Pulmonary ventilation reserve function is used to predict intraoperative ventilation function and postoperative outcome in patients with spinal orthopedic surgery

Mingshuai Yu, Ke Zhang, LeiQi and Siyuan Liu

Abstract

Objective: To investigate the effect of pulmonary ventilation reserve function on perioperative pulmonary function and postoperative outcome in patients undergoing spinal orthopedic surgery.

Methods: Ninety patients undergoing spinal orthopedic surgery in our hospital from June 2019 to December 2020 were divided into two groups according to the percentage of preoperative pulmonary reserve function index MVV in the predicted value. Arterial oxygen partial pressure, carbon dioxide partial pressure, oxygenation index (OI), airway plateau pressure (Pplat), and airway resistance (AR) of patients in each group were observed before the start of surgery (T0), at 1 h (T1) and 2 h (T2) after the start of surgery, and at the end of surgery (T3). After the end of surgery, the probability of patient transfer to ICU, time to resume spontaneous breathing, and time to extubation were recorded, and PaO2 and inflammatory factors interleukin-6, procalcitonin, and C-reactive protein of patients were followed up for 1 week.

Results: In both groups, PaO2 and OI decreased obviously while Pplat and AR increased significantly at T1, T2, and T3, but in Group A, Pplat and AR were markedly lower than those in Group B while PaO2 and OI were notably higher than those in Group B (p < 0.05). Both time to resume spontaneous breathing and time to extubation in Group B were longer than those in Group A (p < 0.05). The probability of entering ICU in Group B is higher than that in Group A. Both PaO2 and OI at day 3 after surgery in Group B were lower than those in Group A. While, there is no difference at T2.

Conclusion: For patients, both intraoperative pulmonary function and time to postoperative resuscitation can be predicted by measuring the preoperative MVV, and long-term prognosis will not be affected by the pulmonary function impairment.

Keywords
spinal orthopedic surgery, preoperative maximal voluntary ventilation, pulmonary function, perioperative period

Introduction

The preoperative pulmonary function status of patients may directly influence occurrence and prognosis of intraoperative and postoperative pulmonary complications. Thus, clinical pulmonary function is an important item to be assessed before preoperative anesthesia. According to the book on Clinical Pulmonary Function written by Zheng
Jinping MVV is the earliest evaluation index of surgical tolerance. It can reflect the degree of airway obstruction and patients’ respiratory reserve, respiratory muscle strength, and power level. In the classification of pulmonary insufficiency, VC or MVV is regarded as the first observation index, so MVV is selected as the parameter of pulmonary function in this study. Low preoperative MVV indicates an increased anesthesia risk and a higher incidence of postoperative pulmonary complications.

Scoliosis causes deformities such as spinal deviation and shortening, thoracic collapse, and thoracic asymmetry. These deformities result in a decreased thoracic volume, atelectasis, and decreased lung compliance, thereby leading to restrictive ventilatory impairment. The spinal orthopedic surgery can increase thoracic height and thoracic volume to improve diaphragmatic motion amplitude and thereby breathing, eventually ameliorating pulmonary function and quality of life of patients. But, anesthesia is a big risk for scoliosis patients. During this surgery, scoliosis patients stay in the prone position under general anesthesia. This position decreases lung compliance and functional residual capacity while increasing AR, and anesthesia will further aggravate atelectasis of patients, causing an increased anesthesia risk.

Patients requiring spinal orthopedic surgery have poor pulmonary function and need this surgery to improve this function, so the requirements for preoperative pulmonary function indicators need to be loosened. Currently, no studies on postoperative pulmonary function status and pulmonary complications of low-MVV patients undergoing this surgery have been reported. The spinal deformities can be divided into idiopathic, congenital neuromuscular, interstitial, and traumatic deformities according to their causes. All the cases selected for this study suffered from idiopathic scoliosis. Preoperative and postoperative pulmonary function statuses and postoperative pulmonary complications of such patients were analyzed in the present study to assess the safety of anesthesia for this surgery in patients with different MVVs, providing guidance for clinical anesthesia.

Materials and methods

Basic data

It was an observational clinical case–control study. The present study had been approved by the Medical Ethics Committee of our hospital. Both patients and their families had been informed of details about the present study and signed the written informed consent form. A total of 90 patients from June 2019 to December 2020 undergoing the spinal orthopedic surgery were selected for this exploratory study. They were divided into the mild-pulmonary-function-impairment group and the pulmonary-function-impairment group.

Inclusion criteria: (1) patients should undergo preoperative pulmonary function examination and preoperative evaluation. (2) The patient has completed cardiopulmonary function exercise and met the requirements by 6-min climbing test. (6-min stair climbing test. The patients whose heart rate and breathing rate recovered to pre-climbing levels within 10 min and had no arrhythmias after climbing were eligible for the study.)

Exclusion criteria: Patients with significant organ dysfunction such as heart, liver, and kidney should be excluded.

Methods

Patients were divided, by percentage of measured preoperative MVV in predictive MVV value, into the mild-pulmonary-function-impairment group (Group A, MVV > 50% of the predictive value) and the pulmonary-function-impairment group (Group B, MVV < 50%), 45 patients per group (Figure 1). Basic characteristics of patients, such as gender and age, were comparable between two groups, suggesting no statistically significant difference (p > 0.05). All patients underwent 8-hour food fasting and 4-hour water fasting before the surgery. After entering the operation room, patients were conventionally monitored for heart rate, blood pressure, pulse, and oxygen saturation and warmed with a heating blanket. General anesthesia was induced using midazolam (0.05 mg/kg), sufentanil (0.3 μg/kg), etomidate (0.25 mg/kg), and.

![Figure 1. The flowchart of the study.](image-url)
cscicatrucurium besylate (0.2 mg/kg). In the present study, intubation was conducted using a bronchofiberscope, and breathing was controlled with a ventilator, with a fraction of inspired oxygen of 50%. Anesthesia of patients in both groups was maintained via intermittent push injection of propofol (4–7 mg/(kg h)), remifentanil (0.1–0.2 μg/(kg min)), and cisatracurium besylate. The maintenance was also achieved by adjusting the pump rate of propofol and remifentanil in the intraoperative period. The anesthesia depth was monitored via bispectral index (BIS) monitoring. At 10 min before the end of surgery, the infusion of propofol and remifentanil was terminated in both groups, while sufentanil was administered for analgesia. After the end of surgery, patients were transferred to the resuscitation room. The tracheal catheter was removed when patients became conscious, resumed spontaneous breathing, and had stable vital signs.

### Evaluation indicators

Arterial oxygen partial pressure (PaO₂), carbon dioxide partial pressure (PaCO₂), oxygenation index (OI), airway plateau pressure (Pplat), and airway resistance (AR) of patients in both groups were observed before the start of surgery (T₀), at 1 h (T₁) and 2 h (T₂) after the start of surgery, and at the end of surgery (T₃). The time to postoperative extubation was recorded after the end of surgery. PaO₂ and inflammatory factors (IL-6, PCT, and CRP) were followed up on day 3 (t₁) and day 7 (t₂) after surgery.

### Table 1. Comparison of basic characteristics between two groups.

| Group  | Number of patients | Age (year) | Gender (males/females) | BMI (kg/m²) |
|--------|--------------------|------------|------------------------|-------------|
| Group A | 45                 | 32.2 ± 7.5 | 37/8                   | 21.5 ± 4.2  |
| Group B | 45                 | 30.6 ± 7.1 | 35/10                  | 19.9 ± 3.8  |

### Table 2. Comparison of PaO₂, OI, Pplat, and AR at different time points between the two groups (mean ± SD mmHg).

| Indicator | Group | T₀         | T₁         | T₂         | T₃         |
|-----------|-------|------------|------------|------------|------------|
| PaO₂      | A     | 259.5 ± 20.1 | (253.5–265.5) | 246.3 ± 28.1 | **(237.9–254.8) | 250.3 ± 26.5** | **(242.3–258.2) | 248.2 ± 27.1** | **(240.1–256.4) |
|           | B     | 264.2 ± 32.2 | (254.6–273.9) | 250.5 ± 22.3** | (243.8–257.2) | 238.5 ± 29.1** | **(229.7–247.2) | 236.5 ± 25.4** | **(228.8–244.1) |
| OI        | A     | 518.4 ± 34.1 | (508.2–528.7) | 492.8 ± 45.6** | (479.0–506.5) | 501.3 ± 39.4** | **(489.5–513.2) | 496.1 ± 28.3** | **(487.6–504.6) |
|           | B     | 528.1 ± 35.5 | (517–538.7)  | 502.2 ± 38.3** | (490.7–513.7) | 476.8 ± 32.2** | **(467.2–486.5) | 472.6 ± 37.1** | **(461.5–483.8) |
| AR        | A     | 17.2 ± 1.9 (16.6–17.7) | 16.8 ± 2.0 (16.1–17.6) | 18.6 ± 2.4** (17.8–19.3) | 18.0 ± 1.7** (17.5–18.5) |
|           | B     | 18.0 ± 2.1 (17.3–18.6) | 17.5 ± 1.6 (17.0–17.9) | 19.5 ± 1.8** (18.9–20.1) | 19.1 ± 1.6** (18.6–19.5) |
| Pplat     | A     | 16.1 ± 2.6 (15.3–16.9) | 17.4 ± 2.3** (16.7–18.1) | 17.2 ± 2.1** (16.6–17.9) | 17.6 ± 4.3** (16.3–18.9) |
|           | B     | 16.7 ± 4.3 (15.5–18.0) | 17.3 ± 5.1 (15.8–18.9) | 18.4 ± 3.0** (17.5–19.2) | 19.5 ± 3.5** (18.5–20.6) |

* p < 0.05 when compared to Group A, and ** p < 0.05 when compared to T₀. Abbreviations: PaO₂: arterial oxygen partial pressure; OI: oxygenation index; Pplat: airway plateau pressure; AR: airway resistance.

### Table 3. Comparison of time to resume spontaneous breathing and time to extubation between two groups (mean ± SD min).

| Group  | Number of patients | Time to resume spontaneous breathing | Time to extubation |
|--------|--------------------|-------------------------------------|--------------------|
| Group A | 42                 | 20.8 ± 9.4 (17.9–23.6)              | 29.8 ± 6.6 (27.8–31.8) |
| Group B | 34                 | 26.5 ± 11.8* (23.0–30.1)            | 45.4 ± 7.4* (43.2–47.7) |

* p < 0.05 when compared to Group A.

### Table 4. Comparison of probability of transfer to ICU between two groups.

| Group               | Ward | Transfer to ICU | p value |
|---------------------|------|----------------|---------|
| Group A (n = 45)    | 42   | 3              | X² = 4.406 |
| Group B (n = 45)    | 35   | 10             | p = 0.036 |

Yu et al.
Statistical analysis

All laboratory data were processed using the statistical software SPSS 19.0. Measurement data were expressed as mean ± standard deviation (x ± s). Inter-group comparisons were performed by an independent-samples t-test, and intra-group comparisons by a paired-samples t-test. The Fisher’s exact test, a χ² test for independent samples, was carried out to compare count data. p < 0.05 denotes a significant difference.

Results

Comparison of basic characteristics between two groups

No statistically significant inter-group differences were found in basic characteristics. See Table 1.

Comparison of PaO₂, OI, Pplat, and AR between two groups

Compared to T₀, PaO₂ and OI in Group B decreased obviously while Pplat and AR increased significantly at T₁, T₂, and T₃. At T₂ and T₃, Pplat and AR in Group A were markedly lower while PaO₂ and OI were substantially higher than those of Group B, indicating statistically significant differences (p < 0.05). See Table 2 for statistical results.

Comparison of time to resuscitation and probability of transfer to ICU between two groups

The comparison results showed that it was more probable for patients in Group B (moderate-pulmonary-function-impairment) to be transferred to ICU after surgery, indicating a significant inter-group difference (Tables 3 and 4).

Comparison of postoperative PaO₂ and inflammatory factors between two groups

For PaO₂ and OI at T₂, no statistically significant difference from those at T₁ was observed in Group A, but a statistically significant increase from those at T₁ was identified in Group B; the inter-group comparison suggested no statistically significant difference. As for CRP at T₂, a gradual decrease from that at T₁ was found in both groups, showing a statistically significant difference, but no statistically significant inter-group difference was identified in CRP at T₁. Both IL-6 and procalcitonin (PCT) showed no statistically significant inter-group difference at T₂. See Table 5 for statistical results.

Discussion

The pulmonary function status of patients is an important preanesthesia assessment item and closely associated with prognosis. Among important pulmonary function observation items, forced expiratory volume in one second (FEV₁) and MVV are included because they are an indicator of the severity of airway obstruction, respiratory muscle strength, and ventilatory reserve capacity. Some scholars have studied the rational use of drugs during general anesthesia to protect pulmonary function and reduce lung injury. Peng et al. investigated the efficacy of protective ventilation in improving postoperative oxygenation in elderly patients with pulmonary insufficiency. Besides, the impacts of preoperative pulmonary function on postoperative pulmonary function impairment and relevant complications of patients have been studied by some scholars. Currently, some scholars recommend the use of preoperative FEV₁% and MVV% to predict the incidence of cardiopulmonary complications following...
lobectomy. Their study results showed that low preoperative FEV1% and MVV% caused a high incidence of postoperative pulmonary complications in patients undergoing lobectomy for lung cancer, which is consistent with the results of the present study. Some scholars and related institutions have established pulmonary function assessment criteria. For example, MVV < 50% of predicted, FEV1/forced vital capacity (FVC) < 50%, or single-breath diffusion lung capacity for carbon monoxide (DLCO) < 50% indicates a surgery risk, and patients with MVV < 30% of predicted are contraindicated for surgery. The present study showed intraoperative and postoperative pulmonary functions of patients in Group A (MVV > 50%) was better than those in Group B (MVV < 50%), but no significant inter-group difference was observed in the long-term prognosis.

The intraoperative blood gas analysis results of patients directly reflect pulmonary function and oxygenation during the surgery. As quantitative indicators of pulmonary function, PaO2, OI, Pplat, and AR reflect the intraoperative pulmonary function status of patients. In the present study, patients with different pulmonary function statuses were monitored for changes in these indicators during anesthesia. In both groups, these four indicators at T2 and T3 obviously changed from those at T1, but in Group A, Pplat and AR were markedly lower while PaO2 and OI were significantly higher than those in Group B. These results showed the preoperative pulmonary function status was a direct indicator of the intraoperative pulmonary ventilation of patients. At each time point, patients in Group A had a higher PaO2, a better OI, and lower Pplat and AR, so it was less probable for them to be transferred to ICU after surgery. Nevertheless, no increase was found in the postoperative death rate, and no inter-group difference was observed in the long-term prognosis. Besides, observations showed, with an increase in the duration of surgery, OI decreased and airway pressure elevated to different extents in each group. Therefore, it was concluded in the present study that preoperative MVV% was inversely proportional to the incidence of postoperative pulmonary complications, and preoperative pulmonary function measures were directly proportional to intraoperative PaO2 and OI. Better preanesthesia pulmonary function indicates easier postoperative recovery, a reduced probability of postoperative transfer to ICU, and a lower incidence of pulmonary complications.

Some studies have demonstrated that multi-modal monitoring helps improve the quality of anesthesia and reduce the incidence of postoperative complications. These studies also suggest that both BIS and degree of muscle relaxation can be monitored to better control the anesthesia depth so as to avoid delayed postoperative resuscitation and extubation due to excessive anesthesia and muscle relaxants. The multi-modal monitoring was also adopted in the present study to reduce the possibility of delayed resuscitation and factors interfering with the collection of postoperative resuscitation data. The results showed no obvious difference in OI, PCT, IL-6, and other inflammatory factors on day 7 after surgery. The possible reason is analyzed as follows: The levels of inflammatory factors are influenced by many factors (e.g., duration of surgery, Cobb angle, amount of bleeding, and severity of trauma), and these factors will have large impacts on statistical results when the sample size of a study is small.

In summary, intra-anesthesia pulmonary oxygenation status and incidence of postoperative pulmonary complications can be predicted based on the preoperative MVV% of patients undergoing spinal orthopedic surgery. Low preoperative MVV of patients will result in poor pulmonary ventilation during surgery, increasing the probability of postoperative transfer to ICU. However, no inter-patient difference in prognosis will be observed in case of sufficient preoperative preparations to protect the cardiopulmonary function and intraoperative implementation of pulmonary protection policies.

Some limitations of this study included the following: The study sample size is limited, and the small sample size may cause the deviation of the results, which will be further supplemented and observed in the later stage. Cobb angle is an important aspect affecting the degree of pulmonary insufficiency. Based on different Cobb angles, the pulmonary function of patients has different degrees of injury. The duration of surgery and the amount of bleeding are also the factors affecting the study results. However, grouping by MVV was used in the study design, and each group has different degrees of Cobb angle, so it was not included in the observation. The increase in Cobb angle ultimately affects the shape of the thorax and the lung function, and the study team will also include Cobb angle and other influencing factors in the observation in the subsequent study.

**Conclusion**

For patients undergoing the spinal orthopedic surgery, both intraoperative pulmonary function and time to postoperative resuscitation can be predicted by measuring the Pulmonary Ventilation Reserve Function, and long-term prognosis will not be affected by the moderate pulmonary function impairment.

**Acknowledgments**

We are thankful to all the patients and/or their guardians who showed consent and participated in the study. We are also thankful to the hospital administration and lung function test center for the provision of research facilities.
Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Our work was supported by the Health Research Project of Sichuan Province (No. 19PJ210).

Ethics approval

Ethical approval for this study was obtained from the Ethics Committee of the Nuclear Industry 416 Hospital (approval No. / IDKJ2019005).

Informed consent

Written informed consent was obtained from all subjects before the study.

Trial registration

This randomized clinical trial was not registered because it was not until the writing stage of the paper that the author decided to submit this study to your journal, there was no registration of clinical trials in the early stage.

ORCID iD

Mingshuai Yu  https://orcid.org/0000-0002-3679-0353

References

1. Colice GL and Shafazand S. Physiologic evaluation of the patient with lung cancer being considered for resectional surgery: ACCP Evidenced-Based Clinical Practice Guidelines. Chest 2007; 132(3Suppl): 161–177.
2. Zheng J. Pulmonary Function [M]. Guangzhou: Guangdong Science and Technology Publishing House, 2007; 61–62.
3. Qiu Y. The current review and prospects of the genetic study and clinical treatment of adolescent idiopathic scoliosis. Chin J Surg 2018; 56(8): 578–582.
4. He Q, Maochuan F, Yan L, et al. Protective effect of low tidal volume combined with positive end-expiratory pressure on lung function of patients undergoing percutaneous nephrolithotomy in prone position. J Xinxiang Med Univ 2020; 37(10): 959–963.
5. Yuan Z, Kuai J, Mao J, et al. Effect of dexmedetomidine on cerebral function and pulmonary function protection and stress reaction factors of patients with lung cancer radical resection during perioperative period. J Clin Palm Med 2018; 23(12): 2268–2272.
6. Liu L, Tong L, Pei X, et al. Effects of dexmedetomidine combined with selective lobectomy on lung function and serum cytokines in patients undergoing esophageal cancer surgery. J Clin Anesthesiology 2018; 34(11): 1081–1091.
7. Peng X, Gu E, Zheng L, et al. Effect of low tidal volume lung protective ventilation strategy on the outcome of elderly patients with poor pulmonary function after abdominal operation. J Clin Anesthesiology 2017; 33(4): 364–368.
8. Taylor LT, Julliard WA, Maloney JD, et al. Predictive value of pulmonary function measures for short-term outcomes following lung resection: analysis of a single high-volume institution. J Thorac Dis 2018; 10(2): 1072–1076.
9. Wang D, Chen Q and Bi P. Correlation analysis of preoperative pulmonary function and postoperative cardiopulmonary complication after left pneumonectomy for lung cancer. Chin J Clin Oncol 2015; 32(7): 421–423.
10. Zhu L, Liu Y and Yu R. Clinical Pulmonary Function. Beijing: People’s Medical Publishing House, 2004.
11. Slutsky AS and Ranieri VM. Ventilator-induced lung injury. N Engl J Med 2013; 369(8): 2126–2136.
12. Green D, Bidd H and Rashid H. Multimodal intraoperative monitoring: an observational case series in high risk patients undergoing major peripheral vascular surgery. Int J Surg 2014; 12(3): 231–236.
13. Wu X and Li C. The application of multi-mode anesthesia monitoring and management in the operation of elderly patients with gastrointestinal tumor and fragile brain function. Int J Anesthesiological Resusc 2019; 40(12): 1099–1104.
14. Naffo OO and Dobija N. Preoperative pulmonary function tests to predict postoperative outcomes. Anesth Analgesia 2019; 129(1): 16–18.