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Advances in Prone Ventilation in Obese Patients with Severe Acute Respiratory Distress Syndrome

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Abstract: *Severe Acute Respiratory Distress Syndrome (ARDS) commonly arises as a critical complication in the context of critically ill patients, and the management of ARDS is significantly complicated in obese individuals due to their unique physiological configuration and distinctive metabolic attributes. Prone Position Ventilation, a therapeutic intervention designed to enhance oxygenation and mitigate mortality rates in patients suffering from severe ARDS, nonetheless presents considerable challenges in the care of obese patients. In the present study, we undertake an extensive review of documented successful cases involving prone position ventilation.*

Keywords: *Severe Acute Respiratory Distress Syndrome; Obesity; Prone Position Ventilation; Application Status*

1. Introduction

The impact of obesity on health has become an important issue of global concern. According to the World Health Organization, obesity (i.e., body mass index (BMI) ≥ 30 kg/m²) is not only a state of excess fat accumulation, but also a serious health risk. Global obesity rates continue to rise, and it is predicted that the combined prevalence of overweight or obesity among Chinese adults will reach 65.3% by 2030[1]. The increase in chest wall weight and accumulation of abdominal fat caused by obesity lead to decreased lung compliance, reduced functional residual capacity and arterial oxygenation, which significantly prolong the hospital stay and mechanical ventilation time of obese patients in the intensive care unit (ICU)[2]. Acute Respiratory Distress Syndrome (ARDS) is a type of acute respiratory failure caused by a variety of direct or indirect lung injuries. It is clinically characterized by acute development of hypoxemia, pulmonary infiltrating lesions, and alveolar damage. At present, the morbidity and mortality of ARDS are relatively high, especially in severe patients[3]. Prone Position Ventilation (PPV), as an important treatment for severe ARDS, has been shown to significantly improve gas exchange and improve the survival rate of patients with moderate to severe ARDS[4,5]. However, due to the unique physiological characteristics and underlying diseases of obese patients, the application and effect of PPV therapy still face challenges[6], and more research is needed to further explore its mechanism and further optimize its application in clinical practice. Therefore, this paper analyzed and summarized the pathophysiological basis, mechanism of action, application status and treatment points of obese patients with severe acute respiratory distress syndrome, aiming to provide more accurate and effective treatment guidance for clinical practice.

2. Pathophysiological basis of obese patients with severe acute respiratory distress syndrome

With the continuous deepening of research[7], it has been found that several pathophysiological disorders are the core of ARDS development, which are mainly reflected in four aspects: respiratory mechanical changes, systemic inflammation, metabolic disorders and oxygenation difficulties. Obesity leads to decreased chest wall compliance and increased respiratory muscle load, resulting in insufficient ventilation and gas exchange disorders, and is prone to hypoxemia[8]. Obese patients often have chronic low-grade inflammation[9]. Pro-inflammatory factors such as tumor necrosis factor-α (TNF-α) and interleukin-6 (IL-6) released by obese tissues can enhance inflammatory response and exacerbate lung injury. Obesity is also accompanied by metabolic problems such as insulin resistance and hyperglycemia[10], which affect the body's response to inflammation and further aggravate ARDS. In addition, the oxygenation capacity of obese patients is reduced, and hypoxemia is more difficult to correct,

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increasing the complexity and risk of treatment. According to the Berlin definition[11], ARDS is divided into three severity levels according to the degree of hypoxemia: mild (PaO2/FiO2 200-300 mm Hg), moderate (PaO2/FiO2 100-200 mm Hg), and severe (PaO2/FiO2<100 mm Hg). Compared with normal weight patients, obese patients have increased respiratory load and impaired gas exchange, and these two disturbances can have significant effects on physical strength and health if exposed to respiratory stress[12]. In obese patients, functional residual volume (FRC) is further reduced during anesthesia due to the loss of respiratory muscle tone and the frequent use of sedatives and muscle relaxants in ICU[13]. In addition, obese patients are often accompanied by obstructive sleep apnea syndrome, which will lead to repeated apnea during sleep, thus affecting the normal function of the respiratory system and inducing perioperative hypopnea syndrome[14],which greatly increases the risk of post-cardiac surgery.

3. Mechanism of PPV in obese patients with severe ARDS

PPV is an effective treatment strategy for obese ARDS patients, which has been proven to improve the ventilation/blood flow ratio imbalance. Due to the large accumulation of fat in the chest wall and abdomen of obese patients, the heart and abdominal organs in supine position have an occupying effect on the lungs, limiting lung expansion[15], while prone position can reduce abdominal pressure on the diaphragm and increase lung volume. Thus reducing atelectasis and hypoxemia[16]. At the same time, obese patients have a large mechanical load on the lungs, and are more likely to suffer local lung overexpansion and stretch injury in supine position. Prone position can reduce the uneven distribution of such load, reduce lung mechanical damage, and protect lung tissue[21,22]. In addition, obese patients are usually accompanied by higher internal abdominal pressure. Compared with supine position, prone position can better relieve the pressure of internal abdominal pressure on the diaphragm, improve the diaphragm function, and promote more effective respiratory activities[17]. Studies have found that obese patients with Stanford Type A aortic dissection have fewer adverse reactions, significantly improved lung compliance and oxygenation status, and reduced ventilator-related complications when undergoing prone ventilation after surgery[18]. Xin[19]further supported this view, indicating that prone position in obese patients improved lung function, increased functional residual capacity, lung compliance, and oxygenation.

4. Application status of PPV in obese patients with severe ARDS

4.1 Application Objects

In recent years, scientifically sound PPV, as an effective means of improving oxygenation and respiratory mechanics, has provided a low-cost, feasible, effective, and safe intervention program for the clinical treatment and nursing management of obese patients with severe ARDS[20]. Studies have shown that early application of a prolonged prone position regimen significantly reduces 28- and 90-day mortality in patients with severe ARDS[21]. Prone position ventilation increases alveolar ventilation area and improves lung compliance and blood oxygenation levels by altering the effect of gravity on the lungs[22], and this method is effective in improving the oxygenation index (PaO2/FiO2) and decreasing intrapulmonary shunting, thus reducing hypoxemia. Obese patients have certain operational difficulties in implementing prone ventilation due to their special body shape and large weight in the chest and abdomen, and the intervention process not only requires sufficient nursing staff, but also poses a great challenge to the comprehensive ability of nursing staff and may lead to increased patient discomfort and risk of pressure injury[23]. In this regard, for the PPV technique for obese patients, in 2022 Hao [24] published a demonstration video of PPV operation for intubated obese patients. Although obesity increases the difficulty of operation, optimization of operation procedures and nursing management can still be effectively applied to obese ARDS patients to improve their prognosis and survival.

4.2 Treatment time

Several national and international guidelines[26–29]recommend early implementation of prone position ventilation on top of conventional treatment for no less than 16 hours per day in invasively mechanically ventilated ARDS patients with PaO2/FiO2 <150 mmHg to reduce mortality. Clinical evidence[21] suggests that early implementation of prone position and muscle paralysis helps to protect lung function and improve oxygenation. In another multicenter study of patients with moderate-to-severe ARDS on noninvasive ventilation and high oxygen flow humidified oxygen therapy, it was recommended that early initiation of the prone position, especially applied in patients with baseline SpO2 >95% was effective in

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avoiding intubation[29]. With the in-depth study of prone position ventilation for ARDS at home and abroad, the European Society of Intensive Care Medicine guidelines[27]recommend that patients with ARDS undergoing invasive mechanical ventilation should be started in the prone position at an early stage after intubation, and that low tidal volumes should be applied and PEEP should be adjusted during stabilization, and that at the end of the stabilization period PaO2/FiO2 should be maintained at <150 mmHg; the prone position should be applied for a prolonged period of 16 hours or more consecutively , to reduce mortality. Some even recommend starting this intervention in the emergency room as in the study done by Caputo et al [30]. When implementing treatment in the awake prone position, the duration of each session should be determined based on the patient's oxygenation improvement and tolerance, and it is recommended that the prone position be converted to the supine position for 1-2 hours after 2-4 hours each time, and that this should be repeated 3-6 times per day, with the total duration of treatment exceeding 12 hours if possible, in order to ensure that the therapeutic effect is maximized [31].

With comprehensive reference to expert recommendations and existing randomized controlled trials [25,32], the criteria for the end of treatment include (i) after the patient resumes the supine position, PaO_2 is maintained at ≥80 mmH for more than 4 hours under $FiO_2$0.5 without serious complications; and (ii) even if two sessions of prone ventilation have been performed, there is no improvement in oxygenation compared with that before the use of prone ventilation[33]. In patients with severe ARDS, termination of prone position ventilation should be promptly considered if no significant improvement in oxygenation is seen within 2 to 4 hours or if severe exacerbation of respiratory failure occurs[34]. Overall, the importance of prone ventilation in the management of ARDS is increasing, and timely initiation and adjustment of the duration and frequency of prone ventilation according to the condition of obese patients can help to improve the prognosis of patients and reduce the risk of complications.

5. Risk management of PPV complications in obese patients with severe ARDS

5.1 PPV complications

Obese patients with severe ARDS and prone ventilation face a variety of potential complications and challenges. For example, obese patients are often accompanied by metabolic syndrome[10], sleep apnea[14]and other co-existing diseases, which affect the efficacy of prone ventilation to a certain extent. Studies have shown that, compared with non-obese patients, obese patients during prone ventilation are more likely to have adverse events such as obstructive apnea syndrome or obese hypopnea syndrome[14], tracheal intubation displacement, rhabdic myolysis[36], facial edema, stress injury[37], and worsening multiple organ failure[38]. In addition, prone ventilation may increase cardiovascular load, which in turn affects multiple organ function, especially in the case of clinical stress and limited medical resources. A meta-analysis found that pressure ulcers of any grade were 37% more common when the prone position was used compared to the supine position[39]. There are also some challenges and issues with the use of PPV in the obese patient population. For example, due to the shortage of ICU beds during the COVID-19 pandemic and the lack of training of medical staff and their unfamiliar nursing procedures in the intensive care unit[41], the risk of complications increased, which was similar to the findings of Rodriguez-Huerta[42].

5.2 PPV nursing management

At present, it is generally believed that obesity has multiple effects on human hemodynamics and ARDS pathophysiology, so it is difficult to care for severely obese patients and an experienced multidisciplinary team is required. In order to prevent the occurrence of adverse events, Song Chun [45] conducted a randomized controlled study on the application effect of prone position ventilation management pad in patients with severe acute respiratory distress syndrome (ARDS), and found that the use of prone position ventilation management pad had better therapeutic effect than traditional prone position. Boyko [46]recommend the use of special mattress and skin care measures such as frequent unloading and repositioning to reduce pressure points. In addition, choosing the appropriate prone position Angle and posture during PPV, such as the reverse Trendelenburg position or the "swimmer's position," can improve patient comfort and ventilation while reducing the risk of nerve damage; For those wearing non-invasive respirator masks, the "dolphin position" is recommended to maintain the physiological curvature of the patient's spine, increase comfort, and improve the patient's tolerance to PPV[36,47]. For patients who are mechanically ventilated in prone position and connected to various monitors, probes and duct systems, the nursing staff should regularly check the patency of the pipe, properly fix the pipe, prevent the occurrence of adverse events in the pipe during position change, and

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closely monitor the physiological parameters and oxygenation status of the patient, which are also key steps to ensure the success of treatment and prevent complications[48]. Therefore, nursing staff can combine clinical work experience, through consulting a large number of domestic and foreign latest research progress, invite nurses with PPV patient care experience, ICU specialized nurses and nursing managers to discuss together, etc., to develop feasible, suitable for clinical operation procedures and norms. At the same time, the hospital adopts lectures, scene simulation and other forms of training for medical staff in the department to improve PPV nursing.

6. Clinical indications and contraindications of PPV in obese patients with severe ARDS

6.1 Clinical indications

In clinical practice, there are two main indications for prone ventilation in ARDS patients: the need to improve oxygenation and reduce mortality. When lying prone, the lung tissue in the back region is more easily reopened than that in the abdomen region, and the expansion of the lung is more evenly distributed along the dorsoventral axis. This position is especially suitable for obese patients, because this position not only improves oxygenation, but also excrets respiratory secretions, improves hemodynamics, and prevents ventilators induced lung injury. This conclusion has also been confirmed in other studies[49]. Compared with other treatments such as extracorporeal membrane oxygenation (ECMO), the advantage of PPV is that it not only reduces the over-expansion of the independent lung area and the periodic opening and closing of the dependent area, thereby reducing the risk of ventilators induced lung injury, but also is more common and easier to implement in clinical practice[50]. However, ECMO may provide more robust oxygenation support in some cases, especially when patient oxygenation is difficult to correct or PPV applications are limited. One randomized controlled study showed that PPV use during intravenous ECMO support was associated with improved oxygenation and reduced in-hospital mortality[51], and future studies could further compare the long-term effects and cost-effectiveness of these two treatment strategies to guide clinical decision making.

6.2 Contraindications

Contraindications to PPV include unstable hemodynamic status, malignant arrhythmia, uncontrolled increased intracranial pressure, severe facial or neck trauma or spinal fracture, recent abdominal surgery or intra-abdominal hypertension, uncontrolled bleeding or coagulation disorders, inability to properly secure an airway device, and respiratory mechanical problems accompanying extreme obesity, and PPV may increase the risk of treatment for these contraindications. Although the technical difficulty of performing PPV is increased in obese patients due to their specific physiology[52], PPV may benefit patients with higher levels of obesity by increasing the relief of diaphragmatic pressures, thereby opening small airways and lung reopening. Mid to late pregnancy has been considered a contraindication to prone position ventilation, but with increasing research, PPV has been shown to consistently improve oxygenation index ratio and alveolar ventilation levels[53]. In the 24 hours following the use of the prone position, there were no emergency deliveries or suspected fetal distress in pregnancies ≥25 weeks of gestation, validating that the prone position is a safe and effective method for mid- to late-pregnant patients undergoing mechanical ventilation due to severe ARDS and can help to delay preterm labor in patients with severe ARDS [54]. Therefore, the clinical team should perform a thorough evaluation when deciding on the applicability of PPV and compare it with other therapeutic means in order to develop the best individualized treatment plan.

7. Conclusions

The pathophysiological characteristics, therapeutic modalities, and critical aspects of severe ARDS in obese individuals are intricate and diverse. PPV has demonstrated a reduction in mortality rates among ARDS patients, albeit the particular efficacy in the context of obesity necessitates further corroboration through additional clinical evidence. Subsequent research endeavors should be explored comprehensively by delving into the following dimensions: (1) To determine the best time and course of implementation of prone ventilation in obese patients, and the difference of treatment response in patients with different body weight; (2) Further optimize the implementation technology and perioperative management strategy of prone position ventilation to reduce operational risks and improve treatment effect; (3) Combined with a multidisciplinary team, the combined application of prone position ventilation and other ARDS treatment means (such as extracorporeal membrane oxygenation) is deeply

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discussed, and more effective treatment strategies are explored to ensure the safety and optimal treatment effect of ARDS obese patients, and provide more scientific and effective guidance for their clinical treatment.

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