



Progress in Clinical Application of Positive End-Expiratory Pressure

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

In the surgery patient under general anesthesia doesn't breathe spontaneously, and lung movement is completely dependent on the mechanical ventilation of the anesthesia machine. In order to achieve effective and safe mechanical ventilation of the patient's lungs during the operation, the concept of lung protective ventilation strategy (LPVS) was proposed, that is, the use of a low tidal volume and an appropriate level of positive end expiratory pressure (PEEP) to reduce alveolar overexpansion and prevent alveolar collapse. In the past, PEEP was an important measure to treat acute lung injury(ALI) or acute respiratory distress syndrome(ARDS) by improving oxygenation and reducing pulmonary edema. Subsequent studies found that PEEP not only be used to treat patients with ALI or ARDS, but also can reduce the incidence of postoperative pulmonary complications(PPCs) in some thoracoabdominal operations. Moreover, PEEP can prevent atelectasis during and after surgery in patients undergoing thoracic and abdominal surgery under general anesthesia, and decrease the incidence of postoperative infection. However, PEEP can affect venous return by increasing intrathoracic pressure, thereby causing changes in heart function and hemodynamics, and indirectly affecting intracranial pressure and renal function. Therefore, with the widespread clinical application of PEEP, more and more people are starting to focus on how to choose the appropriate PEEP. This article reviews the research progress of PEEP selection method, the influence of PEEP on physiological function and the clinical application of PEEP during mechanical ventilation.

Keywords: Positive end-expiratory pressure; acute respiratory distress syndrome; general anesthesia; mechanical ventilation; lung protection.

1. INTRODUCTION

Lung protective ventilation strategies include many measures: low tidal volume, positive end-expiratory pressure (PEEP), lung recruitment, lower FiO_2 , respiratory rate, inspiratory/expiratory ratio, and permissive hypercapnia [1,2]. The application of low tidal volume combined with appropriate PEEP ventilation is the most commonly used lung protective ventilation strategy in general anesthesia. Positive end-expiratory pressure ventilation refers to a ventilation method in which the ventilator generates positive pressure during the inspiratory phase to press oxygen into the lungs, but at the end of expiration, the airway pressure still maintains a certain positive pressure level. Acute respiratory distress syndrome (ARDS) is caused by intrapulmonary and extrapulmonary factors, and is a disease characterized by refractory hypoxemia [3]. PEEP can redilate the collapsed alveoli in ARDS patients, increase the pulmonary function residual capacity and pulmonary compliance, improve ventilation and oxygenation function, reduce intrapulmonary shunt, and reduce the mortality rate of ARDS [4]. In addition, PEEP is also one of the strategies of lung protective ventilation in general anesthesia patients with mechanical ventilation [5]. In general anesthesia patients undergoing thoracic and abdominal surgery, the application of PEEP can improve oxygenation, reduce the incidence of PPCs, and improve the postoperative outcome of surgical patients [6-9]. Some studies have shown that PEEP can affect cardiovascular function and cerebral blood perfusion by increasing intrathoracic pressure. Therefore, we need to choose the best PEEP to reduce the impact of mechanical ventilation on circulatory function and cerebral hemodynamics. Influences in this article, we review the research progress of PEEP selection method, the influence of PEEP on physiological function and the clinical application of PEEP during mechanical ventilation.

2. DETERMINATION OF THE OPTIMAL PEEP LEVEL

The following is the method of choosing the optimal PEEP [Table 1].

2.1 Pressure-Volume Curve

The pressure-volume curve is based on the functional residual capacity, which depicts the

relationship between alveolar pressure and lung volume. It reflects the static mechanical characteristics of the lungs and thorax, as well as the compliance of the respiratory system. This is the most commonly used clinical method to determine the level of PEEP. In the past, many scholars believed that the lower inflection point (LIP) of the inspiratory branch of the P-V curve is the end of alveolar recruitment, and the upper inflection point (UIP) of the inspiratory branch is the beginning of alveolar hyperinflation. Setting the optimal PEEP near $LIP+2cmH_2O$ can prevent the alveolar collapse at the end of respiration and keep the alveoli open [10, 11]. However, some scholars believe that the role of PEEP is to avoid the collapse of the alveoli at the end of expiration, so it is more reasonable to set PEEP according to the expiratory branch of the P-V curve [12]. The point of maximum curvature (PMC) of pressure-volume curve expiratory branch setting PEEP can effectively prevent alveolar collapse in expiratory phase, improve lung oxygenation, increase lung volume, and have no serious impact on hemodynamics adverse effects [13]. Therefore, it is more supportive to use P-V curve expiratory branch PMC to determine the best PEEP. The aforementioned P-V curves all refer to static P-V curves. In clinical practice, the ventilator displays dynamic P-V curves. There are slightly different. We can use the dynamic P-V curve to infer the approximate position of the static P-V curve to observe the changes in lung compliance.

2.2 PEEP Titration

2.2.1 Optimal oxygen method

PEEP selection method based on optimal oxygenation. The specific operation is to implement adequate recruitment. The criterion for adequate recruitment is that the oxygenation index (PaO_2/FiO_2) $>400mmHg$ after the recruitment maneuver is implemented or the change of $PaO_2/FiO_2 <10\%$ after two recruitments. After lung recruitment, directly set PEEP to a higher level (such as $20cmH_2O$), and then reduce PEEP by $2cmH_2O$ every 3 to 5 minutes until PaO_2/FiO_2 decreases $>10\%$ (indicating alveolar collapse), and then adjust the PEEP level to $PaO_2/FiO_2 <400mmHg$ or reduce it by $>10\%$ after lung recruitment. At this time, $PEEP+2cmH_2O$ is the best PEEP [14]. This method requires multiple collections of the

patient's arterial blood to determine PaO₂, which is not convenient.

2.2.2 Lung compliance

Set PEEP based on the compliance measured at the bedside. The specific operation is to set a higher PEEP level (such as 20cmH₂O) on the basis of adequate lung recruitment, and then slowly decrease the PEEP, and record the dynamic lung compliance (C_{dyn}) obtained from the ventilator monitoring after each PEEP adjustment. When the C_{dyn} reaches the maximum value, the corresponding PEEP is the best PEEP [15]. This method requires the ventilator to have the function of monitoring dynamic compliance, and at the same time it can draw dynamic compliance curve.

2.2.3 Minimum dead space fraction

The dead space fraction (V_D/V_T) can be used as an index to reflect the efficiency of ventilation. The ratio of healthy adults is usually less than 0.30, that is to say that 70% of the ventilation is effective. In severe obstructive pulmonary disease, V_D/V_T can increase to 60%-70%, and the ventilation efficiency is significantly reduced. The specific operation is: after adequate lung recruitment, set a higher PEEP level (such as 20cmH₂O), and then slowly decrease to 0cmH₂O with 2 cmH₂O, and use the NICO single breath CO₂ curve method [16] to determine V_D/V_T [dead space fraction = (PaCO₂-PETCO₂)/PaCO₂], PEEP when V_D/V_T is the smallest is the best PEEP.

2.2.4 Computer tomography

Computer Tomography (CT) scan is the most reliable method to reflect whether the collapsed alveoli is recruited. Selecting PEEP based on chest CT scan is considered the gold standard for the best PEEP selection. The specific operation is to perform sufficient lung recruitment first, then set PEEP to a higher level (such as 20cmH₂O), and decrease PEEP by 2cmH₂O every 3 to 5 minutes. A chest CT scan is required each time the PEEP level is set, until alveoli appear obviously collapsed (collapsed alveoli>5%), at this time PEEP is the critical value for the alveoli to collapse again, and the PEEP+2cmH₂O is the best PEEP [17]. At present, due to the shortcomings of radioactivity, high cost, and inability to perform at the bedside, CT has limited its clinical application and is only suitable for experimental research.

2.2.5 Electrical impedance tomography

Electrical impedance tomography (EIT) is a relatively new non-invasive, non-radiation, and real-time monitoring technology that can perform individual, real-time bedside imaging of the lungs. Its principle is to stick a set of electrodes around the chest, apply a basically imperceptible current and measure the voltage it generates, and then reconstruct the change in the relative electrical impedance on the measurement plane [18,19]. The EIT image divides the lung cross-section into four equal parts from the ventral side to the dorsal side, which are ROI1 (ventral lung area), ROI2 (near retest lung area), ROI3 (near dorsal lung area), ROI4 (Dorsal lung area). EIT can be used as an imaging technique for titrating PEEP, which can simultaneously monitor pulmonary blood flow distribution and ventilation-perfusion matching, and has good consistency with CT [20]. The specific operation method is: at the level of PEEP of 5cmH₂O, increase PEEP by 2cmH₂O every 3 to 5 minutes, when the monitoring ROI3+ROI4 reaches the maximum value, and ROI1+ROI2 reaches the minimum value, the PEEP is the best PEEP. Compared with the traditional P-V curve and optimal oxygen titration of PEEP, the titration of PEEP under the guidance of EIT has higher accuracy, which will promote the realization of individualized PEEP in the future [21].

2.2.6 Bedside lung ultrasound technology

PEEP was titrated with bedside ultrasound. The specific operation method is: after adequate lung recruitment, decrease PEEP by 2cmH₂O every 5minutes, observe two consecutive ultrasound reinflation scores suddenly drop by more than 30%, at this time PEEP+2cmH₂O is the best PEEP [22]. However, bedside ultrasound also has certain limitations. For patients with severe obesity, chest wall subcutaneous emphysema, and severe pulmonary edema, it is difficult to use this method due to unclear imaging and difficult ultrasound recognition.

2.2.7 Transpulmonary pressure monitoring

Transpulmonary pressure (PTP) is the difference between alveolar pressure and intrathoracic pressure, which can reflect the pressure of expanding lung tissue and has nothing to do with chest wall elasticity. When the transpulmonary pressure at the end of inspiration is greater than 0cmH₂O, the alveoli open, while when the transpulmonary pressure at the end of inspiration

is less than 0 cmH₂O, the alveoli collapse and atelectasis is likely to occur. In clinical practice, the esophageal pressure measuring tube is usually inserted through the nose and connected to a specially configured ventilator. The pressure at the lower third of the esophagus is measured to estimate the transpulmonary pressure to guide the setting of PEEP [23]. The specific operation is: set a higher PEEP level (such as 20cmH₂O), and then reduce by 2cmH₂O every 5 minutes until it drops to 0cmH₂O. When the end-expiratory transpulmonary pressure is less than 0 cmH₂O, the previous PEEP maintains end-expiratory P_{tp}>0 cmH₂O and end-inspiratory transpulmonary pressure< 25 cmH₂O, the PEEP at this time is the best PEEP [24]. At present, the measurement of transpulmonary pressure has been used to titrate the PEEP of ARDS patients in many different ways, and it is expected to realize the individual adjustment of PEEP.

2.3 Stress Index

Stress index (SI) describes the pressure-time change curve of the alveoli during constant flow ventilation. The SI can reflect whether the alveoli are constantly recruited or over-expanded as PEEP increases. When SI>1, it indicates that with the increase of inspiratory tidal volume, the alveoli are over-expanded, and lung compliance continues to decrease; when SI<1, it indicates that as the inspiratory tidal volume increases, the alveoli continue to expand and the alveolar compliance continues to increase; When SI=1, it indicates that the corresponding alveoli are not collapsed or over-expanded, and are always in an open state. Therefore, the optimal PEEP should be adjusted to the level of SI=1, at which time the slope of the pressure-time curve changes the least during the inhalation process [25]. Because this method requires the respiratory function monitor to record all airway pressure values and corresponding time during the inhalation process, and calculate them through computer software. This limits its current application in clinical practice.

2.4 ARDS Net Table [Table 2]

The ARDS net table method selects PEEP according to the FiO₂-PEEP table [26] set by the international ARDS working group. This method is simple to use and has a wide range of clinical applications. However, since PEEP is selected according to the corresponding relationship between FiO₂ and PEEP, it lacks individualization for setting PEEP.

3. EFFECTS OF PEEP ON THE BODY'S PHYSIOLOGICAL FUNCTIONS [TABLE 3]

3.1 Effects of PEEP on Respiratory Function

PEEP can increase the functional residual capacity and increase the PaO₂ level by making small alveoli expand and collapsed alveolar recruitment to reduce intrapulmonary shunt, and its effect is related to the level of PEEP. When PEEP is below 10cmH₂O, it mainly expands the alveoli; when PEEP is greater than 10cmH₂O, it can recruit collapsed alveoli [28]. In patients with ARDS, the application of PEEP can expand the poorly ventilated alveoli and re-expand the collapsed alveoli, resulting in reduced intrapulmonary shunt, thereby improving oxygenation status and lung compliance [29]. Setting PEEP during mechanical ventilation can also bring disadvantages to patients. When PEEP over-expands the normal alveoli, it will compress the surrounding blood vessels and reduce gas exchange, thereby increasing the ventilation of the ineffective cavity. For lesions of the alveolar applies the appropriate PEEP, alveolar recruitment and expansion can improve the Ventilation/blood flow ratio, with no significant effect on ineffective ventilation.

3.2 Effects of PEEP on Circulatory Function

In clinical practice, in addition to preventing lung injury, PEEP can also cause changes in the hemodynamics of the cardiovascular system through cardiopulmonary interaction.

Mechanical ventilation and PEEP can affect cardiac function by changing lung volume and intrathoracic pressure. During mechanical ventilation, PEEP increases the pressure in the chest cavity while increasing the pressure of the superior and inferior vena cava vessels, which obstructs the venous return of the systemic circulation and reduces the venous return. At the same time, during mechanical ventilation, due to the increase of pulmonary vascular resistance, the right ventricular afterload increases and the right ventricular stroke volume decreases [30]. The blood in the right ventricle returns to the left atrium through the pulmonary circulation and then flows through the atrial septum to the left ventricle (that is, the afterload of the right ventricle is the preload of the left ventricle). After

Table 1. The method of choosing the optimal PEEP in reported literature

Author	Method	Characteristics
Hickling KG 1998 Martin-Lefevre L 2001 Albaiceta GM 2004	P-V curve LIP+2cmH ₂ O PMC(The point of maximum curvature)	Widespread clinical application This method is simple and easy to implement and lacks precision
Ranieri VM 1999	Optimal Oxygen Method	This method requires multiple collections of the patient's arterial blood to determine PaO ₂ , which is not convenient.
Suarez-Sipmann F 2007	Lung compliance	This method can better reflect the changes in the ventilated and non-ventilated areas after lung recruitment, and is easy to operate.
Kallet RH 2005	Minimum Dead Space Fraction	This method can significantly reduce dead space ventilation, and improve lung compliance.
Luecke T 2012	Computer Tomography	CT is considered to be the gold standard for the best PEEP selection. It has the disadvantages of radioactivity, high cost, and inability to perform at the bedside.
Frerichs I 2017 Zhao Z 2019	Electrical impedance tomography	EIT is a relatively new non-invasive, non-radiation, real-time, bedside lung imaging monitoring technology, and has higher accuracy.
Cho RJ 2020	Bedside lung ultrasound technology	For patients with severe obesity, chest wall subcutaneous emphysema, and severe pulmonary edema, it is difficult to use this method due to unclear imaging and difficult ultrasound recognition.
Mauri T 2016	Transpulmonary pressure monitoring	This method requires a specially configured ventilator and an esophagus monitoring pressure tube, and it is expected to realize the individual adjustment of PEEP.
Pepin JL 2016	stress index	This method requires a respiratory function monitor to record all the airway pressure values and corresponding time during the inhalation process, which is calculated by computer software, and the operation is more complicated.
Brower RG 2000	ARDSnet table	This method is simple to use and easy to promote clinically, but it has the disadvantage of lack of individualization of PEEP settings.

Table 2. NIH ARDS net [27]

(a) Lower PEEP : FiO₂ combination														
FiO ₂	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.9	0.9	0.9	1
PEEP	5	5	8	8	10	10	10	12	14	14	14	16	18	18-24
(b) Higher PEEP : FiO₂ combination														
FiO ₂	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.7	0.8	0.8	0.9	0.9	1.0
PEEP	12	14	14	16	16	18	20	20	20	20	22	22	22	22-24

Table 3. Effects of PEEP on physiological function in reported literature

Author	Physiological function	Effects
Maisch S 2008	Respiratory function	PEEP reduces intrapulmonary shunt by expanding small alveoli and re-expansion of collapsed alveoli to increase functional residual capacity and increase PaO ₂ levels. For patients with ARDS, PEEP can improve their oxygenation and lung compliance.
Vieillard-Baron A 2009 Marini M 2017	Circulatory function	PEEP increases the pressure in the chest cavity to obstruct the venous return of the systemic circulation and reduces the venous return. At the same time, due to the increase of pulmonary vascular resistance, the right ventricular afterload increases and the stroke volume of the right ventricle decreases. After a few beat cycles, the stroke volume of the left heart decreases. PEEP can improve heart function by reducing oxygen consumption.
Haddad SH 2012	Intracranial pressure and cerebral hemodynamics	The application of PEEP will increase intrathoracic pressure and reduce intracranial venous reflux; The application of low tidal volume and appropriate level of PEEP is likely to produce CO ₂ retention. It will expand the intracranial blood vessels and increase intracranial pressure. It is relatively safe to choose an appropriate level of PEEP under the conditions of stable hemodynamics, and has no obvious effect on ICP and CPP.
Pannu N 2004 Andrivet P 1991	Kidney function	Decreased renal function by reducing renal perfusion. Reduce renal plasma flow and glomerular filtration rate by increasing sympathetic nerve-mediated renin activity. Decrease in urine flow rate and sodium excretion rate by reducing the release of ANP.

a few beat cycles, the filling volume of the left ventricle decreases and the stroke volume of the left heart decreases [31]. Because the left and right ventricles are intertwined by the same myocardium, share the interventricular septum, and coexist in the same pericardium, this close anatomical connection determines their functional interdependence and mutual influence. When the preload of the right ventricle decreases, the left ventricular diastolic compliance, left ventricular preload, and left ventricular cardiac output all indirectly increase. Thus, during positive pressure ventilation, by limiting the filling of the right ventricle, so that the right ventricular volume reduction, reduced ventricular interdependence, left ventricular volume increases at the same filling pressure [32]. When applying high levels of PEEP, the airway plateau pressure will increase significantly, leading to increased pulmonary vascular resistance and pulmonary hypertension, resulting in a decrease in right ventricular stroke volume, an increase in right ventricular end-diastolic volume, and right ventricular dilation. The latter restricts left ventricular dilation through inter-ventricular interdependence, and the left ventricular diastolic compliance, left ventricular preload and left ventricular stroke volume are successively reduced [31].

The effects of PEEP on hemodynamics are not necessarily all adverse, and it can improve heart function by reducing oxygen consumption [33]. Jardin et al.[34] found that high levels of PEEP can have an adverse effect on hemodynamics, but appropriate levels of PEEP can also have a positive effect on hemodynamics. In clinical work, we should pay attention to the ventilator-associated lung injury caused by PEEP, which can also lead to ventilator-related heart damage.

3.3 Effects of PEEP on Intracranial Pressure and Cerebral Hemodynamics

Many studies have found that mechanical ventilation may have certain effects on intracranial pressure (ICP) and cerebral perfusion pressure (CPP). First, the application of PEEP will increase intrathoracic pressure and reduce intracranial venous reflux; second, during lung protective ventilation, the application of low tidal volume and appropriate level of PEEP is likely to produce CO₂ retention. It will expand the intracranial blood vessels and increase intracranial pressure [35].

It has been reported in patients with brain injuries may have pulmonary complications such as

ARDS and neurogenic pulmonary edema [36, 37]. In clinical practice, we usually choose an appropriate level of PEEP to improve oxygenation and re-expand collapsed alveoli to reduce lung complications [38]. However, some researchers have long been concerned that the use of PEEP in patients with brain injury will affect ICP and even cause neurological damage, especially in patients with cerebral edema. Therefore, it is very important to know whether PEEP has adverse effects on ICP and CPP. Boone et al.[39] showed that PEEP has no significant effect on ICP and CPP in patients with acute brain injury, and it can be applied to patients with acute brain injury. They also found that in patients with acute brain injury and severe lung injury, PEEP is significantly correlated with ICP and CPP (for every 1 cmH₂O increase in PEEP, ICP increases by 0.31 mmHg, while CPP decreases by 0.85 mmHg). Similarly, Georgiadis D et al.[40] found that PEEP had no significant effect on the ICP of patients with acute stroke. For patients with severe arterial aneurysmal subarachnoid hemorrhage, PEEP gradually increased to 20cmH₂O may result in mean arterial pressure decreased, while in the case of relatively stable hemodynamics, the increase of PEEP level has no significant effect on cerebral perfusion pressure [41]. Based on the research above, we may be able to draw a conclusion that it is relatively safe to choose an appropriate level of PEEP under the conditions of stable hemodynamics, and has no obvious effect on ICP and CPP.

3.4 Effects of PEEP on Kidney Function

In the 1970s, the widespread application of PEEP in patients with respiratory failure such as ARDS prompted many scholars to explore the impact of positive pressure ventilation on renal function. They found that when PEEP is 10cmH₂O, it can reduce urine flow rate, creatinine clearance, and sodium excretion rate [42]. Farge and other researchers [43] found that when PEEP was used in critically ill patients, urine flow rate and sodium excretion rate decreased, but glomerular filtration rate did not decrease significantly.

Mechanical ventilation affects two major mechanisms of renal function: during mechanical ventilation, cardiac output decreases and renal perfusion decreases, resulting in decreased renal function; [44] and renal plasma flow and glomerular filtration rate are reduced by increasing sympathetic nerve-mediated renin

activity. Andrivet et al.[45]found that during mechanical ventilation,increased intrathoracic pressure would reduce venous return, thereby reducing the pressure in the right atrium and reducing the release of atrial natriuretic peptide (ANP).The ANP has a strong diuretic and natriuretic effect. Therefore, when PEEP is used, a decrease in ANP can also lead to a decrease in urine flow rate and sodium excretion rate.

Since many of the above cited studies have a history of more than 40 years, further research is needed to explore the impact of mechanical ventilation on renal function.

4. CLINICAL APPLICATION OF PEEP

PEEP can be used not only to improve oxygenation in respiratory failure patients such as ARDS/ALI, but also to general anesthesia patients with normal lung function to prevent postoperative pulmonary complications.

4.1 Application of PEEP in ARDS Patients

ARDS is a disease mainly manifested by the collapse of a large number of alveoli, the imbalance of ventilation and blood flow and the resulting refractory hypoxemia. Some studies have shown that lung protective ventilation strategies can improve the prognosis of ARDS and reduce the mortality rate [46].Setting an appropriate level of PEEP is one of the most important measures in the treatment of ARDS in lung protective ventilation strategies.However, too high PEEP can cause excessive expansion of the alveoli, and too low PEEP can cause the alveoli to collapse, ultimately leading to ventilator-induced lung injury (VILI). Therefore, setting an appropriate level of PEEP to maintain collapsed alveolar recruitment after lung recruitment is the key to improving and maintaining the oxygenation of ARDS patients and realizing the process of mechanical ventilation.[47].

The lung of ARDS is composed of three parts: normal area, collapse area and consolidation area. In the collapsed area, some recruitable alveoli will open and close repeatedly in each breathing cycle, generating shear force. An appropriate level of PEEP can maintain these alveoli in an open state at the end of expiration.The study found that the use of high levels of PEEP for patients with moderate to severe ARDS is beneficial, while the use of high levels of PEEP for patients with mild ARDS does

not have any benefits, and even does more harm than good. Therefore, high levels of PEEP are only recommended for patients with moderate to severe ARDS [48, 49].

4.2 Application of PEEP in General Anesthesia

In recent years, with the increase of general anesthesia operations, we have found that postoperative pulmonary complications are the main cause of postoperative complications and death after general anesthesia [1, 50]. In general anesthesia, mechanical ventilation is highly correlated with postoperative pulmonary complications. For some patients with poor lung function and prone to pulmonary complications after surgery, the appropriate PEEP can improve oxygenation, which is beneficial.In clinical anesthesia, appropriate PEEP can prevent postoperative pulmonary complications. When applying high levels of PEEP, the alveoli may over-dilate, leading to an increase in pulmonary vascular resistance; while applying low levels of PEEP may not prevent atelectasis.

During general anesthesia, we found that lung protective ventilation strategies such as low tidal volume, appropriate PEEP and lung recruitment can improve the respiratory function of surgical patients and reduce the incidence of postoperative lung infections [51]. Studies have shown that in laparoscopic surgery, due to the need for a special posture (head high and low feet), the application of PEEP can improve patient oxygenation and lung compliance, and has no significant impact on hemodynamics [52]. During laparotomy, D'Antini et al.[53]found that compared with low-level PEEP, setting high-level PEEP after lung recruitment does not seem to cause excessive alveolar expansion, and it can also reduce the shear damage caused by the periodic opening and closing of alveoli. In contrast, another randomized controlled trial conducted during abdominal surgery showed that high levels of PEEP (12cmH₂O) and lung recruitment maneuvers did not prevent postoperative lung complications concurrent compared with low levels of PEEP (0-2cmH₂O) [54]. For the above research, we believe that it does not overturn the concept of lung protection in abdominal surgery, but tells us that choosing an appropriate level of PEEP is beneficial to improve the lung function and prognosis of patients with abdominal surgery while maintaining hemodynamic stability.For chest surgery, some traditional views in the past

believed that PEEP may increase the intrathoracic pressure, reduce venous return, and indirectly reduce the perfusion of organs and tissues throughout the body, leading to imbalance of ventilation and blood flow and affecting oxygenation [55].

5. CONCLUSION

In summary, whether it is patients with lung diseases such as ARDS or patients undergoing general anesthesia with normal lung function, the application of appropriate PEEP seems to be beneficial. However, according to which method and principle to choose the best PEEP to implement lung protection ventilation still puzzles clinicians. The application of transpulmonary pressure and EIT titration of PEEP is the most commonly used method for setting PEEP in recent years, which promotes the further development of individualized PEEP in the future. In future clinical studies, we choose the method of titrating PEEP not only to pay close attention to the changes in the patient's oxygenation level and lung compliance, but also to pay attention to the impact on circulation and cerebral hemodynamics, At the same time, it must not ignore the impact on kidney function and gastrointestinal tract.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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