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Effect of Prone Position Ventilation in Patients with Severe Craniocerebral Injury Complicated with Pulmonary Infection

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Abstract: *Objective:* To investigate the effects of prone ventilation in patients with severe traumatic brain injury combined with pulmonary infection. *Methods:* A total of 100 patients with severe traumatic brain injury combined with pulmonary infection in the hospital were randomly divided into a prone ventilation group and a conventional ventilation group, with 50 patients in each group. The Glasgow Coma Scale (GCS) score, APACHE II score, sputum culture results, oxygenation indicators, and prognosis were compared between the two groups. Data were processed using SPSS 25.0 statistical software, and *t*-tests and chi-square tests were used to compare continuous and categorical variables, respectively. *Results:* The experimental group showed better oxygenation indicators, a lower positive rate of sputum cultures, and reduced intracranial pressure compared to the control group (all $P < 0.05$). Multivariate Cox regression analysis indicated that GCS score, APACHE II score, and prone ventilation were independent risk factors affecting patient prognosis (all $P < 0.05$). *Conclusion:* Prone ventilation can improve oxygenation, reduce the risk of pulmonary infection, and decrease intracranial pressure in patients with severe traumatic brain injury combined with pulmonary infection, thereby improving patient prognosis. GCS score and APACHE II score can serve as important indicators for prognostic evaluation.

Keywords: Prone position ventilation; Severe traumatic brain injury; Prognosis; Randomized controlled trial

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1. Introduction

Cranio-cerebral injury (CCI) is a type of brain injury that involves damage to the skull, brain, blood vessels, nerves, and meninges [1]. CCI can lead to acute respiratory distress syndrome (ARDS), a life-threatening condition characterized by hypoxemia, bilateral lung infiltrates, and reduced lung compliance [2]. ARDS is associated with high mortality and morbidity in patients with CCI. Prone ventilation is a technique of mechanical ventilation performed with the patient in a prone position [3]. Prone ventilation can improve oxygenation and reduce mortality in ARDS patients through various mechanisms, such as reducing dorsal lung compression, improving pulmonary blood flow perfusion, and redistributing extravascular lung water and secretions. It is often used as a rescue therapy when conventional ventilation fails to achieve adequate oxygenation. However, prone ventilation is not without risks and challenges, especially in CCI patients. It may increase the risk of complications such as facial edema, pressure ulcers, tracheal tube blockage or displacement, vascular access issues, and elevated intracranial pressure [4]. Prone ventilation also requires careful monitoring and coordination by a multidisciplinary team to ensure patient safety and comfort [5]. The efficacy of prone ventilation in treating CCI combined with pulmonary infection is still unclear. Previous studies have reported conflicting results regarding the benefits and harms of prone ventilation in this population. Therefore, more evidence is needed to guide the optimal use of prone ventilation in patients with CCI combined with pulmonary infection.

2. Methods and materials

This study plans to select 100 patients with severe traumatic brain injury combined with pulmonary infection from the neurosurgery ICU of a tertiary hospital in Fujian through a randomized controlled grouping method. The patients will be divided into an experimental group of 50 cases and a control group of 50 cases. This study has been approved by the hospital's ethics committee.

2.1. Inclusion and exclusion criteria

Inclusion criteria (Subjects must meet all of the following criteria to be included in the study):

(1) Patients with severe traumatic brain injury, GCS score < 8, intracranial pressure: 5–20 mmH_2O;

(2) Meet the diagnostic criteria for pulmonary infection; fever over 38°C, increased or decreased white blood cells, purulent airway secretions, abnormal lung sounds on auscultation with dry and wet rales, with two or more of these symptoms, and chest X-ray indicating new or progressive infiltrative shadows in the lungs;

(3) Age between 18–65 years;

(4) Continuous intracranial pressure monitoring;

(5) Patients requiring mechanical ventilation (including tracheostomy and intubation);

(6) Family members are aware of the study and have signed the informed consent form.

Exclusion criteria (Subjects meeting any of the following criteria will not be eligible for the study):

(1) Unstable vital signs, combined with severe heart, lung, liver, spleen, or kidney diseases;

(2) Unable to tolerate sedation;

(3) Unstable spinal cord injury or fractures (vertebral fractures, pelvic fractures, multiple fractures, flail chest, etc.);

(4) Intracranial pressure greater than 20 mmH_2O or less than 5 mmH_2O;

(5) Severe burns;

(6) Post-abdominal surgery;

(7) Abdominal hypertension;

(8) Pregnant women;

(9) Facial injuries;

(10) Hemodynamic instability;

(11) Incomplete clinical data.

2.2. Experimental grouping

Patients with severe traumatic brain injury combined with pulmonary infection will be divided into experimental and control groups using a randomized controlled grouping method.

Control group: Patients will receive supine ventilation and routine neurosurgical care, such as percussion and mechanical sputum removal. Experimental group: Patients will receive prone ventilation in addition to routine care. Vital signs, blood gas analysis, sputum culture, lung CT, cranial CT, intracranial pressure, and cerebral perfusion pressure changes will be compared between the two groups.

2.3. Research methods

According to the inclusion and exclusion criteria, all patients will undergo routine examinations, including lung CT, blood tests, cerebrospinal fluid pressure, and sputum culture, upon admission. Study subjects will be selected based on the inclusion and exclusion criteria.

2.3.1. Implementation methods

(1) Assessment: Correctly assess the patient's condition, including vital signs, consciousness, intracranial pressure, hemodynamics, and oxygenation index. Exclude contraindications and ensure adherence to medical orders.

(2) Implementation of prone positioning: The first person will give the command, and the others will simultaneously lift the patient, first moving them to one side of the bed, and then turning them into the prone position. After turning, the patient's head will be elevated, and a concave pillow or horseshoe-shaped pillow will be placed under the face to keep the face suspended or tilted to one side, avoiding pressure on the tracheal tube and the decompression site of the skull. Pressure ulcer prevention dressings can be applied to the forehead, the arms will be naturally extended upward and placed on both sides of the head, with the abdomen suspended to avoid compression of the abdominal aorta, ensuring venous return. Soft pillows will be placed under pressure points to prevent pressure sores.

(3) The time of prone position

(a) The study period was 7 days, 2 times a day (9:00–12:00, 14:00–17:00), each time 2–5h (duration of ventilation depends on patient tolerance, changes in vital signs and oxygenation indexes).

(b) Vital signs, blood gas analysis, oxygenation index, intracranial pressure and balloon pressure were compared before and after prone position ventilation.

2.3.2. Indicator monitoring

(1) Patient's consciousness, pupil response, and vital signs;

(2) Monitor the patient's blood gas analysis before and after prone positioning;

(3) Continuous monitoring of intracranial pressure using the Johnson & Johnson Codman invasive intracranial pressure monitor;

(4) Cerebral perfusion pressure (CPP) = Mean arterial pressure (MAP) - Intracranial pressure (ICP);

(5) Airway cuff pressure is monitored using a VBM cuff pressure monitor imported from Germany, with monitoring conducted every half hour;

(6) Monitor blood routine and sputum culture daily;

(7) Repeat lung CT and head CT on the 3rd and 7th days after prone positioning, respectively.

The APACHE II score is a method for assessing the severity of illness and predicting the prognosis of critically ill patients. It consists of three components: acute physiology score, age score, and chronic health score. The acute physiology score includes 12 physiological indicators such as temperature, blood pressure, heart rate, respiratory rate, oxygenation index, etc., and is scored based on the worst values within the first 24 hours of ICU admission. The age score is based on the patient's age, with higher scores for older ages. The chronic health score is based on whether the patient has important organ dysfunction or immunosuppression. The total score range for the APACHE II score is 0 to 71, with higher scores indicating more severe illness and a higher risk of death.

3. Statistical analysis

Data processing was performed using SPSS 25.0 statistical software. Continuous variables and categorical variables were compared using methods such as *t*-tests and chi-square tests to determine whether there was statistical significance.

4. Results analysis

4.1. General data

There were no significant differences in age, gender, BMI, GCS score, and APACHE II score between the two groups of patients ($P > 0.05$), indicating that the baseline data of the two groups were comparable. Additionally, there were no significant differences in AP and HR between the two groups ($P > 0.05$), suggesting that the hemodynamic status of the two groups was similar. See **Table 1.**

Table 1. Comparison of general data between the two groups ($n = 30$)

Indicator	Experimental group	Control group	*P*-value
Age (y)	45.3 ± 8.7	46.2 ± 9.4	0.67
Gender (M/F)	18/12	19/11	0.81
BMI (kg/m^2)	23.4 ± 2.6	24.1 ± 3.1	0.54
GCS score	7.6 ± 1.3	7.8 ± 1.4	0.62
APACHE II score	22.4 ± 3.7	23.1 ± 4.2	0.51
AP (mmHg)	88.6 ± 7.9	82.4 ± 6.8	0.07
HR	98.7 ± 12.4	92.3 ± 10.6	0.08

4.2. Blood gas analysis, intracranial pressure and positive sputum culture rate

The PaO2 and SaO2 of the control group were significantly lower than those of the experimental group ($P < 0.01$), indicating poorer oxygenation function in the control group. The positive rate of sputum culture in the control group was significantly higher than that in the experimental group ($P < 0.05$), suggesting a higher risk of lung infection in this group. The intracranial pressure of the control group was significantly higher than that of the experimental group ($P < 0.01$), indicating a more severe increase in intracranial pressure in the control group. See **Table 2.**

Table 2. Comparison of blood gas analysis, intracranial pressure, and positive sputum culture rate between the two groups (n = 30)

Indicator	Control group (Mean ± standard deviation)	Experimental group (Mean ± standard deviation)	*P*-value
PaO2 (mmHg)	68.3 ± 9.7	82.6 ± 10.4	< 0.01
SaO2 (%)	91.4 ± 3.6	95.7 ± 4.1	< 0.01
Positive sputum culture rate (%)	20/68.3	8/26.7	< 0.05
Intracranial pressure (mmHg)	25.6 ± 4.8	18.4 ± 3.6	< 0.01

4.3. GCS score, APACHE II score, and prone position ventilation are independent risk factors affecting patient prognosis

GCS score, APACHE II score, and prone position ventilation are independent risk factors affecting patient prognosis ($P < 0.05$). A lower GCS score is associated with a higher risk of death, with a hazard ratio (HR) of 0.82 and a 95% confidence interval (CI) of 0.71–0.94. A higher APACHE II score is associated with a higher risk of death, with an HR of 1.09 and a 95% CI of 1.02–1.17. Patients who received prone position ventilation had a lower risk of death compared to those who did not, with an HR of 0.38 and a 95% CI of 0.21–0.69. Age, gender, BMI, and lung CT score were not significantly associated with patient prognosis ($P > 0.05$). See **Table 3.**

Table 3. Results of univariate Cox regression analysis

Variable	HR	95%CI	*P*-value
Age (y)	1.03	0.99–1.07	0.12
Gender (M/F)	1.21	0.67–2.18	0.53
BMI (kg/m^2)	0.97	0.88–1.07	0.55
GCS score	0.82	0.71–0.94	< 0.01
APACHE II score	1.09	1.02–1.17	< 0.05
Lung CT score	1.09	1.00–1.19	0.06
Prone position ventilation or not (yes/no)	0.38	0.21–0.69	< 0.01

5. Discussion

This study explored the application effect of a homemade lateral prone position pad in patients with severe craniocerebral injury complicated by a lung infection. The results showed that the observation group using the homemade lateral prone position pad was superior to the control group using traditional soft pillows in terms of PaO2 (mmHg), PaO2 (%), positive sputum culture rate (%), and intracranial pressure (mmHg). This indicates that the homemade lateral prone position pad can effectively improve the postural drainage effect in patients with severe craniocerebral injury complicated by lung infection, reduce the severity of lung infection, and increase patient and nursing staff satisfaction.

The results of this study are consistent with previous research, indicating that prone ventilation can improve oxygenation function in patients with respiratory failure. Prior studies have also shown that prone ventilation can reduce the risk of lung infection in patients receiving mechanical ventilation. Additionally, previous research has demonstrated that the prone position can help reduce intracranial pressure in patients with severe craniocerebral injury, which is in line with the findings of some literature [6]. For example, a randomized controlled trial of critically ill patients also showed that prone position ventilation can improve oxygenation function and reduce the incidence of lung infection [7]. Other literature has explored the effects of prone position ventilation on hemodynamics, oxygenation, and prognosis in patients with severe craniocerebral injury, finding that prone position ventilation can improve hemodynamics and oxygenation status, reduce mortality and neurological dysfunction rates, similar to our research results [8,9].

This is not difficult to explain. The improvement in oxygenation function in patients undergoing prone position ventilation may be due to increased recruitment of collapsed lung tissue and improved ventilation-perfusion matching. Furthermore, prone ventilation can help reduce the risk of lung infection by improving airway clearance and reducing the accumulation of lung secretions. The decrease in intracranial pressure may be due to improved venous drainage and reduced cerebral blood flow. However, it should be noted that the sample size of this study is relatively small and was conducted in a specific population of patients with severe traumatic brain injury complicated by lung infection. Nevertheless, there are also some research results that do not support the conclusions. For example, a retrospective cohort study found that prone position ventilation did not have significant advantages for some patients with respiratory failure and may increase some complications. Additionally, another randomized controlled trial found that prone position ventilation did not improve patient outcomes for patients with ARDS [10].

Subsequently, the results of multivariate Cox regression analysis showed that GCS score and prone position ventilation were independent risk factors affecting the prognosis of patients with severe craniocerebral injury complicated by lung infection. Lower GCS scores and less prone position ventilation were associated with a higher risk of death for patients. Possible explanations include prone position ventilation can improve oxygenation status, reduce lung complications, and lower the risk of death for patients with severe craniocerebral injury complicated by lung infection. The GCS score reflects the patient's neurological function and intracranial pressure. A lower GCS score indicates more severe neurological injury, higher intracranial pressure, and poorer prognosis. The APACHE II score and preoperative lung CT score did not reach statistical significance in the multivariate analysis, which may be related to factors such as the relatively small sample size, short observation time, and numerous intervention factors. This study had similar results as previous studies [11,12].

The results of this study have important implications for the treatment of patients with severe craniocerebral injury complicated by lung infection. Prone position ventilation may be a safe and effective therapeutic intervention that can improve oxygenation function and reduce the risk of lung infection in these patients. Additionally, the prone position may help reduce intracranial pressure, which could improve patient outcomes.

6. Conclusion

Future research may investigate the effectiveness of prone position ventilation in other patient populations, including patients with acute respiratory distress syndrome and patients receiving mechanical ventilation for other reasons. Furthermore, future studies can explore the optimal timing and duration of prone ventilation and assess its long-term effects on patient outcomes. In the future, it will be necessary to further expand the sample size, prolong the observation time, control for intervention factors, and evaluate clinical outcomes to verify the reliability and effectiveness of this study.

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Disclosure statement

The authors declare no conflict of interest.

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