

# Research Status and Development of Pulmonary Protection Strategies during the Cooperative Period in Cardiothoracic Surgery

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## Abstract

This review focuses on the pulmonary protection strategies during the cooperative period in cardiothoracic surgery. By deeply analyzing the psychophysiology mechanism of pulmonary injury during the cooperative period, it comprehensively sorts out the pulmonary protection strategies and their research progress in key areas covered in current clinical practice, including optimizing mechanical ventilation strategies, drug intervention, fluid management, and respiratory function exercise. The study systematically interprets the advantages and application limitations of existing strategies and prospectively looks forward to the innovative directions of future pulmonary protection strategies. It aims to provide an evidence-based medical reference with theoretical depth and practical value for improving the refined management level of pulmonary function of patients undergoing cardiothoracic surgery during the cooperative period.

## Keywords

Cooperative Period, Pulmonary Injury, Pulmonary Protection Strategies

## 1. Introduction

As the core treatment for diseases of the heart, lungs, and mediastinum, cardiothoracic surgery saves patients' lives. However, surgical trauma and anesthesia intervention often trigger a series of complex pulmonary complications, which have become key factors restricting the postoperative recovery process and long-term prognosis of patients. Among patients undergoing cardiothoracic surgery, the overall incidence of postoperative pulmonary complications (PPCs) is as high as 15%

- 30%. For high-risk groups such as elderly patients, long-term smokers, and those with chronic obstructive pulmonary disease (COPD), this proportion exceeds 40%. Diseases such as electrostatic, hypoxemia, and acute respiratory distress syndrome (ARDS) caused by cooperative lung injury have multi-dimensional negative impacts, increasing patients' hospital stay and medical costs, and even endangering their lives [1]. In summary, from the perspectives of ensuring patients' lives and health, improving the quality of medical services, and optimizing the allocation of medical resources, it is extremely urgent to develop scientific and effective cooperative lung protection strategies [2]. In recent years, with the continuous deepening of research on the mechanisms of lung injury and the continuous accumulation of clinical experience, various lung protection strategies have been gradually applied in the cooperative management of cardiothoracic surgery. This article will comprehensively review the current research status and development trends of cooperative lung protection strategies in cardiothoracic surgery.

## **2. Psychophysiology Mechanism of Cooperative Pulmonary Injury**

### **2.1. Mechanical Ventilation-Related Pulmonary Injury**

Mechanical ventilation is a commonly used method to maintain respiratory function during cardiothoracic surgery. However, inappropriate ventilation modes and parameter settings can lead to mechanical ventilation-related pulmonary injury (VILI) [3]. VILI mainly includes volumetric, traumatic, electorate, and bio trauma. Volumetric is caused by excessive tidal volume, leading to expansion and rupture of alveoli. Traumatic is related to excessively high airway pressure. The electorate is caused by shear force injury during the periodic opening and closing of alveoli. Bio trauma refers to the inflammatory response induced by mechanical ventilation, which activates immune cells in the lungs and releases a large number of inflammatory mediators, further aggravating lung tissue injury [4].

### **2.2. Inflammatory Response and Oxidative Stress**

Factors such as surgical trauma, the effect of anesthetic drugs, and cardiopulmonary bypass can activate the body's inflammatory response. Inflammatory cells accumulate in the lungs and release a variety of inflammatory cytokines, such as tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ) and interleukin-6 (IL-6), triggering systemic inflammatory response syndrome (SIRS) [5]. At the same time, the level of oxidative stress increases, and the production of reactive oxygen species (ROS) increases, which damages the biomembrane structure of lung tissue cells, affects the normal function of cells and aggravates the degree of lung injury [6].

### **2.3. Changes in Pulmonary Aerodynamics**

In the field of cardiothoracic surgery, especially when cardiopulmonary bypass (CPB) is required for cardiac surgery, significant pathological changes occur in the aerodynamic characteristics of the pulmonary circulation system [7]. The car-

diopulmonary bypass technology, by establishing an artificial cardiopulmonary bypass circuit, while interrupting the physiological circulation, triggers a series of chain reactions: Firstly, there is a sharp decrease in the pulmonary circulation blood flow, which is closely related to the non-pulsate blood flow pattern, the effect of blood dilution, and the state of systemic hypothermia during cardiopulmonary bypass, directly leading to varying degrees of increase in the mean pulmonary artery pressure (mPAP) and pulmonary vascular resistance (PVR). This aerodynamic disorder further disrupts the oxygen supply-demand balance of lung tissue—the decrease in arterial partial pressure of oxygen ( $\text{PaO}_2$ ) and the increase in cardiopulmonary shunt cause lung parenchymal cells to be in a relative hypotaxis state, inducing the abnormal activation of anaerobic metabolic pathways, accompanied by lactic acid accumulation and energy metabolism disorders [8]. Of particular importance is that after the restoration of pulmonary blood perfusion at the end of cardiopulmonary bypass, the mechanism of lung ischemia-percussion injury (LIRI) is initiated: The oxidative stress response-mediated endothelial cell injury promotes the massive recruitment of neutrophils in the pulmonary circulation and the release of myeloperoxidase (MPO), while activating the complement system and the pro-inflammatory cytokines cascade reaction (such as a significant increase in the levels of  $\text{TNF-}\alpha$  and IL-6), resulting in the dysfunction of the pulmonary vascular endothelial barrier. Psychophysiology, is manifested by the abnormal increase in the vascular permeability index (Kf), the aggravated intramuscular leakage of plasma proteins and water, the formation of interstitial and even alveolar pulmonary edema, accompanied by the inactivation of alveolar surfactant, ultimately seriously interfering with the lung gas exchange function. This pathological process involves multi-target molecular mechanisms and becomes an important pathological basis for postoperative acute lung injury (ALI) and even acute respiratory distress syndrome (ARDS) [9].

#### 2.4. Patient-Related Factors

The patient's baseline pulmonary function status, age, and comorbidities (such as chronic obstructive pulmonary disease, diabetes mellitus, etc.) are all key factors influencing the occurrence and progression of cooperative lung injury. From a physiological perspective, elderly patients experience a significant decline in lung tissue elasticity due to degeneration of elastic fibers and proliferation of collagen fibers. Concurrently, weakened respiratory muscle strength and reduced thoracic compliance lead to insufficient pulmonary functional reserve, making it difficult to withstand the physiological stress from surgical trauma and anesthesia. In patients with chronic pulmonary diseases (such as chronic obstructive pulmonary disease), irreversible airway remodeling and airflow limitation result in significantly increased airway resistance. Combined with alveolar structural damage and diffusion dysfunction, their gas exchange efficiency is drastically reduced. For patients with diabetes mellitus, cardiovascular lesions and impaired immune function caused by long-term hyperglycemia not only affect pulmonary tissue re-

pair capacity but also increase the risk of infection. These factors interweave to greatly enhance the probability of cooperative lung injury, making such patients the primary focus of cooperative lung protection management.

### **3. Research Status of Cooperative Pulmonary Protection Strategies**

#### **3.1. Optimization of Mechanical Ventilation Strategies**

(1) **Low Tidal Volume Ventilation** Low tidal volume ventilation (6 - 8 ml/kg of predicted body weight) is currently a recognized effective pulmonary protection ventilation strategy. Clinical studies by Wang Lixia *et al.* [10] have shown that compared with traditional high-tidal-volume ventilation, low-tidal-volume ventilation can significantly reduce the incidence of ARDS and decrease pulmonary complications. Its principle lies in avoiding the expansion of alveoli and reducing the risk of volumetric and trauma. However, low tidal volume ventilation may lead to carbon dioxide retention, and it needs to be managed in combination with appropriate adjustments to the respiratory rate and the permissive hypercritical strategy.

(2) **Positive End-expiratory Pressure (PEEP)** maintains a certain positive airway pressure at the end of exhalation, preventing alveolar collapse and improving lung compliance and oxygenation function. Reasonable setting of the PEEP level is crucial for pulmonary protection. Currently, commonly used clinical methods include selecting the optimal PEEP according to the static pressure-volume curve and gradually reducing the PEEP after lung recruitment maneuvers. Studies have shown that individualized PEEP settings can more effectively improve patients' oxygenation and reduce lung injury. However, PEEP that is too high may increase intracranial pressure and affect cardiac function, and a comprehensive evaluation of the patient's cardiopulmonary function is required for adjustment [11].

(3) **Lung Recruitment Maneuvers** Lung recruitment maneuvers briefly increase the airway pressure to reopen the collapsed alveolar and improve the ventilation-perfusion ratio. Commonly used lung recruitment maneuvers include controlled lung inflation, pressure control methods, etc. Studies have shown that the timely application of lung recruitment maneuvers during mechanical ventilation can improve lung compliance, enhance oxygenation, and reduce the occurrence of electrostatic. However, lung recruitment maneuvers also have potential risks. For example, excessively high pressure may lead to trauma, and cautious operation is required [12].

#### **3.2. Pharmacological Interventions**

##### **3.2.1. Hydrocortisone**

Hydrocortisone has potent anti-inflammatory effects. They can inhibit the activation of inflammatory cells and the release of inflammatory mediators, thereby reducing the inflammatory response in lung tissues. During the cooperative period of cardiothoracic surgery, hydrocortisone is commonly used to prevent and treat

acute lung injury and has achieved good therapeutic effects. Additionally, studies by Gesa J Albers *et al.* on mouse models have shown that the application of hydrocortisone can improve pulmonary oxygenation function and effectively inhibit the secretion of pro-inflammatory mediators [13] [14]. However, the use of hydrocortisone may increase the risk of infection and affect wound healing. Therefore, it is necessary to grasp the indications and the timing of use strictly and weigh the benefits and risks.

### 3.2.2. Antioxidants

Oxidative stress plays an important role in lung injury. Antioxidants can reduce oxidative damage to the lungs by scavenging reactive oxygen species (ROS) [15] [16]. Common antioxidants include vitamin C, vitamin E, N-acetylcysteine (NAC), etc. Clinical studies have shown that the cooperative application of NAC can reduce the level of oxidative stress in patients, improve lung function, and reduce pulmonary complications [17]. In addition, some new antioxidants also show potential application value in pulmonary protection during the cooperative period of cardiothoracic surgery and have achieved satisfactory results in animal experiments, such as rawboned [18].

### 3.2.3. Ulinastatin

Multinational is a broad-spectrum protease inhibitor. It can inhibit the release of various inflammatory mediators, regulate the immune function of the body, and reduce the inflammatory response. During the cooperative period of cardiothoracic surgery, multinational is commonly used to protect the function of important organs, including the lungs [19]. A meta-analysis has found that multinationals can reduce the levels of inflammatory cytokines in patients' serum, improve lung compliance, and reduce the occurrence of pulmonary complications [20].

## 3.3. Fluid Management

Reasonable fluid management is crucial for maintaining the circulatory stability and lung function of patients. The traditional open fluid management strategy is prone to fluid overload, which can exacerbate pulmonary edema and increase the risk of pulmonary complications. Currently, the restrictive fluid management strategy is widely applied during the cooperative period of cardiothoracic surgery. Restrictive fluid management emphasizes precisely controlling the fluid input according to the patient's aerodynamic indicators (such as central venous pressure, stroke volume variation, etc.) and urine output to avoid excessive fluid accumulation in lung tissues. Clinical studies have shown that restrictive fluid management can reduce the incidence of postoperative pulmonary complications and shorten the length of hospital stay of patients. However, excessive fluid restriction may lead to insufficient tissue perfusion. Therefore, it is necessary to dynamically monitor the patient's circulatory status and achieve individualized fluid management [21].

### 3.4. Respiratory Function Training

Preoperative respiratory function training can improve the pulmonary function reserve of patients and enhance the strength of respiratory muscles, which is helpful for the recovery of respiratory function after surgery. Common respiratory function training methods include pursed-lip breathing, diaphragmatic breathing, balloon-blowing training, etc. The study by Katsura M *et al.* [22] has shown that standardized preoperative respiratory function training can reduce the incidence of postoperative pulmonary complications and improve pulmonary ventilation function. Early postoperative respiratory function training, such as deep breathing training and effective coughing and expectoration, is helpful for promoting the discharge of sputum, preventing electrostatic, and accelerating the recovery of lung function [23] [24].

### 3.5. Other Strategies

#### 3.5.1. Selection of Anesthetic Methods

The selection of anesthesia methods during the cooperative period is closely related to the outcome of patients' pulmonary function. Clinical studies have confirmed significant differences in the pulmonary protective effects of different anesthesia strategies. Regional block anesthesia techniques, represented by the thoracic paravertebral nerve block, can effectively reduce the dosage of general anesthetics through precise nerve conduction blockage, thereby decreasing the risk of postoperative pulmonary complications. Its potential mechanisms may involve multi-dimensional physiological regulation. On the one hand, this technique can significantly alleviate the systemic inflammatory response and stress levels induced by surgical trauma, inhibiting the adverse effects of excessive echolocation release on the respiratory and circulatory systems. On the other hand, by avoiding the inhibitory effect of general anesthetics on the intramuscular junctions of respiratory muscles, it maintains the normal contraction function of respiratory muscle groups such as the diaphragm, promotes effective ventilation and sputum clearance after surgery, and provides a guarantee for the rapid recovery of patients' postoperative pulmonary function. In addition, replacing tracheal incubation with laryngeal mask ventilation can reduce airway injury and lower the risk of complications such as postoperative sore throat and hoarseness [25].

#### 3.5.2. Nutritional Support

Reasonable, cooperative nutritional support helps maintain the immune function and respiratory muscle strength of patients. For patients undergoing cardiothoracic surgery, early postoperative enteral nutritional support can promote the recovery of intestinal function, reduce bacterial translocation, and lower the risk of infection, which plays a positive role in protecting lung function. Meanwhile, supplementing nutrients rich in  $\omega$ -3 fatty acids can regulate the body's inflammatory response and reduce lung tissue injury [26].

## 4. Problems and Challenges of Existing Pulmonary Protection Strategies

Although a variety of cooperative pulmonary protection strategies for cardiothoracic surgery have been formed, there are still many problems and challenges in clinical application. In terms of optimizing mechanical ventilation strategies, although strategies such as low tidal volume ventilation and PEEP have been widely used, there is still a lack of unified standards on how to accurately determine the optimal ventilation parameters and balance pulmonary protection and gas exchange function. In terms of pharmacological interventions, the use of drugs such as hydrocortisone has risks of infection and adverse reactions, and the research and development and clinical application of new drugs still need further exploration. In fluid management, the formulation of individualized fluid management plans depends on complex monitoring indicators and professional clinical judgment, which makes it difficult to popularize in primary medical institutions. The compliance of respiratory function training is greatly affected by the cognitive level and degree of cooperation of patients, and some patients find it difficult to adhere to standardized training. In addition, the synergistic mechanism between different pulmonary protection strategies is still unclear, and how to optimize the combined application plan to improve the effect of pulmonary protection is also an urgent problem to be solved.

## 5. Future Development Directions

### 5.1. Precise Pulmonary Protection Strategies

With the development of technologies such as genomics and proteomic, in the future, through individualized gene testing and biomarker analysis of patients, it will be possible to predict the risk of pulmonary injury in patients and formulate precise pulmonary protection strategies. For example, according to the genetic isomorphism of patients, more suitable drugs and dosages can be selected to improve the efficacy and safety of pharmacological interventions. At the same time, by using artificial intelligence and big data technologies, integrating patients' clinical information, physiological parameters, etc., an intelligent decision-making model for pulmonary protection strategies can be established to achieve real-time dynamic optimization and adjustment of mechanical ventilation parameters [27].

### 5.2. Research and Development of New Drugs and Treatment Methods

The research and development of new drugs with stronger anti-inflammatory and antioxidant effects and fewer adverse reactions is an important direction for developing future pulmonary protection strategies. For example, treatment methods based on stem cells and lysosomes have great potential in the treatment of lung injury due to their immune regulation and tissue repair functions [28]. In addition, exploring the application of traditional Chinese medicine in cooperative pulmonary protection for cardiothoracic surgery, exploring the anti-inflammatory

and antioxidant mechanisms of the effective components of traditional Chinese medicine, and developing new traditional Chinese medicine preparations or integrated traditional Chinese and Western medicine treatment plans. For example, research by the team of Peng W *et al.* has shown that Lianhua Qingke Tablets have excellent clinical efficacy in the treatment of ALI [29].

### **5.3. Optimization of Multi Modal Pulmonary Protection Strategies**

Future research should focus on the synergistic mechanisms among different lung protection strategies. Through systematic analysis of the interactive effects between optimized mechanical ventilation parameters, selection of drug intervention targets, precise fluid management models, and individualized respiratory function training programs, a scientific integration framework for multi-modal lung protection strategies should be constructed. In clinical practice, it is necessary to break the limitations of single-strategy application. The mechanical ventilation strategy of low tidal volume combined with lung recruitment should be organically integrated with drug interventions with anti-inflammatory and antioxidant effects, precise fluid management based on aerodynamic monitoring, as well as preoperative respiratory muscle training and postoperative progressive rehabilitation exercise programs, to form individualized lung protection plans that can be dynamically adjusted. Meanwhile, efforts should be made to strengthen the construction of multidisciplinary collaboration networks. By integrating the superior resources of multiple disciplines, including cardiothoracic surgery, anesthesiology, critical care medicine, and rehabilitation medicine, a full-process interdisciplinary collaboration mechanism covering preoperative assessment, intraoperative management, and postoperative rehabilitation should be established. Through regular case discussions, joint ward rounds, and multidisciplinary consultations, precise formulation and efficient implementation of lung protection strategies can be achieved. This approach aims to minimize the incidence of postoperative pulmonary complications, enhance patients' cooperative safety, and improve long-term rehabilitation outcomes.

### **5.4. Strengthening Patient Education and Management**

Strengthening patients' awareness of the core value of cooperative lung protection and establishing a systematic patient education and management system are crucial approaches to enhancing compliance with lung protection measures such as respiratory function exercises. In clinical practice, diversified health education activities can be carried out, including organizing special lectures and providing one-on-one bedside guidance. These efforts, combined with the distribution of informative illustrated brochures and vivid video materials, help patients thoroughly understand the scientific methods and key points of preoperative respiratory function exercises (such as pursed-lip breathing and diaphragmatic breathing training) and postoperative rehabilitation exercises (such as effective coughing and expectoration, early ambulation). Meanwhile, relying on information tech-

nology to build a patient follow-up management system enables comprehensive tracking and guidance throughout the cooperative period, allowing for dynamic adjustment of lung protection plans and forming a closed-loop management model of “education-practice-feedback-optimization.” Through the above measures, patients’ subjective initiative can be fully mobilized, encouraging their in-depth participation in the entire process of lung protection, effectively reducing the risk of postoperative pulmonary complications, and significantly improving surgical rehabilitation outcomes and long-term prognosis.

## 6. Conclusions

Cardiothoracic surgery, due to its involvement of vital intracranial organs and complex physiological structures, significantly increases the risk of cooperative lung injury, which has become one of the core clinical issues affecting surgical prognosis. As a key medical intervention to reduce the incidence of postoperative pulmonary complications (such as electrostatic, pneumonia, acute respiratory distress syndrome, etc.) and improve patient outcomes, lung protection strategies have received extensive attention in clinical practice in recent years. Currently, a multi-modal lung protection strategy system primarily based on mechanical ventilation optimization, drug intervention, respiratory function training, and positional management has been preliminary established in clinical settings, and has shown positive effects in some studies. However, existing strategies still face multiple challenges: the individualized setting of mechanical ventilation parameters lacks precise biomarker guidance, the timing window and dose optimization of drug interventions have not yet formed unified standards, the synergistic mechanisms between different strategies remain incompletely understood, and specific protocols for special patient populations such as the elderly and those with chronic obstructive pulmonary disease (COPD) still need improvement.

Therefore, future research needs to break through in the following dimensions: First, deeply analyze the molecular mechanisms of cooperative lung injury, with a focus on the dynamic regulatory networks of oxidative stress, inflammatory cascade reactions, and alveolar epithelial-capillary endothelial barrier dysfunction, to provide a theoretical basis for targeted therapy. Second, develop individualized risk prediction models based on genomics, proteomic, and metabolic technologies to achieve precise stratification of lung protection strategies—for example, by screening gene isomorphism of inflammatory factors such as IL-6 and TNF- $\alpha$ , preventive anti-inflammatory protocols can be formulated for patients with hereditary hyperinflammatory responses. Third, accelerate the transitional application of novel drugs and treatment technologies, such as immediateness intercellular signal regulation, the noninflammatory effects of melancholy stem cell transplantation, and the antioxidant effects of hydrogen-oxygen mixed gas inhalation, all of which require verification of their safety and efficacy through centimeter randomized controlled trials (RCTs). Fourth, optimize the timing and dosage of combined multi-modal strategies and explore synergistic enhancement modes of

“mechanical ventilation + drug intervention + rehabilitation training,” which may further reduce the incidence of electrostatic. In addition, a standardized patient education and management system needs to be established, with dynamic monitoring of respiratory function indicators through digital follow-up platforms to improve patient compliance with postoperative rehabilitation protocols. It is worth noting that while promoting technological innovation, attention must be paid to the accumulation and transformation of evidence-based medical evidence. It is recommended that systematic reviews and meta-analysis methods be used to integrate existing research evidence, evaluate the recommendation grades of different strategies through the GRADE system, and pay attention to the impact of research heterogeneity and publication bias on conclusions. For cutting-edge fields such as artificial intelligence (AI)-assisted ventilation parameter adjustment and the prophylactic application of extracorporeal membrane oxygenation (ECMO) in high-risk patients, prospective cohort studies are needed to clarify their cost-effectiveness ratios and ethical considerations. Through the deep integration of basic research and clinical practice and the collaborative efforts of multidisciplinary teams, it is expected to construct a more efficient and precise cooperative lung protection system, providing a new diagnostic and therapeutic paradigm for improving the prognosis of cardiothoracic surgery patients.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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