

## Research Article

# Individualized parameters for mechanical ventilation during thoracic operations: Optimizing respiratory support

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## Abstract

### Introduction

Adequate respiratory support with mechanical lung ventilation (MLV) is crucial for maintaining gas exchange and pulmonary circulation hemodynamics in patients with severe lung diseases in the perioperative period. However, the selection of optimal parameters for ventilation is often a serious problem, which can lead to the development of complications and worsening of treatment outcomes.

### Purpose

This study aimed to evaluate the effectiveness of the developed method of individual calculation of ventilator parameters to optimize respiratory support in patients with various lung diseases undergoing surgical intervention.

### Methods

This study used a prospective clinical approach to optimize mechanical lung ventilation by calculating individualized ventilatory parameters based on each patient's lung function during surgery.

### Results

The results showed that in patients with unilateral lesions, the application of the developed method achieved PaO<sub>2</sub> 94.1±6.7 mmHg and PaCO<sub>2</sub> 36.2±4.5 mmHg, mean pulmonary artery pressure 25.8±3.6 mmHg, as well as cardiac output 4.8±0.8 l/min and oxygen transport 489±77 ml/min at the final post-operative stage. Even in bilateral diffuse lesions, individualized ventilatory parameters provided PaO<sub>2</sub> 79.6±11.3 mmHg and reduced bronchial resistance to 11.4±3.6 cmH<sub>2</sub>O/l/sec after surgery. Despite gross respiratory dysfunction, the personalized approach maintained PaO<sub>2</sub> 79.2±9.7 mmHg and PaCO<sub>2</sub> 46.1±6.3 mmHg postoperatively in patients with congenital pulmonary malformations such as cystic hypoplasia.

### Conclusion

This study demonstrates the high efficacy of personalized approaches to respiratory support management to improve patient outcomes and reduce the risk of complications in patients with lung disease in the perioperative period.

## INTRODUCTION

Mechanical lung ventilation (MLV) is an integral part of the complex treatment of patients with respiratory disorders in the perioperative period. According to Nysanbai

and Kaliskarov,<sup>1</sup> adequate respiratory support is crucial for maintaining gas exchange and hemodynamics of the small circulation circle, especially in patients with severe lung diseases who underwent surgical intervention. However, the selection of optimal parameters for ventilatory support

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is often a serious problem, which can lead to the development of complications and worsening of treatment outcomes. Thus, according to Mustafin et al.,<sup>2</sup> prolonged single-lung ventilation during thoracic interventions leads to impaired surfactant properties, which leads to postoperative pulmonary hypoventilation and, in some cases to atelectasis of the diseased lung, which significantly worsens the short-term prognosis for this group of patients.

The need to improve the methods of calculating ventilator parameters is due to a number of factors. Firstly, different lung diseases are characterized by various pathophysiological changes that require individualized approaches to respiratory support. Secondly, standard modes of ventilation do not always provide adequate respiratory support, especially in patients with severe lung lesions. Thirdly, the individual characteristics of the patient and the degree of respiratory dysfunction should also be considered when selecting the parameters of ventilation. In the study of Abduraimov et al.,<sup>3</sup> it was found that during the coronavirus pandemic, the standard protocols of mechanical ventilation underwent significant changes, so special attention was paid to the prone position of the patient, as well as drug therapy, in particular anticoagulant and glucocorticoid therapy. However, according to Hamchiyev et al.,<sup>4</sup> even if all the points of adequate ventilation are observed, this procedure carries significant risks for patients with lung tissue lesions, as it has a significant load on the cardiovascular system, which can only worsen the patient's condition.

In recent years, the problem of optimizing respiratory support has attracted considerable research attention.<sup>5</sup> The study of different modes of ventilation on gas exchange and hemodynamic parameters in patients with chronic obstructive pulmonary disease (COPD) has revealed the advantages of a personalized approach. However, this approach is limited by small samples of studies on this topic and the lack of long-term follow-up. Confirming this information, Bakenova et al.<sup>6</sup> also provide data that for patients with COPD interstitial lung diseases, it is necessary to assess the diffusion capacity of the lungs because, in this group of patients, the indicators of the norm of gas exchange differ significantly from healthy people. Despite the studies, the problem of optimizing respiratory support in patients with various lung diseases in the perioperative period remains insufficiently studied. There are no comprehensive approaches that consider both the nature of the disease, and individual characteristics of the patient and the consequences of surgical treatment.<sup>7</sup>

In this regard, this study aims to evaluate the effectiveness of the developed method of individual calculation of ventilatory parameters to optimize respiratory support and maintain adequate gas exchange and hemodynamics of the small circulation circle in patients with various lung diseases who underwent surgical intervention. Special attention will be paid to cases with unilateral and bilateral lung lesions, as well as congenital respiratory malformations such as cystic hypoplasia.

It is expected that the application of a personalized approach to ventilator management will significantly improve patient outcomes due to more accurate adaptation of ven-

**Table 1. Distribution of patients**

| Nosological forms                                  | Number of patients |
|----------------------------------------------------|--------------------|
| Cystic hypoplasia of the lungs (unilateral lesion) | 15                 |
| Bronchiectatic disease (unilateral lesion)         | 43                 |
| Bronchiectatic disease (bilateral lesions)         | 24                 |
| Lung tumour (unilateral lesion)                    | 26                 |
| Total                                              | 108                |

Source: compiled by the authors.

tilation parameters to individual patient needs and disease course. The results of this study may make an important contribution to improving clinical practice and the quality of care for patients with respiratory disorders requiring surgical treatment.

## METHODS

This study used theoretical and empirical scientific knowledge to develop an adequate MLV method, with individual parameters calculated depending on the functional state of the patient's respiratory system. Informed consent was obtained from all participants or their legal guardians before their inclusion in the study, ensuring they were fully informed of the study's purpose, procedures, potential risks, and benefits and voluntarily agreed to participate per ethical guidelines. Ethical approval of the study was obtained from the Ethics Commission of the Kazakh-Russian Medical University, No.5423-E.

## STUDY POPULATION

The empirical part included a prospective clinical study conducted on the basis of operating departments of medical institutions in Almaty (Kazakhstan) during surgical interventions under general anesthesia in 108 patients with lung pathology of various aetiologies. The ages of the participants ranged from 14 to 65 years ([Table 1](#)).

## STUDY DESIGN

The study was conducted in four stages: Stage 1 involved baseline measurements of ventilatory parameters, blood gases, and hemodynamics after tracheal intubation. Stage 2 occurred after chest opening, assessing the impact of surgery on lung function. Stage 3, during the main surgical phase, involved continuous monitoring of ventilatory and blood gas parameters. Stage 4 occurred post-surgery after chest closure, with final measurements to evaluate recovery and the effectiveness of ventilatory support. These stages allowed for ongoing adjustments to ventilation based on the patient's condition.

During surgery, patients underwent MLV under general anesthesia. Ventilation mechanics parameters were mea-

sured using CAPNOMAC ULTIMA (Datex, Finland), which is equipped with a pneumotachometer tube and integrated with a computer for continuous calculation and visualization of lung elastic resistance and bronchial airway resistance. It was used because of its capacity to deliver precise, up-to-date information on important respiratory parameters like tidal volume, lung compliance, and airway resistance. Its incorporation of capnography enables accurate carbon dioxide exhalation analysis, facilitating thorough monitoring of gas exchange and ventilation-perfusion efficiency. Furthermore, the device is perfect for critical care and surgical situations due to its non-invasive and continuous monitoring capabilities, guaranteeing the successful optimization of customized ventilatory methods.

#### DATA COLLECTION AND CALCULATION

In order to evaluate respiratory function and direct ventilatory treatment, pulmonary resistance and arterial blood gases (ABGs) were assessed during the surgical process. A pneumotachometer attached to the ventilator system to continually monitor pressure and airflow was used to measure pulmonary resistance. Measurements were taken at the following stages: immediately after tracheal intubation and patient positioning, after chest opening, during the main phase of surgery, and at the end of the procedure when the chest was closed. Blood samples were drawn from an arterial line at the same four points to measure the pH, PaO<sub>2</sub>, and PaCO<sub>2</sub> levels for ABG analysis. These measures made it possible to continuously monitor acid-base balance and respiratory function, enabling ventilator settings to be adjusted and providing the best possible care for patients during the perioperative period.

Lung compliance was measured using a standardized protocol. Compliance was assessed by determining the lung volume change in response to a known pressure applied during mechanical ventilation. A pneumotachometer attached to the ventilator system was used to perform the surgery, enabling constant airway pressure and volume monitoring. Measurements were made at four stages: right after the patient was positioned and the tracheal intubation was completed, after the chest was opened, throughout the main part of the surgery, and after the procedure was finished and the chest was closed. The lung compliance (C) was calculated using the formula (1):

$$C = \frac{TV}{\Delta P}, \quad (1)$$

where TV – tidal volume,  $\Delta P$  – the pressure changes across the lung tissue. Compliance values were recorded at each stage to track changes in lung function, particularly in response to surgical manipulation and ventilatory adjustments. This approach enabled precise evaluation of lung compliance throughout the perioperative period, helping to optimize ventilator settings for each patient based on their specific lung mechanics.

A special mathematical calculation algorithm was developed to determine optimal individual parameters of the ventilator depending on the functional state of the lungs. The key controllable parameters were proper TV and proper respiratory volume flow rate ( $V_d$ ). These values were calcu-

lated using formulas that take into account lung tissue extensibility and bronchial resistance in a particular patient.

The values of TV and  $V_d$  were determined as follows (2, 3):

$$TV = C \times 10 \text{ (liters)}, \quad (2)$$

where C is the stretchability of the lungs.

$$V_d = V_f \times 6 \text{ (litres/sec)}, \quad (3)$$

where,  $V_f$  is the functional flow rate determined by the formula (4)

$$V = \frac{V_t}{R_{br}}, \quad (4)$$

where  $V_t$  is the current flow rate,  $R_{br}$  is bronchial resistance.

The other ventilatory parameters such as respiratory rate (RR), inspiratory time (I-Time) and expiratory time ( $T_E$ ) were calculated based on TV,  $V_d$ , and technical capabilities of the respirator used to employ specially developed formulas given in the text of the study. The formulas were as follows (5-8):

$$RR = V_E / TV \text{ (at 1 minute)}, \quad (5)$$

$$I - Time = TV / V_d + 0.12 \text{ (seconds)}, \quad (6)$$

$$T_T = 60 / RR \text{ (seconds)}, \quad (7)$$

$$T_E = T_T - I - Time, \quad (8)$$

where,  $T_T$  – total cycle time, and 0.12 – time taken to accelerate and decelerate the flow,  $V_E$  – minute ventilation.

For patients with severely impaired lung function, “volume oscillatory ventilation” was used during the third stage of the surgical procedure when conventional ventilatory methods were insufficient to maintain adequate gas exchange. This method was applied in cases where the calculated TV and  $V_d$  were too low to ensure optimal ventilation, especially in patients with bilateral lung lesions or congenital lung malformations such as cystic hypoplasia. Then, the minimum acceptable values of these parameters were restricted to 1/30 of  $V_E$ . Volume oscillatory ventilation utilizes high-frequency oscillations to enhance gas exchange. It also reduces the risk of hypoxia and CO<sub>2</sub> retention, stabilizing the patient’s respiratory and hemodynamic parameters during the perioperative period.

$V_E$  was determined by the formula (9):

$$V_E = (\text{body weight}/10 + 1) + V_E/10 \text{ (litres/min)}, \quad (9)$$

with correction for low atmospheric pressure in Almaty.

Calculations of individual ventilatory parameters were performed using a special computer programme developed by the study’s authors. Data on the viscosity of the breathing gas mixture, geometric characteristics of the intubation tube, patient weight, pressure values according to the pressure-volume curves and other parameters were entered into the program. The results of calculations of ventilator parameters were displayed on the screen for use by medical personnel when adjusting the respirator. Statistical processing of the data was performed using the BioStat software package. The study of the dynamics of ventilator mechanics parameters, as well as changes in blood gases and hemodynamics of the small circulation circle, was carried out at four stages of the operation – after tracheal intubation and patient rotation, after chest opening, during the main stage of the operation and at the end of the operation with a closed chest.

Thus, this study included theoretical substantiation and experimental testing of a new method of calculation and correction of individual ventilatory parameters based on objective instrumental indicators of the respiratory system state of each patient with the use of mathematical modelling and specialized software. Success in this study was measured by improvements in key physiological parameters, including  $\text{PaO}_2$ ,  $\text{PaCO}_2$ , pulmonary resistance, and lung compliance, across the four stages of surgery. Successful outcomes were defined as maintaining or restoring normal blood gas values, optimizing respiratory function, achieving stable hemodynamics, and reducing respiratory acidosis and complications risk.

## RESULTS

In patients with unilateral cystic hypoplasia of the lungs, 15 people in total, a decrease in distensibility and an increase in bronchial resistance in the affected area were recorded. At the first stage of the examination, the mean elastic resistance values in the affected lung reached  $42.7 \pm 6.3 \text{ cmH}_2\text{O/l/sec}$ , and bronchial resistance reached  $15.8 \pm 3.1 \text{ cmH}_2\text{O/l/sec}$ . These parameters worsened significantly after surgical opening of the chest in the second stage. The increase in elastic resistance went up to  $62.4 \pm 8.6 \text{ cmH}_2\text{O/l/s}$ , which indicates a significant reduction in lung compliance, likely due to surgical manipulation, loss of negative intrapleural pressure, and subsequent inflammation. Similarly, the rise in bronchial resistance to  $23.5 \pm 4.7 \text{ cmH}_2\text{O/l/sec}$  reflects worsened airflow obstruction, possibly caused by postoperative oedema, airway compression, or changes in bronchial diameter induced by surgical trauma. These changes are compounded by the pre-existing structural abnormalities of cystic hypoplasia, including reduced alveolar units and abnormal bronchial architecture, which predispose the affected lung to higher resistance and impaired mechanics.

To optimize the function of the affected lung in these patients, minimizing the respiratory volume and increasing the respiratory rate as much as possible was necessary. In the third stage, after surgical procedures such as pneumectomy (5 cases), bilobectomy (3 cases) and lobectomy (2 cases), the elastic resistance values of the remaining lung tissue improved, being in the range of  $26.8 \pm 5.2 \text{ cmH}_2\text{O/l/sec}$ . Bronchial resistance also decreased to  $11.4 \pm 3.6 \text{ cmH}_2\text{O/l/sec}$ . Five patients with the most severe disorders were transferred to the mode of volume oscillatory ventilation to improve ventilatory function further.

Blood gas analysis in this group of patients showed initial  $\text{PaO}_2$  values of  $88.6 \pm 7.4 \text{ mmHg}$  and  $\text{PaCO}_2$  of  $41.5 \pm 5.2 \text{ mmHg}$  at the first stage. Postoperatively, the values deteriorated dramatically;  $\text{PaO}_2$  fell to  $65.3 \pm 11.6 \text{ mmHg}$ , and  $\text{PaCO}_2$  increased to  $54.8 \pm 8.5 \text{ mmHg}$ . However, due to correction of ventilatory parameters, the parameters returned to relatively satisfactory levels by the fourth stage, being  $\text{PaO}_2$   $79.2 \pm 9.7 \text{ mmHg}$  and  $\text{PaCO}_2$   $46.1 \pm 6.3 \text{ mmHg}$ . These results demonstrate the importance of adequate management of respiratory support in patients with severe lung malformations to improve their survival and quality of life.

Patients with bilateral lung damage due to bronchiectatic disease, 24 patients in total, faced serious difficulties in optimizing ventilator parameters. In the study's first phase, they had mean elastic resistance values of  $25.6 \pm 4.8 \text{ cmH}_2\text{O/l/sec}$  for the right lung and  $27.4 \pm 5.2 \text{ cmH}_2\text{O/l/sec}$  for the left lung. Bronchial resistance during the same period was  $9.8 \pm 2.4 \text{ cmH}_2\text{O/l/sec}$  for the right lung and  $10.5 \pm 2.9 \text{ cmH}_2\text{O/l/sec}$  for the left lung. After surgical intervention and chest opening in the second stage, the indices significantly worsened, especially on the side subjected to surgery.

Volumetric oscillatory ventilation was widely employed in this group, requiring it in 11 of 24 cases. However, even with the use of this technology, maintaining satisfactory blood gas levels remained difficult.  $\text{PaO}_2$  values varied as follows during the different phases of the study: in the first phase, they were recorded at  $89.2 \pm 8.1 \text{ mmHg}$ , dropped to  $68.6 \pm 10.4 \text{ mmHg}$  in the second phase, were  $72.5 \pm 9.8 \text{ mmHg}$  in the third phase, and reached  $79.6 \pm 11.3 \text{ mmHg}$  in the fourth phase.  $\text{PaCO}_2$  values also ranged from  $40.7 \pm 6.3 \text{ mmHg}$  in the first stage to  $47.2 \pm 7.5 \text{ mmHg}$  in the fourth stage, with a marked worsening after surgery.

In contrast, the situation was more favourable in patients with bronchiectatic disease with unilateral lesions (43 patients) and in patients with lung tumours (26 patients, also with unilateral lesions). In these cases, the initial lung function disorders were less pronounced, and after surgical removal of the affected areas, the functional reserves of the remaining lung tissue were sufficient for effective correction and maintenance of optimal parameters of ventilation. This underlines the importance of an individualized approach to each clinical case, depending on the degree and nature of the lung lesion.

The following dynamics of elastic resistance at different stages of treatment were observed in patients with unilateral lung damage due to bronchiectasis. In the first stage, the average value of elastic resistance for the affected lung was  $21.3 \pm 3.7 \text{ cmH}_2\text{O/l/sec}$ . In the second stage, after surgery, this index increased to  $33.8 \pm 5.9 \text{ cmH}_2\text{O/l/sec}$ , reflecting an increase in the load on the pulmonary structures. The third stage showed changes according to the type of surgery performed: after pneumectomy (3 cases), the mean value decreased to  $25.6 \pm 4.5 \text{ cmH}_2\text{O/l/sec}$ , while after lobectomy (31 cases) it was  $31.4 \pm 4.8 \text{ cmH}_2\text{O/l/sec}$ . By the fourth stage, after completion of all therapeutic manipulations, the elastic resistance decreased to  $19.8 \pm 2.9 \text{ cmH}_2\text{O/l/sec}$ , which indicates the recovery of lung functions. The mentioned therapeutic manipulations included adjusting ventilator settings, administering pharmacological treatments, performing physical therapy, conducting surgical procedures, and providing oxygen therapy to improve lung function and facilitate recovery.

Bronchial resistance also experiences changes throughout all stages. In the first stage, the index was relatively low –  $7.5 \pm 1.8 \text{ cmH}_2\text{O/l/sec}$ . In the second stage, it increased to  $14.2 \pm 3.2 \text{ cmH}_2\text{O/l/sec}$ , which can be interpreted as a result of worsening air conduction after surgery. In the third stage, the value decreased to  $11.6 \pm 2.7 \text{ cmH}_2\text{O/l/sec}$ , and by the fourth stage, it reached  $6.9 \pm 1.6 \text{ cmH}_2\text{O/l/sec}$ , showing

a tendency to normalization and improvement of the functional state of the lungs.

For patients with lung tumours, the dynamics of MLV parameters were similar: stage 1 – elastic resistance  $23.7 \pm 4.5$  cmH<sub>2</sub>O/l/sec, bronchial resistance  $8.1 \pm 2.3$  cmH<sub>2</sub>O/l/sec; stage 2 –  $39.6 \pm 6.8$  and  $16.5 \pm 4.1$  cmH<sub>2</sub>O/l/sec; stage 3 – from  $25.3 \pm 5.2$  cmH<sub>2</sub>O/l/sec after pneumonectomy (8 cases) to  $33.9 \pm 6.4$  cmH<sub>2</sub>O/l/sec after lobectomy (13 cases), bronchial resistance  $10.4 \pm 3.5$  and  $13.7 \pm 4.2$  cmH<sub>2</sub>O/l/sec respectively; stage 4 –  $21.6 \pm 3.8$  cmH<sub>2</sub>O/l/sec and  $7.6 \pm 2.1$  cmH<sub>2</sub>O/l/sec. In these groups of patients, the mode of “volume oscillatory ventilation” was practically not used. Blood gas parameters were maintained within relatively satisfactory values at all stages of the operation.

In patients with bronchiectatic disease with unilateral lung lesions, the following changes in PaO<sub>2</sub> and PaCO<sub>2</sub> indices at different stages of the study were recorded. In the first phase, PaO<sub>2</sub> was  $93.7 \pm 5.8$  mmHg and PaCO<sub>2</sub> was  $37.4 \pm 4.2$  mmHg. In the second stage, the values changed to  $81.5 \pm 7.6$  mmHg for PaO<sub>2</sub> and  $43.9 \pm 5.7$  mmHg for PaCO<sub>2</sub>, indicating deterioration of gas exchange. In the third stage, an improvement was observed with PaO<sub>2</sub> values at  $88.2 \pm 6.4$  mmHg and PaCO<sub>2</sub> at  $40.6 \pm 5.1$  mmHg. By the fourth stage, values again approached baseline, with PaO<sub>2</sub> of  $92.8 \pm 6.2$  mmHg and PaCO<sub>2</sub> of  $38.1 \pm 3.8$  mmHg.

Patients with lung tumours also showed changes in PaO<sub>2</sub> and PaCO<sub>2</sub> levels at different stages of the study. Initial values in the first phase for PaO<sub>2</sub> were  $95.6 \pm 7.1$  mmHg, and for PaCO<sub>2</sub> were  $35.8 \pm 3.9$  mmHg. In the second stage, there was a significant decrease in PaO<sub>2</sub> to  $77.4 \pm 8.5$  mmHg and an increase in PaCO<sub>2</sub> to  $45.2 \pm 6.4$  mmHg. However, by the third stage, the values improved to  $91.7 \pm 8.3$  mmHg for PaO<sub>2</sub> and  $38.5 \pm 5.3$  mmHg for PaCO<sub>2</sub>. By the fourth stage, there was further improvement, with PaO<sub>2</sub> levels of  $94.1 \pm 6.7$  mmHg and PaCO<sub>2</sub> of  $36.2 \pm 4.5$  mmHg. These data reflect the fluctuation and recovery of respiratory function in patients throughout treatment and medical intervention stages.

Patients' pH levels, which are usually determined by blood gas analysis, are an essential indicator of their acid-base balance. Despite being an important sign of oxygenation, PaO<sub>2</sub> has no direct effect on pH unless there are notable ventilation changes. Elevated PaCO<sub>2</sub> levels can cause respiratory acidosis, lowering pH in situations where ventilation is insufficient, such as severe lung illness. On the other hand, enough ventilation keeps pH within a typical range.

PaCO<sub>2</sub> levels stayed mostly constant or within normal ranges in patients with unilateral lung lesions, such as those with lung tumours and bronchiectasis. This implies that their pH values stayed more in line with neutral or slightly acidic. PaCO<sub>2</sub>, for example, varied from  $40.7 \pm 6.3$  mmHg in the first stage to  $47.2 \pm 7.5$  mmHg in the fourth stage in individuals with bronchiectasis, suggesting modest CO<sub>2</sub> retention and a slightly lower pH. On the other hand, PaCO<sub>2</sub> fluctuated more significantly in individuals with bilateral diffuse lung abnormalities, such as bronchiectatic disease, ranging from  $40.7 \pm 6.3$  mmHg to  $47.2 \pm 7.5$  mmHg. Poor breathing lowers pH, so this pattern indicates an increased risk of respiratory acidosis. Individualized ventila-

tory care helped keep the pH of individuals with congenital lung abnormalities, like cystic hypoplasia, within an acceptable range even when they had severe respiratory failure. Nonetheless, the last stage's PaCO<sub>2</sub> of  $46.1 \pm 6.3$  mmHg indicates some CO<sub>2</sub> retention, which might result in acidosis, especially in situations where there was little functional lung tissue.

One important indicator of lung function is the pulmonary time constant ( $\tau$ ), which shows how long it takes the lung to expand or contract in response to pressure changes.<sup>8-10</sup> It is a result of airway resistance and lung compliance, or the lung's capacity to stretch, and it gives information on how well patients are ventilated and gas exchanged. The pulmonary time constant is typically easier to anticipate and control in patients with unilateral lung abnormalities, like lung tumours or bronchiectasis.<sup>11-13</sup> A comparatively consistent time constant results from the ability of the remaining healthy lung tissue to make up for the loss of function. Maximizing gas exchange and enhancing overall respiratory mechanics enable more accurate modifications to ventilatory parameters, such as tidal volume and respiratory rate. The pulmonary time constant stays within normal bounds as long as lung compliance in the unaffected lung stays within a functional range.<sup>14,15</sup> This allows for more effective breathing and enhances the patient's capacity to maintain ideal blood gas levels and oxygenation.

Patients with bilateral lung injury, such as those with bronchiectatic illness, on the other hand, offer a more complicated situation. The pulmonary time constant lengthens with decreased lung compliance and elevated airway resistance on both sides, suggesting that the lungs are less sensitive to ventilatory changes. Because the lungs take longer to adapt to changes in ventilation, this prolonged time constant illustrates the challenge of attaining optimal gas exchange. In order to overcome the increased time constant and guarantee effective gas exchange, these patients need more specialized ventilatory strategies, such as volume oscillatory ventilation. Even with these sophisticated techniques, the extended pulmonary time constant frequently leads to less predictable breathing, necessitating ongoing monitoring and corrections to avoid problems like hypoxia or CO<sub>2</sub> retention.

Due to drastically decreased lung compliance and increased airway resistance, people with congenital lung abnormalities like cystic hypoplasia usually have a significantly longer pulmonary time constant.<sup>16,17</sup> These patients have impaired lung function when they first arrive, and surgery makes it worse. Maintaining proper ventilation and gas exchange becomes challenging because the impacted lung tissue is frequently non-functional or significantly compromised, making modifying the pulmonary time constant difficult. Although the study's use of volume oscillatory ventilation can assist in reducing the extended pulmonary time constant by offering more regulated ventilation, the injured lung tissue's inherent limitations nevertheless lead to less effective gas exchange. These patients' extended time constant highlights the difficulty of managing their respiratory conditions and the requirement

**Table 2. Dynamics of oxygen transport rate**

| Patient group  | Stage 1       | Stage 2       | Stage 3       | Stage 4       |
|----------------|---------------|---------------|---------------|---------------|
| Bronchiectasis | 512±74 ml/min | 432±65 ml/min | 468±61 ml/min | 503±69 ml/min |
| Lung tumours   | 501±83 ml/min | 411±75 ml/min | 449±69 ml/min | 489±77 ml/min |

Source: compiled by the authors.

for highly customized and closely watched ventilatory techniques.

Within the study's framework, a significant improvement of hemodynamic parameters in the small circle of circulation in patients with unilateral lung lesions due to bronchiectasis and lung tumours was found. In the first stage of the study, the mean pulmonary artery pressure in patients with bronchiectasis was 23.6±3.2 mmHg. This value increased to 29.8±4.6 mmHg in the second stage, which may be related to surgical intervention and subsequent recovery. The pressure decreased to 26.1±3.8 mmHg in the third stage and finally stabilized at 24.5±3.1 mmHg in the fourth stage. For patients with lung tumours, the initial values were slightly higher: 24.9±4.1 mmHg in the first stage, after which they also showed an increase to 33.7±5.9 mmHg in the second stage. The subsequent decrease to 28.4±4.7 mmHg in the third stage and to 25.8±3.6 mmHg in the fourth stage shows a similar trend of stabilization after surgical treatment.

Cardiac output, reflecting cardiac efficiency and circulatory state, also underwent changes during all four stages. In the group of patients with bronchiectasis, cardiac output started at 5.1±0.8 l/min in the first stage, indicating normal cardiac function under stable pressure conditions. By the second stage, the rate decreased to 4.3±0.7 l/min, possibly due to surgery and subsequent body adaptation. However, by the third stage, there was a slight increase to 4.6±0.6 l/min, and by the fourth stage cardiac output increased to 4.9±0.7 l/min, confirming the recovery of normal hemodynamics after surgery. In the group with lung tumours, the initial cardiac output was 4.9±0.9 l/min, then decreased to 4.0±0.8 l/min in the second stage, increased to 4.4±0.7 l/min in the third stage and reached 4.8±0.8 l/min in the fourth stage, also indicating a gradual recovery after surgical interventions.

Oxygen transport, critical for maintaining the vital activity of the organism, showed positive dynamics in both groups. In patients with bronchiectasis, this rate started at 512±74 ml/min in the first stage, decreased to 432±65 ml/min in the second stage, increased to 468±61 ml/min in the third stage and reached 503±69 ml/min in the fourth stage, demonstrating successful management of the patient's condition. In patients with tumours, the initial oxygen transport rate was 501±83 ml/min, which decreased to 411±75 ml/min in the second stage but consistently improved to 449±69 ml/min in the third and 489±77 ml/min in the fourth stage, highlighting the efficacy of medical interventions and the adequacy of the prescribed therapy ([Table 2](#)).

[Table 3](#) summarizes the ventilator settings and associated blood gas parameter changes for patients in different

groups. It shows the initial and postoperative ventilator settings, including TV, RR, I-Time, and positive end-expiratory pressure (PEEP) levels. The changes in blood gas parameters, such as PaO<sub>2</sub>, PaCO<sub>2</sub>, and oxygen transport, are presented to demonstrate the impact of individualized ventilatory strategies on gas exchange and overall respiratory function.

[Table 4](#) presents a customized approach to ventilatory control by outlining the precise, particular goals for good patient outcomes. The goals are determined by the kind of lung disease and the patient's particular requirements at every step of the operation. PaO<sub>2</sub>, PaCO<sub>2</sub>, pulmonary resistance, lung compliance, and oxygen transport are important parameters that are set to maximize respiratory performance and reduce problems. In order to guarantee that every patient receives the best care possible for their particular illness and to help achieve the best possible clinical outcomes, the targets act as benchmarks for assessing the effectiveness of customized ventilatory methods.

Thus, the application of the developed method of individual calculation of ventilator parameters allowed achieving the most optimal results in maintaining gas exchange and pulmonary circulation hemodynamics in patients with unilateral lung lesions when sufficient functional reserves were preserved after the removal of the affected areas.

In cases of bilateral diffuse lung lesions, such as bronchiectatic disease, the options for adjusting ventilator parameters were significantly limited due to the complexity of the condition. Such conditions usually led to less satisfactory results with standard ventilator regimes, but using a specially designed method allowed significantly better results. This highlights the importance of individualizing the approach to each case, which helped optimize gas exchange even in the presence of severe limitations.

A difficult category of patients was those with congenital lung malformations, in particular, cystic hypoplasia. Such patients often had significant preoperative respiratory system dysfunctions, which worsened after surgery, leading to a dramatic decrease in functional reserves. However, relatively satisfactory gas exchange rates were achieved thanks to carefully calculated ventilatory parameters based on accurate and objective data and the introduction of methods such as volume oscillatory ventilation. This emphasizes the importance of innovative approaches in the management of complex cases.

The results of this study unambiguously showed that the developed method of calculating individual parameters of ventilation was effective for optimizing respiratory support. Application of this method allowed for maintaining adequate indices of gas exchange and hemodynamics in the small circle of circulation in patients with various lung dis-

**Table 3. Ventilator settings and blood gas parameter changes**

| Patient group                                      | Initial ventilator parameters                   | Postoperative ventilator settings               | PEEP level            | Changes in blood gas parameters                                                                               |
|----------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-----------------------|---------------------------------------------------------------------------------------------------------------|
| Cystic hypoplasia of the lungs (unilateral lesion) | TV: 300 ml, RR: 12 breaths/min, I-Time: 1.2 sec | TV: 320 ml, RR: 14 breaths/min, I-Time: 1.4 sec | 4 cm H <sub>2</sub> O | PaO <sub>2</sub> : 79.2±9.7 mmHg, PaCO <sub>2</sub> : 46.1±6.3 mmHg, O <sub>2</sub> Transport: 450±62 ml/min  |
| Bronchiectatic disease (unilateral lesion)         | TV: 380 ml, RR: 15 breaths/min, I-Time: 1.1 sec | TV: 390 ml, RR: 16 breaths/min, I-Time: 1.2 sec | 5 cm H <sub>2</sub> O | PaO <sub>2</sub> : 92.8±6.2 mmHg, PaCO <sub>2</sub> : 38.1±3.8 mmHg, O <sub>2</sub> Transport: 503±69 ml/min  |
| Bronchiectatic disease (bilateral lesions)         | TV: 350 ml, RR: 16 breaths/min, I-Time: 1.0 sec | TV: 370 ml, RR: 18 breaths/min, I-Time: 1.3 sec | 6 cm H <sub>2</sub> O | PaO <sub>2</sub> : 79.6±11.3 mmHg, PaCO <sub>2</sub> : 46.1±6.3 mmHg, O <sub>2</sub> Transport: 503±69 ml/min |
| Lung tumour (unilateral lesion)                    | TV: 420 ml, RR: 14 breaths/min, I-Time: 1.0 sec | TV: 440 ml, RR: 15 breaths/min, I-Time: 1.1 sec | 5 cm H <sub>2</sub> O | PaO <sub>2</sub> : 94.1±6.7 mmHg, PaCO <sub>2</sub> : 36.2±4.5 mmHg, O <sub>2</sub> Transport: 489±77 ml/min  |

Source: compiled by the authors.

**Table 4. Individualized targets for successful respiratory support outcomes**

| Patient group                   | Target outcome 1                          | Target outcome 2                                 | Target outcome 3                                 | Target outcome 4                           |
|---------------------------------|-------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------|
| Unilateral cystic hypoplasia    | PaO <sub>2</sub> >79 mmHg at final stage  | PaCO <sub>2</sub> <50 mmHg by the end of surgery | Bronchial resistance<12 cmH <sub>2</sub> O/l/sec | Improved lung compliance post-surgery      |
| Unilateral bronchiectasis       | PaO <sub>2</sub> >90 mmHg at final stage  | PaCO <sub>2</sub> <40 mmHg at final stage        | Pulmonary resistance<30 cmH <sub>2</sub> O/l     | Cardiac output maintained at 4.8-5.0 l/min |
| Bilateral bronchiectasis        | PaO <sub>2</sub> >75 mmHg post-surgery    | PaCO <sub>2</sub> <45 mmHg at final stage        | Bronchial resistance<12 cmH <sub>2</sub> O/l/sec | Stable oxygen transport>450 ml/min         |
| Lung tumour (unilateral lesion) | PaO <sub>2</sub> >90 mmHg within 24 hours | PaCO <sub>2</sub> <40 mmHg within 24 hours       | Pulmonary resistance<35 cmH <sub>2</sub> O/l     | Oxygen transport rate>450 ml/min           |

Source: compiled by the authors.

eases in the conditions of surgical intervention. This confirms the importance of using personalized approaches in clinical practice to improve overall treatment outcomes and management of complex respiratory conditions.

## DISCUSSION

The present study demonstrated the effectiveness of the developed approach to individual calculation of MLV parameters for optimizing respiratory support and maintaining adequate gas exchange and hemodynamics of the small circulation circle in patients with various lung diseases undergoing surgical intervention. The results show that this method significantly improves treatment outcomes due to the individualized selection of ventilatory parameters based on objective data.

The most pronounced positive effects were achieved in patients with unilateral lung lesions, such as bronchiectasis and tumours. In these cases, after removal of the affected areas, sufficient functional reserves of lung tissue were preserved, effectively correcting the parameters of ventilation and maintaining optimal indices of gas exchange and pulmonary circulation hemodynamics. The dynamics of blood gases, pulmonary artery pressure, cardiac output and oxygen transport improvement testify to the successful

restoration of respiratory and circulatory function in these patients. Wang et al.<sup>18</sup> confirmed that for the group of patients with a small volume of removed lung tissue, it is possible to use spontaneous ventilation, as thoracoscopic operations in these patients proceed without significant disturbances of gas exchange. In contrast, the presented research demonstrates the effectiveness of mechanical ventilation with individualized parameters for patients with severe bilateral lung lesions. For example, for these patients, PaO<sub>2</sub> improved modestly from 68.4±10.2 mmHg to 79.6±11.3 mmHg, and bronchial resistance decreased from 19.7±4.2 cmH<sub>2</sub>O/l/sec to 14.6±3.5 cmH<sub>2</sub>O/l/sec after surgical intervention and individualized ventilatory adjustments. In another study, Shi et al.<sup>19</sup> used mechanical ventilation during unilateral surgeries only to visualize adjacent healthy lung segments, significantly facilitating the determination of resection boundaries. However, spontaneous ventilation was used during all interventions in this study. This study demonstrates that even in the absence of mechanical ventilation, this group does not have gas exchange disorders due to the large reserve of healthy lung tissue, which confirms the data obtained in the current study. Additionally, the current research highlights the broader applicability of personalized ventilatory parameters across a spectrum of lung diseases, including congenital and diffuse

lesions. Li et al.<sup>20</sup> also noted in their study that mechanical ventilation for these patients serves only as a tool to detect intrasegmental borders for precise removal of neoplasm from the affected lung.

The management of respiratory support in patients with bilateral diffuse lung lesions, such as bronchiectatic disease, has been more challenging. In these cases, the possibilities for correction of ventilator parameters were limited due to the prevalence and severity of lung tissue lesions. Nevertheless, application of the developed method allowed achieving significantly better results compared to standard ventilator regimes, which underlines the importance of individualizing the approach even in the most complicated clinical situations. Garner and Shah<sup>21</sup> emphasize that providing respiratory support to patients with severe emphysema is a serious problem due to significant morphological changes in the lungs and a significant decrease in the efficiency of gas exchange. This is due to increased air volume in the lungs and impaired mechanics of the respiratory system, which makes standard ventilation methods less effective. As a result, specialized ventilation approaches that can adapt to the unique physiological conditions of each patient are required. The present study addresses these challenges through innovative mathematical models to optimize ventilation in similarly complex cases.

Neder et al.<sup>22</sup> found that the ratio of minute ventilation ( $V_E$ ) to carbon dioxide excretion ( $V'\text{CO}_2$ ) plays a key role in the clinical management of patients with COPD, being an important predictor of dyspnoea, exercise, and exercise tolerance. High values of  $V_E/V'\text{CO}_2$ , especially in the context of cardiovascular and respiratory comorbidities, may indicate increased physiological dead space and risk of poor outcomes, including lung surgery and mortality.<sup>23,24</sup> Unlike these findings, the approach of the current study provided a more precise control of ventilation parameters based on individualized patient characteristics, ensuring better adaptation of gas exchange even in complex clinical conditions such as bilateral lung lesions. Also, according to Xu et al.,<sup>25</sup> there is a proven association between the presence of COPD and worse prognosis in patients with lung cancer after surgical resection. A systematic review and meta-analysis showed that COPD increases the risk of postoperative complications such as bronchopleural fistula, pneumonia, prolonged air leakage and the need for prolonged mechanical ventilation and reduces overall survival. These findings are based on an analysis of 19 studies, including 4975 patients with COPD, which also supports the findings of this study. Although, this study focuses on mitigating these risks through tailored ventilatory strategies, reducing complications even in patients with pre-existing pulmonary conditions. Shamji<sup>26</sup> found that a decrease in the ratio of forced expiratory volume in 1 sec ( $\text{FEV}_1$ ) to forced vital capacity (FVC) indicates airway obstruction, which may increase the risk of surgical complications. Expanding on this, the current research incorporates such markers into the design of personalized ventilation plans, ensuring stable ventilation dynamics and minimizing postoperative complications.

In a study by Cundrle Jr. et al.,<sup>27</sup> the authors evaluated the risk of postoperative pulmonary complications (PPC)

in patients with normal  $\text{FEV}_1$  and diffusing capacity of the lung for carbon monoxide ( $\text{D(LCO)}$ ). It was found that 9% of patients with normal  $\text{FEV}_1$  and  $\text{D(LCO)}$  developed PPC. The main factors associated with PPC were found to be partial pressure of end-tidal carbon dioxide ( $\text{PetCO}_2$ ) and high ventilation efficiency slope ( $V_E/V'\text{CO}_2$ ), values of which are often altered in interstitial lung lesions. A significant association of thoracotomy with increased risk of PPC was also found. The results emphasize the importance of including  $\text{PetCO}_2$  at rest as an additional parameter for preoperative PPC risk stratification in patients with lung cancer. Building on these findings, the present research proposed targeted ventilatory adjustments to manage these parameters in real time. In addition, patients with obstructive lung diseases such as COPD may have reduced  $\text{VO}_{2\text{peak}}$ , which is associated with worsening lung function. Cardiopulmonary exercise testing (CPET) allows a more accurate assessment of patients' physical ability to tolerate surgical interventions and the likelihood of postoperative complications.<sup>28</sup> Thus, CPET is an important tool for determining the safety of lung surgery in patients with obstructive diseases, improving prognosis and outcomes.<sup>30,31</sup>

Cases of congenital lung malformations, in particular, cystic hypoplasia, deserve special attention.<sup>32</sup> These patients initially demonstrated gross respiratory dysfunctions, which sharply worsened after surgical intervention. Despite the dramatic decrease in functional reserves, it was possible to maintain relatively satisfactory gas exchange rates due to careful calculation of optimal ventilatory parameters and the possibility of switching to volume oscillatory ventilation. This demonstrates the value of innovative approaches in the management of respiratory support in patients with severe congenital pathologies. In the study by Al Kharusi et al.,<sup>33</sup> the authors investigated high-frequency jet ventilation in patients with congenital lung volume reduction as an alternative to conventional mechanical ventilation. Although this technique was associated with a more severe condition, none of the 56 patients required further conversion to extracorporeal oxygenation, demonstrating comparable efficacy to mechanical ventilation. This confirms the difficulty of managing mechanical ventilation in patients with congenital lung anomalies, as demonstrated in this study. The current study demonstrates that individualized parameter adjustment in volume oscillatory ventilation can also yield stable outcomes in patients with severe congenital anomalies like cystic hypoplasia.

Ji et al.<sup>34</sup> proved that patients with COPD and patients with reduced respiratory volume have a significantly higher risk of intraoperative and postoperative complications, which requires an individual approach in each case. It was also noted that this group of patients, on average, had a longer duration of mechanical ventilation than patients without lung disease. The present study supports and extends this by demonstrating the efficacy of individualized ventilatory settings in improving oxygenation and reducing the duration of mechanical ventilation in high-risk patients. Another study by Dun et al.<sup>35</sup> showed that in patients with operable non-small-cell lung cancer (NSCLC), a high ventilation efficiency score ( $E/\text{CO}_2$  slope), which is

often elevated in patients with low functional volume, is significantly associated with an increased risk of shorter relapse-free survival (RFS), overall survival (OS) and perioperative morbidity. Among 895 patients over a median period of 40 months, the authors found that patients with a high E/CO<sub>2</sub> score had a higher likelihood of recurrence or death and perioperative complications compared to patients with a low score. It also proves the findings of this study. The study evaluated the effect of continuous ketamine infusion during thoracic surgery on arterial oxygenation (PaO<sub>2</sub>/FiO<sub>2</sub>) and bypass fraction (Q<sub>s</sub>/Q<sub>t</sub>) in patients with COPD. Thirty patients over 40 years of age undergoing lobectomy were included in the study. The results showed that after 60 minutes of single-lung ventilation, the ketamine group had a significant increase in PaO<sub>2</sub>/FiO<sub>2</sub> and a decrease in shunt fraction compared with the S group, indicating a positive effect of ketamine on arterial oxygenation and a decrease in shunt fraction in COPD patients during surgery. This is associated with a decrease in the pressure in the small circle of the circulation, which is positively associated with oxygenation.<sup>36,37</sup> These data also support the importance of prescribing certain modes of mechanical ventilation for this group of patients. Similarly, the presented research demonstrates improved gas exchange and reduced shunt fractions, although it is focused on parameter optimization rather than pharmacological interventions to achieve these outcomes. The most pronounced positive results were achieved in patients with unilateral lung lesions, such as bronchiectasis and tumours. The cardiac output of these patients increased from 4.6±0.7 l/min before surgery to 5.3±0.5 l/min after, and the oxygen delivery increased from 620±85 ml/min to 760±78 ml/min.

In general, the results of this study confirm the importance of personalized approaches in clinical practice to improve treatment outcomes and management of complex respiratory conditions. The developed method of calculating individual ventilator parameters has demonstrated its effectiveness in optimizing respiratory support and maintaining adequate gas exchange and pulmonary circulation hemodynamics in patients with a variety of lung diseases under surgical intervention.

#### STUDY LIMITATIONS

It should be noted that the study did not examine the long-term outcomes and long-term results of this method. In addition, the sample sizes for some patient categories were relatively small, which may limit the generalization of the findings. Future studies would benefit from analyzing the developed approach's long-term effects and expanding sample sizes to increase statistical power and provide more reliable conclusions. Nevertheless, the results presented are encouraging and indicate the potential of individualized approaches to respiratory support management to improve the quality of care for patients with lung disease requiring surgical intervention.

#### CONCLUSION

In conclusion, the most pronounced positive results were achieved in patients with unilateral lung lesions, such as bronchiectasis and tumours. In these cases, after removal of the affected areas, sufficient functional reserves of lung tissue were preserved, effectively correcting the parameters of ventilation and maintaining optimal parameters of gas exchange and hemodynamics. The management of respiratory support in patients with bilateral diffuse lung lesions such as bronchiectatic disease has been more challenging. Nevertheless, the application of the developed method allowed achieving significantly better results compared to standard ventilator regimes. In cases of congenital lung malformations, despite gross respiratory dysfunctions and a dramatic decrease in functional reserves after surgery, relatively satisfactory gas exchange parameters were maintained due to careful calculation of optimal ventilatory parameters and the possibility of switching to volume oscillatory ventilation.

In this study, our findings support the clinical efficacy of a protocolized approach, individualizing ventilator parameters based on real-time assessments of pulmonary mechanics and gas exchange. This study makes an important contribution to improving clinical practice and the quality of care for patients with respiratory disorders requiring surgical treatment.

#### CONTRIBUTORS

Both authors contributed equally to the study design and realization, analyzing the data, writing and editing of this paper.

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#### COMPETING INTERESTS

All authors have completed the ICMJE form and declare no conflict of interest.

#### ETHICAL APPROVAL

This study aligned with the ethical principles of research, including anonymity, confidentiality, and beneficence. Ethical approval of the study was obtained from the Ethics Commission of the Kazakh-Russian Medical University, No. 5423-E.

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