Risk Factors for the Development of Intraoperative Hypoxia in Patients Undergoing Nonintubated Video-Assisted Thoracic Surgery: A Retrospective Study from a Single Center

AE 1 Lan Lan
BD 1 Yanyi Cen
BF 2,3 Long Jiang
C 4 Huazhang Miao
B 2,3 Weixiang Lu

Corresponding Author: Lan Lan, e-mail: lanlan@gzhmu.edu.cn
Source of support: Departmental sources

Background: Nonintubated video-assisted thoracic surgery (NIVATS) has been demonstrated to be safe and effective in patients. However, the risk factors for intraoperative hypoxia are unclear. This retrospective study aimed to identify the risk factors for the development of intraoperative hypoxia in patients undergoing NIVATS.

Material/Methods: The study included patients who underwent NIVATS between January 2011 and December 2018. Intraoperative hypoxia was defined as $\text{SpO}_2 \leq 93\%$. Risk factors for hypoxia were identified by binary logistic regression analysis, and the characteristic distribution of patients with and without hypoxia was elaborated.

Results: Of 2742 included patients, age, anesthesia method, the technical level of surgeons, stair-climbing ability, and type of thoracic procedure were associated with intraoperative hypoxia ($P<0.05$). The characteristics of patients with hypoxia were older age ($P=0.011$), higher body mass index and revised cardiac risk index level ($P=0.033$ and $P=0.031$), and lower composition of stair-climbing $\geq 22$ m ($P<0.001$). These patients also had more anatomical lung surgery and mediastinal mass resection ($P=0.033$) and more epidural anesthesia ($P=0.005$). The surgeries were more likely to be performed by surgeons with less than 10 years of VATS training ($P=0.009$) and to have increased intraoperative maximum end-expiratory carbon dioxide partial pressure ($P<0.001$) and postoperative hospitalization ($P=0.003$).

Conclusions: The current study suggests that old age and stair-climbing ability of patients, anesthesia method, thoracic procedures, and surgeon experience are risk factors for intraoperative hypoxia in patients undergoing NIVATS.

Keywords: Risk Factors • Hypoxia, Brain • Intraoperative Complications • Thoracic Surgery, Video-Assisted

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/928965
Background

The successful debut of nonintubated video-assisted thoracic surgery (NIVATS) for wedge resection under thoracoscopy was first reported in 1997 [1]. With the enhancement of surgical instruments and advances in minimally invasive thorascopic techniques, NIVATS has been widely adapted for different types of thoracic procedures [2,3], including lobectomy [4], bullectomy [5], lung volume reduction surgery [6], and tracheal reconstruction [7], and it has even been used with a uniportal approach [8].

NIVATS is reported to shorten surgery time and hospital stay [9,10] and to enhance rehabilitation by having fewer complications [2-5,11]. The perioperative surgical outcomes of NIVATS for lobectomy have been confirmed to be comparable to those of the intubated technique [12-14]. These benefits may be due to NIVATS minimizing the adverse effects of intubation-induced airway trauma, ventilation-related lung injury, and residual muscle relaxation [3]. Use of NIVATS may also reduce postoperative nausea and vomiting and decrease the stress hormones and proinflammatory mediators related to mechanical ventilation [15]. Furthermore, patients may benefit from the low risk of intrapulmonary shunt due to the efficient contraction of the dependent hemidiaphragm and preserved hypoxic pulmonary vasoconstriction in spontaneous ventilation [16].

However, the perioperative risk factors for hypoxia in NIVATS are unclear. NIVATS requires spontaneous breathing of 1 lung and the iatrogenic pneumothorax-induced collapse of the other lung to facilitate the operation, which tends to bring about intraoperative hypoxia and hypercapnia. Severe intraoperative hypoxia can jeopardize tissue oxygenation and hemodynamic stability [17-19] and may increase the incidence of postoperative complications [20,21]. Moreover, patients may have to transfer to endotracheal intubation when the hypoxia cannot be corrected in NIVATS. Therefore, it is important to identify the preoperative risk factors for intraoperative hypoxia to exclude high-risk patients and to permit early and timely intervention in others. However, many medical centers fail to do so due to their cases being scarce.

This retrospective study aimed to identify the risk factors for the development of intraoperative hypoxia in patients who underwent NIVATS between 2011 and 2018, and it compared patients’ perioperative characteristics with nonhypoxia and hypoxia events.

Material and Methods

A large single-center retrospective cohort was conducted with a post hoc reanalysis. Exposures and outcomes were defined a priori. This study was reviewed and approved by the Medical Ethics Committee of the First Affiliated Hospital of Guangzhou Medical University (No. K-51; Guangzhou, China) on November 5, 2019. Patient consent was waived due to the study’s retrospective design. The study included adult patients who underwent NIVATS between January 1, 2011, and December 30, 2018, at the Guangzhou Institute of Respiratory Diseases. All data were obtained from medical electronic records, anesthesia record sheets, and the hospital examination system. Patients were excluded if they were <18 years old and if they underwent thoracic surgery under endotracheal intubation anesthesia. Patients were also excluded if they underwent simultaneous operations on organs other than the lungs, proceeded to thoracotomy and tracheal tumor resection under NIVATS, or had intraoperative conversion to endotracheal intubation due to bleeding, pleural adhesions, or other nonhypoxia factors. Patients were also excluded if intraoperative values were missing or postoperative medical records were incomplete. All perioperative data were collected.

Anesthesia Procedure

All patients received thoracoscopic surgery with nonintubated anesthesia under the 3-portal approach as described previously [22,23]. Some patients received a target-controlled infusion of propofol 2-4 μg/mL and remifentanil 1-3 ng/mL and intravenous dexmedetomidine 0.5-1 μg/kg/h. A bispectral index value between 40 and 60 was maintained. Laryngeal mask airway (LMA) was placed when patients became unconscious, and end-expiratory carbon dioxide partial pressure ($P_{ET}\text{CO}_2$) was continuously monitored via capnography. The other patients received epidural anesthesia by placing an epidural catheter into the T5-T6 or T6-T7 epidural space, and anesthesia was maintained with 0.375% ropivacaine with the anesthesia plane titrated to between the 2nd and 10th ribs. All patients received standard monitoring, but $P_{ET}\text{CO}_2$ was not monitored in patients who received epidural anesthesia. Arterial catheterization was used for arterial pressure monitoring and to examine arterial blood gas analysis when $\text{SpO}_2 \leq 93\%$, while central venous catheterization was dependent on the conditions of operation and patients.

The gas flow was inhaled at 4-5 L/min with $\text{FiO}_2$ of 100% during the operation. Synchronous intermittent mandatory ventilation was implemented after the main procedures were completed to exhale carbon dioxide. The main procedures were defined as the removal of the lung lesion, lymph node dissection, and pleural lavage. Dopamine or norepinephrine was used to maintain mean arterial pressure >60 mmHg. Patients were transferred to the Postanesthesia Care Unit to remove the LMA or epidural catheter after the operation. Self-controlled intravenous analgesia was used for all patients after the operation. After that, patients were sent to the Intensive Care Unit or General Ward according to their conditions.
Surgical Procedure

The thoracoscopic procedures followed the consensus guidelines of the American Association for Thoracic Surgery [24]. Skin local anesthesia was performed with 2% lidocaine. After the pleura opening, the surface of the visceral pleura was sprayed with 5 mL of 2% lidocaine, and the intercostal nerve and left vagus nerve were infiltrated with 2.5 mL of 2% lidocaine and 2.5 mL of 0.75% ropivacaine under direct vision for inhibition of pain and the coughing reflex. Lung collapse was achieved through iatrogenic pneumothorax. The patient’s condition and surgical procedures determined whether a chest tube would be placed. All thoracic procedures were classified into 5 types: nonanatomical lung surgery, including wedge resection, bullectomy, and lung volume reduction surgery; anatomical lung surgery, including lobectomy and segmentectomy; mediastinal mass resection; bilateral sympathectomy, and other surgery, including thoracoscopic exploration, lung biopsy, pericardial cyst resection, and so forth.

The surgery time was the interval from skin incision to surgical dressing covering. Blood testing was done before the operation and on the first day after the operation. Postoperative clinical complications, including pleural effusion, dyspnea, air leakage, and reoperation, were recorded.

Outcome Definition

Due to the respiratory volume reduction and rebreathing effect in NIVATS [25], the primary concern is the intraoperative hypoxia values. Since \( \text{SpO}_2 \) reacts to hypoxia quickly and effectively, we chose continuous monitoring of SpO\(_2\) as the main observation indicator instead of intermittent monitoring of PaO\(_2\). An intraoperative SpO\(_2\) \( \leq 93\% \) lasting for 5 min was taken as evidence of hypoxia [26]. Manual assisted ventilation or synchronous intermittent mandatory ventilation was initiated when SpO\(_2\) \( \leq 90\% \). The intraoperative SpO\(_2\) was continuously monitored and recorded in the anesthesia record sheet.

Statistical Analysis

Statistical analyses were performed with SPSS software (version 26.0, Chicago, IL, USA). Continuous variables are presented as means \pm standard deviation or as median (interquartile range). Dichotomous variables are presented as percentages of the total number of data points available for that field. The variables for different patients with and without hypoxia were analyzed by an independent-samples t test for continuous variables and the Mann-Whitney U test for dichotomous variables. Preoperative values with a \( P \) value \( <0.05 \) were included in the logistic regression analysis. The variables evaluated for inclusion in the logistic regression analysis were age, body mass index (BMI), revised cardiac risk index (RCRI), stair-climbing ability, types of thoracic procedure, technique level of surgeons, anesthesia method, preoperative values of leukocytes and neutrophils. Binary logistic regression analysis was used to determine the risk factors of the preoperative variables with intraoperative hypoxia. A propensity score-matching analysis was used to counterbalance the discrepancies between the nonhypoxia and hypoxia groups to further analyze whether hypoxia affected the intraoperative outcomes and postoperative recovery. The propensity score model development was done by including age, BMI, RCRI, stair-climbing ability, types of thoracic procedure, technique level of surgeons, anesthesia method, and preoperative values of leukocytes and neutrophils. A \( P \) value of \( <0.05 \) indicated statistical significance.

Results

A total of 2742 patients who underwent thoracic surgery between 2011 and 2018 met the inclusion criteria (Figure 1), with 2497 patients in the nonhypoxia group and 245 patients in the hypoxia group. Two comparable patient groups (n=240 for each group) were identified by using propensity score-matching analysis to counterbalance the discrepancies (Tables 1-3). No patient was converted to endotracheal intubation due to hypoxia.

Risk Factors of Intraoperative Hypoxia

Logistic regression analysis showed that age, anesthesia method, technical level of surgeons, stair-climbing ability, and types of thoracic procedures were the risk factors for intraoperative hypoxia (\( P<0.05 \)). Moreover, the technical level of surgeons with VATS training \( \leq 5 \) years (\( P=0.029 \)) and the thoracic types of nonanatomical and anatomical lung surgery were risk factors for intraoperative hypoxia (\( P=0.015 \), and \( P=0.002 \) (Table 4).

Preoperative Characteristics of Patients with and without Hypoxia

Further analysis revealed that patients with intraoperative hypoxia were older and a higher proportion were over 60 years (47.32 vs 44.48 years, \( P=0.011 \) and 27% vs 22%, \( P=0.046 \)), and they had higher BMI (21.99 vs 21.55 kg/m\(^2\), \( P=0.033 \)), a higher level of RCRI (\( P=0.031 \)), and a higher proportion of stair-climbing ability \( <22 \) m (4 vs 1%, \( P=0.001 \)). These patients were also more likely to have undergone anatomical lung surgery and mediastinal mass resection (29% vs 25% and 11% vs 7%, \( P=0.033 \)) and to have received epidural anesthesia (29% vs 21%, \( P=0.005 \)), and fewer of the surgeons had VATS training \( \geq 10 \) years (52% vs 63%, \( P=0.009 \) (Table 1).
Thoracic surgery under tracheal Intubated anesthesia
Age <18 years old; Simultaneous operations on organs besides lungs; Thoracotomy, esophagus surgery, and tracheal surgery under NIVATS; Conversion to intubation due to non-hypoxia factors
Invalid or unavailable intraoperative values
Incomplete postoperative medical records (including clinical complications and chest radiography)

Jan 1, 2011 to Dec 30, 2018
18742 cases of thoracic surgery
3350 cases of Non-intubated thoracic surgery
3023 cases of Non-intubated thoracic surgery
2988 cases of Non-intubated thoracic surgery
2742 cases of non-intubated thoracic surgery

Table 1. Preoperative characteristics of patients with or without hypoxia.

| Variables                        | Before matching | After matching |
|----------------------------------|-----------------|---------------|
|                                  | Nonhypoxia (n=2497) | Hypoxia (n=245) | P value | Nonhypoxia (n=240) | Hypoxia (n=240) | P value |
| Age, y                           | 44.48±16.71     | 47.32±16.68   | 0.011    | 46.24±17.46     | 47.02±16.62   | 0.619    |
| Age, n (%)                       | 0.046           | 0.883         |
| 18-44 y                          | 1149 (46)       | 101 (41)      |          | 105 (43)        | 100 (42)      |          |
| 45-59 y                          | 810 (32)        | 78 (32)       |          | 69 (29)         | 78 (32)       |          |
| 60-74 y                          | 497 (20)        | 59 (24)       |          | 60 (25)         | 55 (23)       |          |
| ≥75 y                            | 41 (2)          | 7 (3)         |          | 6 (3)           | 7 (3)         |          |
| Sex, n (%)                       | 0.435           | 0.310         |
| Male                             | 1444 (58)       | 148 (60)      |          | 133 (55)        | 144 (60)      |          |
| Female                           | 1053 (42)       | 97 (40)       |          | 107 (45)        | 96 (40)       |          |
| BMI, kg/m²                       | 21.55±3.02      | 21.99±3.09    | 0.033    | 21.85±3.08      | 21.95±3.08    | 0.213    |
| ASA physical status, n (%)       | 0.140           | 0.331         |
| I                                | 1984 (80)       | 185 (76)      |          | 193 (80)        | 184 (77)      |          |
| II                               | 470 (19)        | 54 (22)       |          | 41 (17)         | 50 (21)       |          |
| III                              | 43 (2)          | 6 (2)         |          | 6 (3)           | 6 (2)         |          |
| Smoking history                  | 450 (18)        | 37 (15)       | 0.254    | 41 (17)         | 36 (15)       | 0.534    |
| Cardiovascular disease           | 187 (8)         | 23 (9)        | 0.286    | 20 (8)          | 22 (9)        | 0.747    |
| Diabetes                         | 79 (3)          | 7 (3)         | 0.793    | 11 (5)          | 5 (2)         | 0.127    |
| Pulmonary operation history      | 73 (3)          | 7 (3)         | 0.953    | 3 (1)           | 7 (3)         | 0.202    |
| Pulmonary disease                | 129 (5)         | 14 (6)        | 0.713    | 12 (5)          | 12 (5)        | 1.000    |
| Hepatic dysfunction              | 33 (1)          | 5 (2)         | 0.358    | 6 (3)           | 5 (2)         | 0.761    |

Figure 1. Flow chart of data collection. NIVATS, nonintubated video-assisted thoracic surgery.
Table 1 continued. Preoperative characteristics of patients with or without hypoxia.

| Variables                                      | Before matching | After matching | P value | Before matching | After matching | P value |
|------------------------------------------------|-----------------|----------------|---------|-----------------|----------------|---------|
| Neurologic diseases                            | Nonhypoxia      | Hypoxia        | 0.569   | Nonhypoxia      | Hypoxia        | 0.254   |
|                                                | (n=2497)        | (n=245)        |         | (n=240)        | (n=240)        |         |
| Nonpulmonary cancer                            | 39 (2)          | 5 (2)          |         | 2 (1)           | 5 (2)          |         |
| RCRI, n (%)                                     | 0.031           | 0.031          |         | 0.031           | 0.031          |         |
| 1 point                                         | 2479 (99)       | 240 (98)       |         | 236 (98)       | 237 (99)       |         |
| 2 points                                        | 18 (1)          | 5 (2)          |         | 4 (2)           | 3 (1)          |         |
| Stair climbing                                  | <0.001          | <0.001         |         | 0.001           | 0.001          |         |
| ≥22 m                                           | 2473 (99)       | 235 (96)       |         | 240 (100)      | 230 (96)       |         |
| <22 m                                           | 24 (1)          | 10 (4)         |         | 4 (2)           | 10 (4)         |         |
| LVEF, n (%)                                     | 71.02±5.35      | 71.44±7.15     | 0.292   | 71.08±5.14      | 71.48±7.14     | 0.511   |
| Pulmonary function tests, n (%)                 | 92.90±18.47     | 92.04±18.70    | 0.555   | 92.99±19.39     | 94.02±18.21    | 0.616   |
| FEV₁/FVC% predicted                             | 95.31±18.37     | 93.63±18.41    | 0.245   | 92.99±19.39     | 94.02±18.21    | 0.616   |
| Types of thoracic procedure, n (%)              | 96.88±11.72     | 97.90±11.72    | 0.272   | 96.88±12.30     | 98.08±11.38    | 0.354   |
| Nonanatomical lung surgery                      | 1482 (59)       | 127 (52)       |         | 131 (54)       | 126 (53)       |         |
| Anatomical lung surgery                         | 615 (25)        | 70 (29)        |         | 54 (22)         | 63 (28)        |         |
| Mediastinal mass resection                      | 174 (7)         | 27 (11)        |         | 23 (10)        | 27 (11)        |         |
| Bilateral sympathectomy                         | 81 (3)          | 9 (4)          |         | 23 (10)        | 10 (4)         |         |
| Other surgery                                   | 145 (6)         | 12 (5)         |         | 9 (4)           | 9 (4)          |         |
| Surgical location, n (%)                        | 0.241           | 0.540          |         | 0.801           | 0.819          |         |
| Left lung                                       | 1042 (42)       | 85 (35)        |         | 90 (37)        | 83 (34)        |         |
| Right lung                                      | 1086 (44)       | 132 (54)       |         | 108 (45)       | 130 (54)       |         |
| Mediastinum                                     | 340 (14)        | 24 (10)        |         | 42 (18)        | 22 (10)        |         |
| Left and right lung                             | 29 (1)          | 4 (2)          |         | 0              | 4 (2)          |         |
| Anesthesia methods, n (%)                       | 0.005           | 0.009          |         | 0.540           | 0.819          |         |
| TCI+LMA                                         | 1975 (79)       | 175 (71)       |         | 177 (74)       | 171 (71)       |         |
| EA                                              | 522 (21)        | 70 (29)        |         | 63 (26)        | 69 (29)        |         |
| Technical level of surgeons, n (%)              | 0.009           | 0.009          |         | 0.819           | 0.819          |         |
| VATS training ≤5 y                              | 355 (14)        | 31 (13)        |         | 49 (20)        | 30 (12)        |         |
| VATS training ≥10 y                             | 559 (22)        | 42 (18)        |         | 42 (18)        | 22 (10)        |         |
| Technical level of anesthetists, n (%)          | 0.203           | 0.203          |         | 0.505           | 0.505          |         |
| Attendings                                      | 2082 (83)       | 212 (87)       |         | 192 (80)       | 208 (87)       |         |
| Residents                                       | 415 (17)        | 33 (13)        |         | 48 (20)        | 32 (13)        |         |

ASA – American Society of Anesthesiologists; BMI – body mass index; EA – epidural anesthesia; FEV₁ % predicted – the forced expiratory volume in the first second in percent of predicted; TCI – target-controlled infusion; FVC% predicted – the forced vital capacity in percent of predicted; LMA – laryngeal mask airway; LVEF – left ventricular ejection fraction; RCRI – revised cardiac risk index; VATS – video-assisted thoracic surgery.
Table 2. Intraoperative comparisons of patients with or without hypoxia.

| Variables                          | Before matching | After matching |
|-----------------------------------|-----------------|----------------|
|                                    | Nonhypoxia (n=2497) | Hypoxia (n=245) | P value | Nonhypoxia (n=240) | Hypoxia (n=240) | P value |
| Surgery time, min                  | 80 (50, 125)    | 80 (50, 135)   | 0.453   | 75 (50, 130)       | 80 (50, 135)   | 0.306   |
| Blood loss, mL                     | 15 (5, 45)      | 15 (10, 50)    | 0.057   | 15 (5, 45)         | 15 (10, 50)    | 0.143   |
| Intraoperative minimum \(\text{SpO}_2\), % | 98.26±1.76     | 90.68±3.05     | <0.001  | 98.32±1.78         | 90.68±3.07     | <0.001  |
| Level of intraoperative \(\text{SpO}_2\), n (%) | <0.001         | <0.001         | <0.001  | <0.001             | <0.001         | <0.001  |

|                                    | Nonhypoxia (n=159) | Hypoxia (n=76)  | P value | Nonhypoxia (n=107) | Hypoxia (n=15) | P value |
|                                    | 94-100%           | 90-93%          | ≤89%    | 34 (14)            | 33 (14)        | <0.001  |
|                                    | 2493 (100)        | 0               | 0       | 0                  | 207 (86)       | <0.001  |
| Intraoperative maximum \(P_{ET\text{CO}_2}\), mmHg | n=1975           | n=175           | <0.001  | n=177              | n=159          | <0.001  |
|                                    | 45.62±7.24       | 49.82±9.65      |         | 45.25±6.73         | 49.90±9.46     |         |
| Level of intraoperative \(P_{ET\text{CO}_2}\), n (%) | n=1975           | n=175           |         | n=177              | n=159          |         |
|                                    | 30-45 mmHg        | 1192 (60.4)     | 76 (43.4) | 107 (61)           | 67 (42)        | <0.001  |
|                                    | 46-60 mmHg        | 724 (36.7)      | 75 (42.9) | 68 (38)           | 70 (44)        |         |
|                                    | 61-80 mmHg        | 59 (3.0)        | 23 (13.1) | 2 (1)              | 21 (13)        |         |
|                                    | >81 mmHg          | 0               | 1 (0.6)   | <0.001             | 0              | 1 (1)   | <0.001  |

\(P_{ET\text{CO}_2}\) = End-expiratory carbon dioxide partial pressure; \(\text{SpO}_2\) = pulse oxygen saturation.

Intraoperative Comparison of Patients with and without Hypoxia

The total incidence of hypoxia (\(\text{SpO}_2 \leq 93\%\)) was 9% (245/2742) and only 1.2% of patients (34/2742) experienced severe hypoxia (<90%). The total incidence of hypercapnia (\(P_{ET\text{CO}_2} \geq 46\) mmHg) was 41% (882/2150), and only 3.8% of patients (83/2150) had moderate hypercapnia (\(P_{ET\text{CO}_2} \geq 61\) mmHg).

The results of propensity score-matching analysis showed that the patients with hypoxia were also combined with a higher-level proportion of \(P_{ET\text{CO}_2} \geq 46\) mmHg (P < 0.001). The intraoperative maximum \(P_{ET\text{CO}_2}\) was higher (49.90 vs 45.25 mmHg, P < 0.001) (Table 2). Arterial blood gas was analyzed when \(\text{SpO}_2\) ≤93% and the mean values of \(\text{PaO}_2\) and \(\text{PaCO}_2\) were 62.28±4.23 mmHg and 56.59 ± 12.84 mmHg in patients with hypoxia (Figure 2).

Postoperative Comparison of Patients with and without Hypoxia

The results of propensity score-matching analysis showed that the patients who experienced intraoperative hypoxia had a longer Intensive Care Unit stay (P=0.039), but the chest-tube drainage, postoperative hospital stay, and the incidence of postoperative clinical complications were similar to those without hypoxia (P=0.077, P=0.059, and P=0.216) (Table 3).

Discussion

This retrospective study revealed that the total incidence of intraoperative \(\text{SpO}_2 \leq 93\%\) was 9%. The main risk factors for intraoperative hypoxia were age, anesthesia method, technical level of surgeons, stair-climbing ability, and the type of thoracic procedure. The overall distribution of characteristics in this study indicated that NIVATS was mostly performed in young-to-middle-aged patients with normal BMI, American Society of Anesthesiologists (ASA) level grade I or II, RCI grade I, and normal cardiopulmonary function. Comorbidities of smoking history, cardiopulmonary disease, and a history of pulmonary operation were not absolute exclusion criteria. The procedure of NIVATS was mainly nonanatomical lung surgery, and it also had no limitation with regard to the sex of the patient or the surgical location.

NIVATS is a safe and feasible alternative procedure and improves postoperative rehabilitation by reducing postoperative complications, hospital stay, and attenuating stress and inflammatory responses [10,13,14]. However, few specific analyses of risk factors for NIVATS have been conducted even though the procedure has been used in a large number of patients [27-31]. The distribution characteristics of patients with intraoperative hypoxia revealed that older patients with higher BMI and inferior cardiopulmonary function who underwent anatomical...
lung surgery under epidural anesthesia by thoracic surgeons with <10 years of VATS training had a high incidence of hypoxia. A logistic regression analysis of these risk factors confirmed these inferences. As reported by the ASA, the risk of morbidity and mortality from general anesthesia is always present, and the risk of laryngotracheal injuries caused by double-lumen tube should not be underestimated [32]. Nevertheless, NIVATS was sometimes advocated for patients with inferior pulmonary function in less invasive procedures. Although the difficulty of intraoperative management increased, the patients recovered quickly after the operation, due to less sedative and analgesic drugs, and the probability of postoperative mechanical ventilation and weaning difficulty was reduced [32-35]. At present, most patients who have undergone NIVATS are successful case
Risk factors of hypoxia for nonintubated VATS

Lan L. et al:
© Med Sci Monit, 2021; 27: e928965

Figure 2. The values of PaO₂ and PaCO₂ in patients with hypoxia. Arterial blood gas was analyzed when SpO₂ ≤93%, and the mean values of PaO₂=62.28±4.23 mmHg and PaCO₂=56.59×12.84 mmHg.

reports, but whether NIVATS is suitable or not still needs to be verified. Therefore, NIVATS must be carefully evaluated to attain more advantages than disadvantages for patients with inferior pulmonary function or those who cannot tolerate tracheal intubation general anesthesia.

In theory, hypoxia does not occur easily in spontaneous ventilation when an individual is in a lateral position. The lower diaphragm contracts more efficiently without obviously decreasing the functional residual capacity during spontaneous respiration [36,37], and more blood distribution occurs in the dependent lung by gravity and hypoxic pulmonary vasoconstriction [16,38]. However, the surgeon's familiarity with the anatomy of the endoscope view is a prerequisite for a quick and accurate operation, which decreases perioperative complications and improves recovery in NIVATS [37,38]. Therefore, to avoid increased incidence of hypoxia and hypoxia in patients, we recommend against surgeons with <10 years of VATS experience. Since the lung is innervated by the visceral nerve, the somatic nerve can be blocked under local anesthesia of the skin and intercostal nerve, and then VATS can be completed under the assistance of moderate sedation and mild analgesia [39,40]. LMA is a strong measure to ensure oxygenation in patients receiving nonintubated anesthesia, and it can decrease the incidence of hypoxia, especially in patients with a high risk of upper airway obstruction. As to the high plane block in thoracic epidural anesthesia, it decreases the inspiratory capacity as a consequence of the motor block of the intercostal muscles [41,42], which may lead to hypercapnia and hypoxia during thoracic surgery. It is possible that patients that received an epidural also had a higher RCRI and more complex resections, resulting in the epidural being seen as increasing the incidence of hypoxia. But which anesthesia method is the best suited for NIVATS? A more detailed comparison is still needed to determine the answer [43].

Furthermore, Bellucci and Qiao [20] and Cureley et al [21] proposed that intraoperative hypoxia may increase the incidence of postoperative complications. However, after the propensity score-matching analysis of preoperative basic characteristics, patients with hypoxia were associated with intraoperative hypercapnia and increased the probability of intensive care, but hypoxia did not affect the overall complications and postoperative hospital stay. This outcome may imply that the impact of intraoperative hypoxia on patients is short-term in NIVATS and has no significant impact on the overall clinical recovery after the operation.

Undoubtedly, this study design could be modified and improved. First, this is a single-center retrospective investigation with data collected over 8 years, and bias (eg, laboratory measurement bias) due to the long period of time was inevitable. In addition, the large sample of data were collected by more than one person, which inevitably led to measurement bias. However, all patients were treated at the same center and a uniform therapeutic regime may have reduced the potential bias. Second, miscellaneous types rather than a specific type of thoracic procedures were included, and cases were consequently less comparable. However, this situation presents a...
real-world clinical scenario. Third, patients younger than 18 years old were excluded, and pediatric patients need to be in-
cluded in future studies to determine whether NIVATS is safe for young patients. Fourth, although the PaO₂ can reflect the
real oxygenation status of patients, a change in SpO₂ is rec-
ognized much more easily and quickly. Therefore, the contin-
uous monitoring index SpO₂ ≤93%, not the PaO₂, was chosen
as the outcome standard. Fifth, although the propensity score-
matching analysis was used to reduce the preoperative bias
to the outcomes, prospective studies are still needed to con-
firm whether intraoperative hypoxia affects the prognosis of
patients in NIVATS.

Conclusions

Rigorous preoperative evaluations should be implemented for
patients who are scheduled for NIVATS. Identification of risk
factors for intraoperative hypoxia in NIVATS may guide rec-
ommendations for early identification of high-risk patients
and enable interventions before the operation. The incidence
of intraoperative hypoxia in our study was related to the pa-
tient’s age, anesthesia method, the technical level of surgeons,
the stair-climbing ability, and the type of thoracic procedure.
However, even if intraoperative hypoxia occurred, it did not
affect the postoperative recovery duration.

Acknowledgments

We are grateful for the help of Dr. Huai Chen for the analyses
of chest radiographs, and we thank our department chairper-
sons, Dr. Qinglong Dong and Dr. Xiaohui Wen, for general sup-
port. We also thank Dr. Yuntai Yao (Fuwai Hospital, National
Center for Cardiovascular Diseases, Chinese Academy of Medical
Sciences and Peking Union Medical College) for his help in re-
vising the language of the article.

Conflicts of Interest

None.

References:

1. Nezu K, Kushibe K, Tojo T, et al. Thoracoscopic wedge resection of blebs un-
der local anesthesia with sedation for treatment of a spontaneous pneu-
mothorax. Chest. 1997;111:230-35
2. Pompeo E, Mineo D, Rogliani P, et al. Feasibility and results of awake tho-
racoscopic resection of solitary pulmonary nodules. Ann Thorac Surg.
2004;78:1761-68
3. Gonzalez-Rivas D, Bonome C, Fieira E, et al. Non-intubated video-assist-
ed thoracoscopic lung resections: the future of thoracic surgery? Eur J
Cardiothorac Surg. 2016;49:721-31
4. Chen JS, Cheng YJ, Hung MH, et al. Nonintubated thoracoscopic lobectomy
for lung cancer. Ann Surg. 2011;254:1038-43
5. Pompeo E, Tacconi F, Frasca L, et al. Awake thoracoscopic bullaplasty. Eur
J Cardiothorac Surg. 2011;39:1012-17
6. Pompeo E, Rogliani P, Tacconi F, et al. Randomized comparison of awake
nonresectional versus nonawake resectional lung volume reduction sur-
ery. J Thorac Cardiovasc Surg. 2012;143:47-54, 54.e1
7. Li S, Liu J, He J, et al. Video-assisted transthoracic surgery resection of a tra-
cheal mass and reconstruction of trachea under non-intubated anesthesia
with spontaneous breathing. J Thorac Dis. 2016;8:575-85
8. Gonzalez-Rivas D, Fernandez R, de la Torre M, et al. Single-port thoraco-
scopic lobectomy in a nonintubated patient: The least invasive procedure
for major lung resection? Interact Cardiovasc Thorac Surg. 2014;19:552-55
9. Deng HY, Zhu ZJ, Wang YC, et al. Non-intubated video-assisted thoraco-
surgical surgery under loco-regional anesthesia for thoracic surgery: A me-
ta-analysis. Interact Cardiovasc Thorac Surg. 2016;23:31-40
10. Zhang K, Chen HG, Wu WB, et al. Non-intubated video-assisted thoraco-
sopic surgery vs intubated video-assisted thoracoscopic surgery for thorac-
ic disease: A systematic review and meta-analysis of 1,684 cases. J Thorac
Dis. 2011;3:3556-68
11. Li S, Jiang L, Ang KL, et al. New tubeless video-assisted thoracoscopic sur-
gery for small pulmonary nodules. Eur J Cardiothorac Surg. 2017;51:689-93
12. Alghamdi ZM, Lynhiau L, Moon YK, et al. Comparison of non-intubated versus intubated video-assisted thoracoscopic lobectomy for lung cancer.
J Thorac Dis. 2018;10:4236-43
13. Yu MG, Jing R, Mo YJ, et al. Non-intubated anesthesia in patients undergo-
ing video-assisted thoroscopic surgery: A systematic review and meta-
analysis. PLoS One. 2019;14:e0224737
14. Wen Y, Liang H, Qiu G, et al. Non-intubated spontaneous ventilation in vid-
eo-assisted thoroscopic surgery: A meta-analysis. Eur J Cardiothorac Surg.
2020;57:428-37
15. Tacconi F, Pompeo E, Sellitri F, et al. Surgical stress hormones response is
reduced after awake video thoracoscopy. Interact Cardiovasc Thorac Surg.
2010;10:666-71
16. Guldner A, Braune A, Carvalho N, et al. Higher levels of spontaneous breath-
ing induces lung recruitment and reduce global stress/strain in experimen-
tal lung injury. Anesthesiology. 2014;120:675-82
17. Brown SI, Barnes MJ, Mundel T. Effects of hypoxia and hypercapnia on human
HRV and respiratory sinus arrhythmia. Acta Physiol Hung. 2014;101:263-72
18. Kievy DG, Cargill RI, Lipworth BJ. Effects of hypercapnia on hemodynam-
ic, inotropic, isometric, and electrophysiologic indices in humans. Chest.
1996;109:1215-21
19. Steinback CD, Saizer D, Medeiros PI, et al. Hypercapnic vs hypoxic control of
cardiovascular, cardiovagal, and sympathetic function. Am J Physiol Regul
Integr Comp Physiol. 2009;296:R402-10
20. Bellucci B, Qiao R. A 47-year-old woman with hypercapnia and altered men-
tal status. Clin Respir J. 2018;12:331-33
21. Cureley G, Contreras MM, Nicolí AD, et al. Hypercapnia and acidosis in sep-
sis: A double-edged sword? Anesthesiology. 2010;112:462-72
22. Lan L, Cen Y, Zhang C, et al. A propensity score-matched analysis for non-
intubated thoracic surgery. Med Sci Monit. 2018;24:8081-87
23. Dong Q, Liang L, Li Y, et al. Anaesthesia with nontracheal intubation in tho-
racic surgery. J Thorac Dis. 2012;4:126-30
24. Svensson LG, Gillinov AM, Weisel RD, et al. The American Association for
Thoracic Surgery consensus guidelines: Reasons and purpose. J Thorac
Cardiovasc Surg. 2016;151:935-39.e1
25. Kregenow DA, Swenson ER. The lung and carbon dioxide: Implications for
permissive and therapeutic hypercapnia. Eur Respir J. 2002;20:6-11
26. Seo DE, Shin SD, Song KJ, et al. Effect of hypoxia on mortality and disable-
tility in traumatic brain injury according to shock status: A cross-sectional
analysis. Am J Emerg Med. 2019;37:1709-15
27. Hung MH, Chan KC, Liu YJ, et al. Nonintubated thoracoscopic lobectomy
for lung cancer using epidural anesthesia and intercostal blockade: A ret-
rospective cohort study of 238 cases. Medicine (Baltimore). 2015;94:e727
28. Klijian AS, Gibbs M, Andonian NT. AVATS: Awake video-assisted thoracic
surgery – extended series report. J Cardiothorac Surg. 2014;9:149
29. Chen KC, Cheng YJ, Hung MH, et al. Nonintubated thoracoscopic lung re-
section: A 3-year experience with 285 cases in a single institution. J Thorac
Dis. 2012;4:347-51
30. Chen KC, Cheng YJ, Hung MH, et al. Nonintubated thoracoscopic surgery using regional anesthesia and vaginal block and targeted sedation. J Thorac Dis. 2014;6:31-36
31. Hung MH, Hsu HH, Chan KC, et al. Non-intubated thoracoscopic surgery using internal intercostal nerve block, vaginal block and targeted sedation. Eur J Cardiothoracic Surg 2014;46:620-25
32. Migliore M, Giuliani R, Aziz T, et al. Four-step local anesthesia and sedation for thoracoscopic diagnosis and management of pleural diseases. Chest. 2002;121:2032-35
33. Rusch VW, Mountain C. Thoracoscopy under regional anesthesia for the diagnosis and management of pleural disease. Am J Surg. 1987;154:274-78
34. Migliore M, Deodato G. A single trocar technique for minimally invasive surgery of the chest. Surg Endosc. 2001;13:899-901
35. Pompeo E, Tacconi F, Mineo TC. Comparative results of non-resectional lung volume reduction performed by awake or non-awake anesthesia. Eur J Cardiothoracic Surg. 2011;39:e51-58
36. Noda M, Okada Y, Maeda S, et al. Successful thoracoscopic surgery for intractable pneumothorax after pneumonectomy under local and epidural anesthesia. J Thorac Cardiovasc Surg. 2011;141:1545-47
37. Liu YJ, Hung MH, Hsu HH, et al. Effects on respiration of nonintubated anesthesia in thoracoscopic surgery under spontaneous ventilation. Ann Transl Med. 2015;3:107
38. Hales CA, Ahluwalia B, Kazemi H. Strength of pulmonary vascular response to regional alveolar hypoxia. J Appl Physiol. 1975;38:1083-87
39. Katic MR. Video-assisted thoracic surgery utilizing local anesthesia and sedation: How I teach it. Ann Thorac Surg. 2017;104:727-30
40. Katic MR, Facktor MA. Video-assisted thoracic surgery utilizing local anesthesia and sedation: 384 consecutive cases. Ann Thorac Surg. 2010;90:240-45
41. Sundberg A, Wattwil M, Arvill A. Respiratory effects of high thoracic epidural anesthesia. Acta Anaesthesiol Scand. 1986;30:215-17
42. Groeben H. Epidural anesthesia and pulmonary function. J Anesth. 2006;20:290-99
43. Umari M, Farini S, Segat M, et al. Anesthesia and fast-track in video-assisted thoracic surgery (VATS): From evidence to practice. J Thorac Dis. 2018;10:5542-54