration of one-lung ventilation was longer in the thoracotomy group than in the thoracoscopy group (median 130 [IQR 115–180] vs. 60 [IQR 50–140] minutes, p = 0.038). The Hodges–Lehmann location-shift estimate was 50 minutes (bootstrap 95% CI 0–80). Total surgical time, duration of postoperative mechanical ventilation, and intensive care unit length of stay were numerically greater after thoracotomy, but the differences were not statistically significant (Table IV).

Table IV. Early perioperative outcomes

Parameter	Thoracoscopy (n = 13)	Thoracotomy (n = 29)	p-value
Duration of OLV (minutes), median [IQR]	60 [50–140]	130 [115–180]	0.038
Total surgical time (minutes), median [IQR]	110 [80–170]	180 [130–200]	0.108
Postoperative mechanical ventilation (minutes), median [IQR]	60 [52.5–150]	120 [60–200]	0.280
ICU length of stay (days), median [IQR]	1 [1–1]	1 [1–1]	0.192

Postoperative mechanical ventilation duration was available for 10 patients in the thoracoscopy group and 25 in the thoracotomy group. ICU length of stay was available for 13 and 23 patients, respectively. OLV = one-lung ventilation; ICU = intensive care unit; IQR = interquartile range.

Discussions

The principal finding for the primary outcome was that patients in the thoracoscopy group maintained a higher peripheral oxygen saturation 30 minutes after initiation of one-lung ventilation. Among the exploratory secondary outcomes, open thoracotomy was associated with a longer duration of one-lung ventilation. Major thoracic procedures were substantially more frequent in the thoracotomy group, indicating an important imbalance in procedural complexity. In the sensitivity analysis excluding conversions, the difference in OLV duration remained statistically significant, whereas the saturation difference was attenuated and no longer statistically significant. No significant differences were detected in the other evaluated intraoperative oxygenation indices, postoperative oxygenation variables, ventilatory settings, or early perioperative outcomes. Because multiple secondary comparisons were performed without formal multiplicity adjustment, these findings should be considered hypothesis-generating.

One-lung ventilation produces ventilation–perfusion mismatch through continued perfusion of the non-ventilated lung, while hypoxic pulmonary vasoconstriction diverts part of the pulmonary blood flow toward the dependent ventilated lung. Surgical compression, lateral positioning, anesthetic effects, and atelectasis in the dependent lung further modify this physiology (1,12). In the present cohort, median SpO_2 during one-lung ventilation was higher in the thoracoscopy group, and the Hodges–Lehmann estimate suggested a 5-percentage-point location shift. Hypoxemia, defined as $SpO_2 < 90\%$ at the standardized intraoperative assessment point, was numerically less frequent after thoracoscopy, although this difference was not statistically significant. The PaO_2/FiO_2 ratio and calculated shunt fraction did not differ significantly between approaches. Peripheral pulse oximetry and arterial blood gas variables assess related but non-identical aspects of oxygenation, and SpO_2 values may be influenced by signal quality, peripheral perfusion, and the plateau of the oxyhemoglobin dissociation curve. The loss of statistical significance for SpO_2 after exclusion of converted procedures further supports cautious interpretation of this finding.

Both groups received high inspired oxygen fractions at the standardized assessment point, with median FiO_2 values close to 1.0. Under the institutional protocol, FiO_2 was titrated according to oxygenation status, with a target SpO_2 of 92–94% whenever possible. The high recorded FiO_2 values therefore suggest that many patients required substantial inspired oxygen to maintain the oxygenation target during OLV. Although this strategy prioritizes avoidance of hypoxemia, high FiO_2 may promote absorption atelectasis and oxidative lung injury, and it may also reduce the ability to identify oxygenation differences attributable to the surgical approach (1,14 – 16).

Absolute tidal volume was similar between groups. When normalized to predicted body weight, median VT/PBW was 5.90 mL/kg in the thoracoscopy group and 5.48 mL/kg in the thoracotomy group, with a median PEEP of approximately 5 cmH_2O in both groups. These settings are consistent with contemporary low-tidal-volume OLV strategies. In a 2025 three-arm randomized trial, Min et al. reported that VT 6 mL/kg PBW with PEEP 5 cmH_2O was associated with better early postoperative oxygenation and fewer immediate pulmonary complications than VT 4 or 8 mL/kg PBW (13). The 2200-patient PROTHOR trial subsequently found that fixed PEEP 10 cmH_2O with recruitment maneuvers did not reduce postoperative pulmonary complications compared with PEEP 5 cmH_2O without routine recruitment; the higher-PEEP strategy caused more hypotension and arrhythmias, although it reduced the need for hypoxemia rescue maneuvers (15). A recent meta-analysis likewise suggested that individualized PEEP may improve oxygenation and compliance without a definitive reduction in overall postoperative pulmonary complications (16). Together, these data favor physiologically individualized ventilation rather than routine escalation of PEEP or recruitment maneuvers for all patients.

Mean $PaCO_2$ exceeded 45 mmHg in both groups, particularly in the thoracotomy group. Mild to moderate permissive hypercapnia may occur during lung-protective OLV and can enhance hypoxic pulmonary vasoconstriction; however, its clinical effect depends on the degree of hypercapnia and the patient's cardiopulmonary status

(1,12,13). Carbon dioxide insufflation during selected thoracoscopic procedures may also increase $PaCO_2$ (17).

Peak inspiratory pressure was not significantly different between groups. Interpretation is limited because plateau pressure, respiratory-system compliance, and driving pressure were not available. These variables are increasingly emphasized in protective OLV because they describe the mechanical load applied to the ventilated lung more accurately than peak pressure alone (1,15,16).

The longer duration of OLV in the thoracotomy group should not be attributed solely to the surgical approach. Major thoracic procedures were significantly more frequent in this group, and OLV time is closely related to the type and complexity of the procedure, extent of resection, intraoperative findings, and surgical workflow. The Hodges–Lehmann estimate suggested a 50-minute location shift toward longer one-lung ventilation with thoracotomy, but the lower confidence limit was close to zero. Furthermore, three procedures initially planned as thoracoscopic were converted to thoracotomy and remained in the thoracoscopy group for the primary analysis. Excluding these conversions did not materially change the direction of the duration finding, but procedural heterogeneity and confounding remain important.

Postoperative PaO_2/FiO_2 ratio and calculated Qs/Qt were similar between groups. These findings suggest that the observed difference in peripheral saturation during OLV was not accompanied by a detectable between-group difference in early postoperative gas exchange. Nevertheless, postoperative measurements were unavailable for several patients, and the timing of postoperative arterial blood gas sampling was not standardized.

Total surgical time, postoperative mechanical ventilation duration, and intensive care unit stay were numerically greater in the thoracotomy group but did not differ significantly. Contemporary minimally invasive thoracic surgery pathways generally report reduced tissue trauma, pain, and recovery time after VATS, although outcomes remain strongly dependent on procedure type, case selection, conversion, analgesia, extubation practice, and institutional pathways (1,8,9,18). Recent thoracic anesthesia research has also evaluated non-intubated VATS, with a 2025 meta-analysis reporting shorter recovery-related intervals in selected patients; however, those findings are not directly applicable to our cohort, in which all patients underwent intubated OLV with a double-lumen tube (19). The absence of a significant difference in ICU stay in the present study therefore should not be interpreted as evidence of equivalent recovery between surgical approaches, given the small sample, procedural heterogeneity, and missing postoperative observations.

Limitations

This study has several limitations. Its retrospective, single-center design introduces risks of selection bias, information bias, and unmeasured confounding. The sample was small and the groups were unequal, reducing statistical power and the precision of the estimates. Procedural complexity differed substantially between groups, and the available dataset did not support multivariable adjustment for this imbalance. Three thoracoscopic procedures required conversion to thoracotomy but were analyzed according to the initial approach. Although a primary outcome was identified to clarify interpretation, the study was not prospectively registered and multiple secondary comparisons were performed without formal multiplicity correction; secondary findings should therefore be considered exploratory. Some baseline, ventilatory, and postoperative oxygenation variables were missing and were analyzed using available cases. Intraoperative arterial blood gas assessment was standardized at 30 minutes after initiation of one-lung ventilation, but the timing of postoperative arterial blood gas sampling was not standardized. The core OLV protocol specified a tidal volume of 6 mL/kg predicted body weight, PEEP of 5 cmH_2O, and FiO_2 titration toward an SpO_2 of 92–94%; however, ventilation mode and the use, frequency, and technique of recruitment maneuvers were not consistently documented, limiting full reproducibility. The duration of exposure to individual FiO_2 levels was also unavailable. VT/PBW could not be calculated for all patients because of missing height or tidal-volume data, while plateau pressure, respiratory-system compliance, and driving pressure were unavailable. Finally, the study did not evaluate postoperative pulmonary complications or longer-term clinical outcomes.

Conclusion

Thoracoscopy was associated with higher SpO_2 at 30 minutes of OLV, whereas open thoracotomy was associated with longer OLV duration; no significant between-group differences were observed for the other evaluated outcomes.

Authors' contributions

GR (Formal analysis; Writing – original draft; Writing – review & editing)
IB (Data curation; Visualization; Formal analysis)
IS (Data curation; Validation; Resources)
RȘF (Conceptualization, Methodology, Resources, Writing – review & editing; Supervision; Validation)

Conflict of interest

There are no conflicts of interest to declare.

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