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CLINICAL REVIEW

Why Continuous Lateral Prone Position Ventilation should be Used for Patients Acute Respiratory Distress Syndrome Living in the Plateau of Xining, Qinghai

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ABSTRACT

Prone position ventilation improves oxygenation and reduces the mortality rate in patients with acute respiratory distress syndrome (ARDS). However, conventional prone ventilation is not sufficient for patients with ARDS living at high altitudes. Accordingly, this report proposes the concept of continuous lateral prone ventilation, which achieves lung protection by improving arterial oxygen and lung compliance as well as reducing the driving pressure while applying positive end-expiratory pressure, in patients with ARDS living at plateaus.

KEYWORDS

Acute respiratory distress syndrome; Plateau; Prone position; Continuous; Lung protective ventilation

ABBREVIATIONS

ARDS: Acute respiratory distress syndrome; PPV: Prone Position Ventilation; PEEP: Positive End-Expiratory Pressure; CLPPV: Continuous Lateral Prone Position Ventilation; PVR: Pulmonary Vascular Resistance; HAPC: High-Altitude Polycythaemia

BACKGROUND

Acute respiratory distress syndrome (ARDS) is a common acute respiratory failure that is characterized by severe hypoxemia, respiratory distress, and multiple organ dysfunction [1,2]. Hypoxic pulmonary vasoconstriction and pulmonary hypertension are crucially involved in ARDS [3]. Patients with severe ARDS present with ventilator-perfusion mismatch and gas exchange disorder, which are mainly characterized by heterogeneous lung damage and alveolar oedema. This causes oxygenation dysfunction and aggravates hypoxic pulmonary vasoconstriction. The inflammatory response, microthrombosis, and vascular remodelling related to ARDS jointly increase pulmonary vascular resistance as well as aggravate pulmonary hypertension and right ventricular afterload. Although a lung-protective mechanical ventilation strategy prevents ventilator-related lung injury, the clinical treatment effect is unsatisfactory. Prone position ventilation (PPV) facilitates homogenization of ventilation distribution; moreover, it reduces the dependence on positive end-expiratory pressure (PEEP), lung stress, and lung strain; improves lung respiratory mechanics, ventilator-perfusion matching, and gas exchange; and improves lung protection and patient prognosis. PPV is widely used in clinical practice.

High altitude pressure and a low oxygen environment result in a physiological increase in pulmonary artery pressure and blood viscosity [4,5]; therefore, there are unique characteristics of the pathophysiology of ARDS within this environment. Specifically, in patients with ARDS living at plateaus, the underlying pathophysiology has several unique characteristics due to physiological factors such as increased pulmonary artery pressure and hemorheological changes resulting from acute and chronic hypoxia. Accordingly, the PPV method should be further improved to obtain a better ventilation effect in these patients. Based on clinical research and practice, we proposed the concept of lung-protective continuous lateral PPV (CLPPV) for patients with ARDS living at high altitudes. This paper discusses its mechanism of action and clinical efficacy.

PATHOPHYSIOLOGY OF ARDS IN LOW-PRESSURE AND HYPOXIC CONDITIONS

In a hypoxic environment, ARDS is mainly characterized by severe pulmonary hypertension [6], which is caused by ARDS itself as well as the low altitude pressure and low oxygen. Other related factors include severe ventilation-perfusion and blood flow disorders. Moreover, ARDS can cause severe hypoxemia and aggravate pulmonary vasoconstriction [7]. This heterogeneous lung damage causes alveolar collapse and local alveolar overexpansion, which compresses external alveolar vessels, resulting in increased total pulmonary vascular resistance (PVR) and pulmonary artery pressure [8], especially within conditions of increased mechanical ventilation [9]. Severe hypoxemia can cause systemic and local inflammatory responses, which aggravate vascular endothelial damage, micro thrombosis, thromboembolism [10], and vascular remodelling, resulting in increased PVR [11] and aggravated pulmonary hypertension [12]. In high-altitude environments, acute and chronic hypoxic stimulation causes excessive release of erythropoietin, which is termed as high-altitude polycythaemia (HAPC), resulting in haemodynamic and volume changes [13]. HAPC has a causal relationship with physiological pulmonary hypertension; moreover, it further aggravates pathological pulmonary hypertension, increases right cardiac afterload, and causes acute pulmonary heart.

CONVENTIONAL PRONE POSITION VENTILATION

During mechanical ventilation, the heterogeneous lung damage in patients with ARDS causes increased ventilation-blood flow imbalance during mechanical ventilation, which results in ventilator-related lung injury [15]. PPV allows a more even distribution of gas-tissue ratios along the dependent-nondependent axis as well as a more homogeneous distribution of lung stress and strain. Generally, this is accompanied by a marked improvement in arterial blood gases mainly due to better overall ventilation/perfusion matching. In patients with ARDS, PPV allows improved oxygenation and a reduced mortality rate. The reduced mortality rate could be mainly attributed to decreased overdistension in non-dependent lung regions as well as less cyclical opening and closing in dependent lung regions [16].

In the treatment of patients with COVID-19, PPV in the awake prone position has shown good efficacy [16]. Conventional prone position ventilation (CPPV) for >16 hours a day can improve mortality in patients with ARDS who have an oxygenation index ≤150 mmHg [17]. Chong et al. [8] observed significantly improved oxygenation in patients with severe COVID-19 after applying high-flow nasal catheter oxygen inhalation in the prone position, left decubitus position, and right decubitus position [18]. However, due to gravity dependence, applying 16-hours PPV in the supine position in turn could result in re-collapse of the alveoli opened in the prone position collapse. Accordingly, a higher PEEP is required to maintain alveolar opening and oxygenation. Excessive alternation between alveolar collapse and dilation results in increased disruption of ventilation/blood flow and exacerbation of hypoxemia. Therefore, traditional PPV is not suitable for patients with ARDS at high altitudes; moreover, it may cause further cardiopulmonary injury and aggravate the patients' conditions.

EFFECTS OF APPLYING CONVENTIONAL PRONE POSITION VENTILATION TO PATIENTS WITH ARDS LIVING AT HIGH ALTITUDES

A study included 38 patients with ARDS (28 men and 10 women; CLPPV [n = 20], and CPPV [n = 18]) living in Xining area (altitude: 2260 m). The patients' primary disease was pulmonary infection. The CLPPV protocol included alternate left and right prone positions ranging from 20° to 30° at 4 hours intervals while the CPPV protocol involved alternating between prone and supine positions at a flat position for about 16 hours a day. In both groups, a skin compression protective film was used to protect the compression area; additionally, the bed was adjusted to a ≈25° slope position between the head height and foot sole to prevent compression oedema in the eyes and face. Patients in both groups underwent airway intubation, volumetric-controlled ventilation, and lung-protective ventilation (a low tidal volume of 4 mL/kg - 6 mL/kg). The PEEP was determined using the oxygen method. Analgesics, sedatives, and muscle relaxants were administered as required. Subsequently, they performed between-group comparisons of the oxygenation index (PaO_2/FiO_2), breathing mechanics, pre- and post-treatment ventilator parameters, duration of mechanical ventilation, length of intensive care unit (ICU) stay, and related complications.

There was no significant between-group difference in baseline parameters. There was a significant post-treatment increase in the PaO_2/FiO_2 (mmHg, 1 mmHg = 0.133 kPa) in the CPPV and CLPPV groups (99.7 ± 15.4 *vs.* 55.5 ± 6.3, 121.8 ± 25.3 *vs.* 55 ± 7.2 both P <0.05]. However, compared with CPPV group, the CLPPV group showed a significantly higher improvement in the PaO_2/FiO_2 (121.8 ± 25.3 *vs.* 99.7 ± 15.4, P = 0.003). There was a significant post-treatment increase in the lung compliance in the CPPV and CLPPV groups (mL/cmH_2O: 36.8 ± 2.4 *vs.* 28.0 ± 2.0, 43.4 ± 6.7 *vs.* 27.7 ± 2.1, both P <0.05). Compared with CPPV group, the CLPPV group showed a significant higher increase in lung compliance (43.4 ± 6.7 *vs.* 36.8 ± 2.4, P = 0.001). There was a significant post-treatment decrease in the drive pressure (cmH_2O, 1 cmH_2O = 0.098 kPa) in the CPPV and CLPPV groups (10.5 [10.0, 12.0] vs. 13.0 [12.3, 14.0]; 10.0 [8.0, 12.0] vs. 13.0 [12.0, 14.0], both P <0.05); however, it was lower in the CLPPV group than in the CPPV group [(10.0 (8.0, 12.0) *vs.* 10.5 (10.0, 12.0), P = 0.033]. There was a significant post-treatment decrease in the PEEP in the CPPV and CLPPV groups [cmH_2O: 12 (12, 14) *vs.* 14 (13, 14), 10 (8, 10) *vs.* 14 (12, 15), both P <0.05]. However, compared with CPPV group, the CLPPV group showed a significantly higher decrease in the PEEP [10 (8, 10) *vs.* 12 (12, 14) P = 0.001]. Compared with CPPV group, the CLPPV group showed a significantly shorter duration of mechanical ventilation and length of ICU stay [days: 6.0 (5.0, 7.3) *vs.* 8.0 (7.0, 9.0), 9.7 ± 1.5 *vs.* 12.1 ± 2.2, both P <0.01]. There was no significant between-group difference in the risk of skin pressure ulcers and related complications (χ^2 = 0.321, P = 0.571). All pressure ulcers appeared 72 hours after PPV treatment; moreover, they were subsequently repaired normally without any adverse consequences.

CONTRAINDICATIONS TO CONTINUOUS LATERAL PRONE POSITION VENTILATION

CPPV and CLPPV have similar contraindications. The only absolute contraindication to PPV is an unstable spinal fracture. Relative contraindications included haemodynamic instability, peritoneal hypertension, haemodynamic instability, abdominal hypertension, unstable airway, and significant Obesity.

ADVANTAGES OF CONTINUOUS LATERAL PRONE POSITION VENTILATION

CLPPV can significantly reduce platform pressure and PEEP application, which effectively prevents the occurrence of Acute Cor Pulmonale (ACP). Moreover, in CLPPV, the alveoli remain open; further, there is relatively stable improvement and maintenance of respiratory mechanical indicators, which significantly reduces lung injury caused by mechanical.

CONCLUSION

Further research on the respiratory physiology and pathophysiology of patients with ARDS living at plateaus could inform improvements in lung-protective mechanical ventilation strategies. Our study suggests that compared with intermittent PPV, CLPPV can significantly improve oxygenation and respiratory mechanics in patients with severe ARDS living at high altitudes; moreover, it has a more significant therapeutic effect and can shorten the time of mechanical ventilation and ICU stay. Furthermore, CLPPV is not associated with increased complications, including accidental tube removal, aspiration, and skin pressure ulcers. However, CLPPV is associated with increased treatment and care difficulty as well as related risks, which requires an experienced medical team. Treatment complications can be effectively prevented by strengthening care as well as close observation and prevention of possible problems.

DECLARATIONS

Ethics approval and consent to participate This clinical trial is registered by Chinese Clinical Trial Registry. The number is ChiCTR1900028628.The study was approved by the Ethics Committee of Qinghai Provincial People's Hospital.

Consent for Publication

Not applicable.

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding authors on reasonable request.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

SQM conceived and designed the review, undertook the initial research and discussed the manuscript. JHH perform side prone ventilation, data collections, statistical analysis and other work.

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