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Safety and efficacy of prone position ventilation in patients with severe pneumonia in neurosurgical intensive care units

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Abstract: Objective To investigate the effectiveness and safety of prone position ventilation in treating critically ill patients with neurosurgical-related diseases complicated by severe pneumonia providing reference for the treatment of severe pneumonia. **Methods** A retrospective analysis was conducted on the clinical data of 41 patients with neurosurgical-related diseases and severe pneumonia admitted to the neurosurgical intensive care unit of Nanjing Drum Tower Hospital, The Affiliated Hospital of Nanjing University Medical School, from January 2023 to November 2024. All patients experienced progressive worsening of pulmonary inflammation and severe hypoxemia after conventional treatment, and were given prone position ventilation. Changes in blood gas analysis [pH, arterial oxygen tension （PaO2）, arterial carbon dioxide tension（PaCO2）, oxygenation index] and hemodynamics [heart rate（HR）, mean arterial pressure（MAP）] were compared before prone positioning, and at 1 day, 3 days, 5 days, and 7 days after resuming supine position following prone position treatment. **Results** The average hospitalization duration in the neurosurgical intensive care unit for the 41 patients was（20.49 ± 5.14）days. The oxygenation index before prone positioning and at 1 day, 3 days, 5 days, and 7 days after resuming supine position were（104.12± 11.09）mmHg, （118.67 ± 18.58） mmHg, （148.20 ± 29.17） mmHg, （237.21 ± 56.91） mmHg, and （303.26 ± 66.78） mmHg, respectively, showing a significant upward trend（F=164.657, P<0.01）. PaO_2 values followed a similar pattern: （79.63±4.8）mmHg, （89.90±6.83）mmHg, （106.98 ±12.26）mmHg, （130.40±12.03）mmHg, and（135.68±13.95）mmHg, also demonstrating a significant increase（F=219.963, P<0.01）. No statistically significant differences were observed in $PaCO_2$, pH, HR and MAP before and after prone position ventilation （P>0.05）. **Conclusion** Prone position ventilation effectively improves the oxygenation index in critically ill neurosurgical patients with severe pneumonia. As treatment duration increases, the oxygenation index gradually improves without significant impact on hemodynamics, proving it to be both safe and effective for such patients.

Keywords: Neurosurgical intensive care unit; Prone position ventilation; Severe pneumonia; Oxygenation index

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Patients admitted to the Neurosurgical Intensive Care Unit (NICU) are primarily critically ill neurosurgical patients, including those with traumatic brain injury, intracerebral hemorrhage, severe subarachnoid hemorrhage, and cerebral infarction, who often present with altered consciousness and require the placement of an artificial airway for mechanical ventilation. This may lead to the occurrence of pulmonary inflammation, and some patients may progress to severe pneumonia, causing life-threatening hypoxemia [1]. Prone position ventilation can promote the reopening of collapsed alveoli, alter lung compliance, and improve the ventilation/perfusion ratio. Previous studies have extensively researched the use of prone positioning in patients with acute respiratory distress syndrome (ARDS) [2-4]. However, there is limited research on its application in patients with severe pneumonia, and even fewer studies have focused on neurosurgical ICU patients with severe pneumonia, possibly due to the challenges of managing intracranial pressure in patients with intracranial hypertension undergoing surgery, as well as difficulties in assessing intracranial pressure during the prone position, which may exacerbate intracranial conditions. This study retrospectively analyzed the clinical data of 41 patients with neurological diseases complicated by severe pneumonia admitted to the neurosurgical ICU, evaluating the value of prone positioning in mechanical ventilation in the neurosurgical ICU.

1. Patients and Methods

1.1 Study Subjects

A retrospective analysis was conducted on the clinical data of 41 patients with severe pneumonia who admitted to the Neurosurgical Intensive Care Unit of Nanjing Drum Tower Hospital, The Affiliated Hospital of Nanjing University Medical School, from January 2023 to October 2024. These patients exhibited progressive worsening of severe pneumonia that could not be improved by routine treatments. All family members of the patients were informed and signed informed consent before the prone position ventilation was implemented.

1.2 Inclusion and Exclusion Criteria

Inclusion criteria: (1) Patients who meet the diagnostic criteria for severe pneumonia [5]; (2) Patients whose pneumonia worsened progressively and developed hypoxemia despite routine treatments such as antibiotics; (3) Patients who were assessed by cranial imaging and did not exhibit significant intracranial hypertension. Exclusion criteria: (1) Unstable circulation; (2) Multiple rib fractures; (3) Concurrent injuries to the thoracic or abdominal organs.

1.3 Data Collection

Clinical data were collected, including gender, age, body mass index (BMI), medical history (hypertension, diabetes), therapeutic interventions (antibiotics, nasogastric feeding), and duration of stay in the NICU. Arterial blood gas analysis was performed before prone position ventilation, and on days 1, 3, 5, and 7 days of treatment. Parameters such as pH, partial pressure of oxygen (PaO_2), partial pressure of carbon dioxide ($PaCO_2$), fraction of inspired oxygen (FiO_2), and the oxygenation index (PaO_2/FiO_2 ratio) were recorded. Changes in hemodynamic parameters, including heart rate (HR) and mean arterial pressure (MAP), were also documented. Chest CT scans were performed before the prone position ventilation, 3 and 7 days after treatment to compare the improvement in pulmonary inflammation.

1.4 Monitoring Indicators

All patients had artificial airways inserted and were continuously mechanically ventilated using the synchronized intermittent mandatory ventilation (SIMV) mode with volume and pressure control. Tidal volume (VT) was set at 8-10 mL/kg, respiratory rate at 15-20 beats/min, FiO_2 at 0.40-1.00, and positive end-expiratory pressure (PEEP) at $\geqslant$5 cmH_2O. Nasogastric tubes were routinely inserted before prone position ventilation. During the prone position, continuous nutritional support through the nasogastric tube ensured adequate nutrition intake. Sedation was provided for restless patients. Every 2 hours, the patient's head and pressure points was adjusted to prevent pressure and edema at dependent body areas. The prone position was maintained for more than 7 days, with each session lasting 6-8 hours. The artificial airway was carefully monitored for secretions, which were cleared in a timely manner. Continuous electrocardiogram monitoring was performed during prone ventilation, and fluctuations in blood pressure and oxygen saturation were closely monitored. If vital signs became unstable, prone ventilation was immediately discontinued.

1.5 Statistical Methods

SPSS 27.0 software was used for statistical analysis. Normally distributed data are presented as $\bar{x}\pm s$, and comparisons were made using one-way analysis of variance. Non-normally distributed data are presented as M (Q_1, Q_3), and comparisons were made using the Kruskal-Wallis test. Count data were presented as case (%). *P*-value of <0.05 was considered statistically significant.

2 Results

2.1 General Information

Among the 41 patients, 28 were male and 13 were female. The age range was from 20 to 88 years, with an average age of 64.98±13.91 years. Disease types included 24 cases of intracerebral hemorrhage (in the basal ganglia, cerebellum, brainstem, cerebral lobes, and ventricles), 7 cases of traumatic brain injury, 6 cases of severe subarachnoid hemorrhage, 1 case of cervical spinal cord hemorrhage, 1 case of hydrocephalus, 1 case of chronic subdural hematoma, and 1 case of Guillain-Barré syndrome. Except for the 2 cases of cervical spinal cord hemorrhage and Guillain-Barré syndrome, the remaining 39 patients exhibited varying degrees of consciousness disturbance. Among these, 34 patients had a Glasgow Coma Scale (GCS) score 3-8, and 5 patients had a GCS score 9-11. Surgical treatment was performed in 33 cases, while 8 cases received conservative treatment. The BMI ranged from 18.52-37.87 kg/m², with an average of 26.05±4.11 kg/m². Thirty-three patients had a history of hypertension, and 7 patients had a history of diabetes. The length of hospital stay ranged from 11 to 33 days, with an average of 20.49±5.14 days. All patients had an artificial airway, including 35 cases of tracheostomy and 6 cases of endotracheal intubation.

2.2 Comparison of Blood Gas Analysis Parameters at Various Time Points during Prone Position Ventilation

Before prone position therapy and on days 1, 3, 5, and 7 of treatment, PaO_2 and oxygenation index gradually increased, while FiO_2 gradually decreased, with statistically significant differences ($P<0.05$). However, there were no statistically significant differences in $PaCO_2$ or pH values at any time point ($P>0.05$). **See Table 1.**

2.3 Hemodynamic Parameter Changes

Before prone position ventilation, the blood pressure of all patients was within the normal range. For those with hypertension, antihypertensive medications were administered to stabilize their blood pressure. There were no statistically significant differences in heart rate (HR) or mean arterial pressure (MAP) before and after prone position ventilation ($P>0.05$). **See Table 2.**

2.4 Improvement in Pulmonary Inflammation

Chest CT scans were performed before, 3 days, and 7 days after prone position ventilation treatment, and showed a gradual improvement in pulmonary inflammation (**Figure 1, Figure 2**).

Tab.1 Comparison of arterial blood gas before and after prone position (n=41)

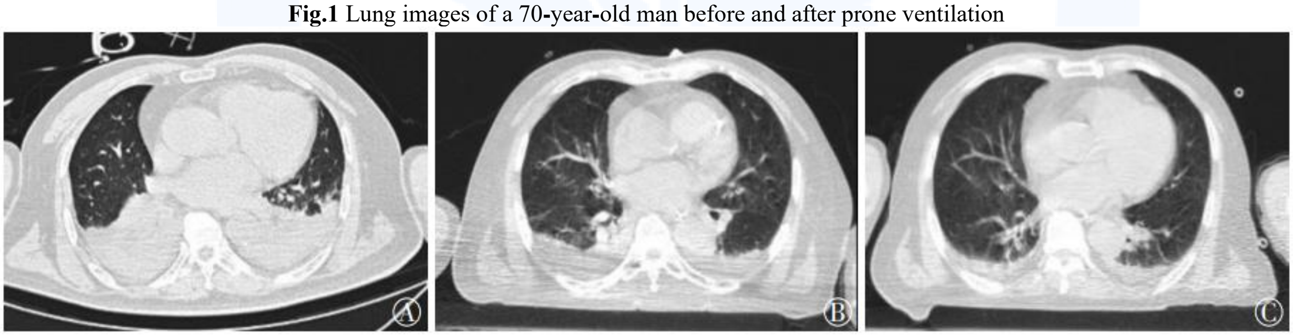
Time	PaO₂(mmHg, $\bar{x}\pm s$)	FiO₂[$M(Q_1,Q_3)$]	PaCO₂(mmHg, $\bar{x}\pm s$)	pH($\bar{x}\pm s$)	PaO₂/FiO₂(mmHg, $\bar{x}\pm s$)
Before treatment	79.63±4.81	0.75（0.70,0.83）	43.12±6.41	7.39±0.07	104.12±11.09
1 d after treatment	89.90±6.83	0.70（0.70,0.80）	42.20±8.23	7.40±0.08	118.67±18.58
3 d after treatment	106.98±12.26	0.70（0.70,0.80）	39.78±7.41	7.42±0.06	148.20±29.17
5 d after treatment	130.40±12.03	0.60（0.50,0.60）	40.23±9.23	7.41±0.07	237.21±56.91
7 d after treatment	135.68±13.95	0.40（0.40,0.50）	39.89±3.89	7.41±0.06	303.26±66.78
***F*/*H* value**	219.963	71.063	1.790	0.661	164.657
***P* value**	＜0.001	＜0.001	0.132	0.524	＜0.001

Tab.2 Hemodynamic changes before and after prone position (n=41, $\bar{x}\pm s$)

Indicator	Before treatment	1 d after treatment	1 d after treatment	1 d after treatment	1 d after treatment	*F* value	*P* value
HR	97.63±24.00	95.76±21.96	88.41±20.41	87.68±17.24	89.98±19.92	1.923	0.108
MAP	92.49±7.65	90.66±9.15	89.71±10.72	89.02±8.26	89.44±10.68	0.889	0.471

Note: The patient was a 70-year-old elderly male who developed hydrocephalus after intracranial aneurysm intervention. During the course of the disease, he developed pulmonary inflammation, which could not be relieved by conventional treatment. Therefore, prone positioning ventilation was implemented. A showed the condition before prone positioning treatment; B showed the condition after 3 days of prone positioning; C showed the condition after 7 days of prone positioning.

Fig.1 Lung images of a 70-year-old man before and after prone ventilation



Note: The patient was a 72-year-old elderly male who underwent hematoma evacuation due to cerebral hemorrhage. During the course of the illness, he developed a pulmonary infection, which did not respond to conventional treatment. Therefore, prone position ventilation was administered. A showed the condition before prone position ventilation;B showed the condition after 3 days of prone position ventilation;C showed the condition after 7 days of prone position ventilation.

Fig.2 Lung images of a 72-year-old man before and after prone ventilation

2.5 Incidence of Adverse Events

During the treatment, no patients experienced intracerebral hemorrhage, increased intracranial pressure, or cerebral infarction on imaging. There were no incidents of circulatory instability, aspiration, or displacement of the artificial airway. Only a few patients developed pressure-induced swelling on the face and head, which improved after returning to the supine position.

3 Discussion

Neurosurgical critically ill patients are often those who have undergone surgery for severe neurological conditions, presenting with altered consciousness, diminished or absent cough reflex, and artificial airways with mechanical ventilation, making them prone to varying degrees of pulmonary infections. Intracranial hypertension-induced nausea and vomiting, the use of antibiotics, and the difficulty in effectively draining deep sputum while in the supine position can lead to complications such as aspiration pneumonia, atelectasis, and pulmonary consolidation [6-7]. Due to the body's catabolic state, neurosurgical critically ill patients often remain in negative nitrogen balance, with impaired immune function, thus increasing the risk of infection.

Severe pneumonia is a critical stage in the development of pulmonary inflammation, and even in intensive care units, it still carries a high mortality rate [8-9], leading to prolonged hospitalization. In this study, the average length of hospital stay for the 41 patients was (20.49 ± 5.14) days, significantly longer than the duration in general wards, which increases the economic burden on patients. Currently, clinical treatment strategies include oxygen therapy, anti-infection treatment, expectoration, and supportive therapies [10]. Supportive therapies mainly involve mechanical ventilation. Supine position mechanical ventilation can, to some extent, improve oxygenation and alleviate clinical symptoms; however, it has limitations in correcting severe hypoxemia and improving ventilation-perfusion matching [11-12]. Traditional mechanical ventilation techniques may fail to restore alveolar function and sometimes even cause overexpansion of normal alveoli, leading to barotrauma [13]. Prone position mechanical ventilation is a therapeutic adjunctive intervention. This position alters diaphragmatic movement and position, improving pulmonary blood flow distribution and gas exchange in non-gravity-dependent lung regions. It not only facilitates the reopening of collapsed alveoli and reduces the loss of pulmonary surfactant but also significantly decreases the incidence of pulmonary edema, accelerates the recovery of spontaneous breathing, and shortens ICU length of stay [14]. Furthermore, it ameliorates cardiac and mediastinal compression on the lungs and adjusts chest wall compliance, thereby improving oxygenation, correcting refractory hypoxemia, and reducing patient mortality [15-[17]. A study by Tang *et al.* [18] found that prone positioning has a certain effect in correcting hypoxemia in patients with traumatic brain injury. Compared to the supine position, prone positioning combined with percussion facilitates drainage of sputum from the lungs, promotes airway secretion clearance, effectively controls infection, and is rarely associated with aspiration [19]. Previous studies have also shown that implementing prone ventilation during hospitalization can reduce levels of inflammatory factors such as C-reactive protein, thereby effectively controlling infection [20].

Currently, prone ventilation has been extensively studied in patients with ARDS, with favorable results reported [21-22]. However, research in patients with severe pneumonia is limited, and even less exists for neurosurgical critically ill patients. Due to the potential for prone positioning to increase intracranial pressure and worsen the condition, neurosurgical critically ill patients often present with impaired consciousness and agitation, requiring artificial airways, particularly tracheostomies, which carry a risk of accidental extubation. Additionally, neurosurgical conditions such as hypertensive intracerebral hemorrhage and severe subarachnoid hemorrhage frequently occur in obese patients; the mean BMI in this study's 41 patients was 26.05 ± 4.11 kg/m². Consequently, prone positioning requires significant manpower, leading to poor compliance in some institutions and a paucity of research reports in this population.The authors selected patients with severe pneumonia who showed no improvement despite conventional treatments including antibiotics, bronchoscopy, and vibratory sputum clearance for prone ventilation. All patients had a disease course exceeding one week prior to treatment and stable intracranial conditions; cranial imaging excluded severe intracranial hypertension and cerebral edema. Favorable outcomes were achieved in all cases. Some patients underwent continuous intracranial pressure monitoring; real-time intracranial pressure monitoring allowed for timely therapeutic adjustments, mitigating adverse outcomes related to prone position-induced intracranial hypertension. Regarding the optimal duration and frequency of prone ventilation therapy, no unified standard currently exists. Previous studies suggest that patients undergoing prone positioning for 12 hours or longer daily experience greater improvements in oxygenation and derive more significant benefits [23]. Due to the specific nature of neurosurgical patients, and to reduce the risk of increased intracranial pressure caused by prolonged prone positioning, this study included 41 patients, with a fixed daily prone position duration of 6 to 8 hours, and a duration of prone positioning for more than 7 days. The study by Demir *et al.* [24] suggested that adequate analgesia and sedation, along with mechanical ventilation, have minimal impact on intracranial pressure during prone positioning. In this study, individualized analgesia and sedation treatment were applied based on vital signs for patients in the prone position. For patients experiencing agitation, an appropriate analgesia and sedation regimen was particularly important. Arterial blood gas measurements taken before prone positioning, and on the 1st, 3rd, 5th, and 7th days of treatment, showed significant increases in PaO_2 and oxygenation index, with a gradual decrease in FiO_2. Dynamic reexaminations of cranial CT scans did not show any intracranial hemorrhage or worsening of cerebral edema. Chest CT scans before prone ventilation, and on the 3rd and 7th days of treatment, showed significant improvement in pulmonary inflammation. Hemodynamic indicators monitored before and after prone positioning did not show any signs of circulatory instability or other adverse reactions. Some patients might have experienced facial and head skin compression and swelling, but since the prone position duration was short and the patient’s head and limbs were repositioned every 2 hours, all such issues improved upon returning to the supine position. No serious adverse reactions, such as extubation, occurred during the treatment in any of the patients. Previous literature has reported suspending enteral nutrition support during prone positioning. However, in this study, patients routinely had nasoenteric tubes inserted and received normal enteral nutrition support during prone positioning without experiencing vomiting or aspiration. This allowed for effective nutritional support during treatment, potentially reducing the risk of poor prognosis.

In conclusion, for neurosurgical intensive care unit patients with severe pneumonia, prone positioning ventilation can improve pulmonary oxygenation index, lung ventilation, and reduce pulmonary inflammation without significant impact on hemodynamics, provided there is no severe intracranial hypertension. However, there are limitations to this study. First, it is a single-center study with a small sample size. Future research should explore more effective non-invasive methods for monitoring intracranial pressure in neurosurgical critically ill patients, such as the potential for estimating pressure indirectly through ultrasound-guided jugular vein pressure, and determine the optimal duration and frequency of prone positioning that minimizes ICP or has the least impact on it. Further large-scale, multi-center studies are needed.

Conflict of interest None

Reference

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·论 著·

俯卧位通气在神经外科重症病房重症肺炎患者中应用的安全性及有效性

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摘要：目的 探讨俯卧位通气治疗神经外科重症病房相关疾病合并重症肺炎的效果及安全性，为重症肺炎的治疗提供参考。**方法** 回顾性分析2023年1月至2024年10月南京大学医学院附属鼓楼医院神经外科重症病房收治的41例神经外科相关疾病合并重症肺炎患者的临床资料，所有患者经常规治疗后肺部炎症无法改善并进行性加重伴严重低氧血症，予行俯卧位通气，比较患者在俯卧位治疗前，俯卧位治疗1、3、5及7 d恢复仰卧位后的血气分析[血酸碱度(pH)、动脉血氧分压(PaO_2)、动脉血二氧化碳分压($PaCO_2$)、氧合指数]、血流动力学[(心率(HR)、平均动脉压(MAP)]指标的变化情况。**结果** 41例患者神经外科重症病房住院天数为(20.49±5.14)d。俯卧位治疗前，俯卧位治疗1、3、5及7 d的氧合指数分别为(104.12±11.09)mmHg、(118.67±18.58)mmHg、(148.20±29.17)mmHg、(237.21±56.91)mmHg及(303.26±66.78)mmHg，呈升高趋势，差异有统计学意义(F=164.657，P<0.01)；PaO_2分别为(79.63±4.81)mmHg、(89.90±6.83)mmHg、(106.98±12.26)mmHg、(130.40±12.03)mmHg及(135.68±13.95)mmHg，呈升高趋势，差异有统计学意义(F=219.963，P<0.01)。俯卧位通气前后$PaCO_2$、pH、HR、MAP比较差异均无统计学意义(P>0.05)。**结论** 俯卧位通气能够有效改善神经外科重症合并重症肺炎患者的氧合指数，随着治疗时间的延长，氧合指数逐渐改善，且对血液流动学无明显影响，对于神经外科重症病房合并重症肺炎患者安全且有效。

关键词： 神经外科重症病房；俯卧位通气；重症肺炎；氧合指数
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Safety and efficacy of prone position ventilation in patients with severe pneumonia in neurosurgical intensive care units

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Abstract: Objective To investigate the effectiveness and safety of prone position ventilation in treating critically ill patients with neurosurgical-related diseases complicated by severe pneumonia, and to provide reference for the treatment of severe pneumonia. **Methods** A retrospective analysis was conducted on the clinical data of 41 patients with neurosurgical-related diseases and severe pneumonia admitted to the Neurosurgical Intensive Care Unit of Nanjing Drum Tower Hospital, the Affiliated Hospital of Nanjing University Medical School, from January 2023 to November 2024. All patients experienced progressive worsening of pulmonary inflammation and severe hypoxemia after conventional treatment, and were given prone position ventilation. Changes in blood gas analysis [pH, arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), oxygenation index] and hemodynamics [heart rate (HR), mean arterial pressure (MAP)] were compared before prone positioning, and at 1 day, 3 days, 5

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days, and 7 days after resuming supine position following prone position treatment. **Results** The average hospitalization duration in the neurosurgical intensive care unit for the 41 patients was (20.49±5.14) days. The oxygenation index before prone positioning and at 1 day, 3 days, 5 days, and 7 days after pone positioning were (104.12±11.09) mmHg, (118.67 ± 18.58) mmHg, (148.20 ± 29.17) mmHg, (237.21 ± 56.91) mmHg, and (303.26 ± 66.78) mmHg, respectively, showing a significant upward trend (F=164.657, P<0.01). PaO_2 values followed a similar pattern: (79.63±4.81) mmHg, (89.90±6.83) mmHg, (106.98±12.26) mmHg, (130.40±12.03) mmHg, and (135.68±13.95) mmHg, also demonstrating a significant increase (F=219.963, P<0.01). No statistically significant difference was observed in $PaCO_2$, pH, HR and MAP before and after prone position ventilation (P>0.05). **Conclusion** Prone position ventilation effectively can improve the oxygenation index in critically ill neurosurgical patients with severe pneumonia. As treatment duration increases, the oxygenation index gradually improves without significant impact on hemodynamics, proving it to be both safe and effective for such patients.

Keywords: Neurosurgical intensive care unit; Prone position ventilation; Severe pneumonia; Oxygenation index

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神经外科重症病房收治的患者多为神经外科危重症患者，包括颅脑外伤、脑出血、重症蛛网膜下腔出血、脑梗死等，表现为意识障碍，需留置人工气道机械通气，可致肺部炎症的发生，部分患者可进展为重症肺炎，导致严重的低氧血症，危及生命[1]。俯卧位通气可促进塌陷肺泡重新开放、改变肺顺应性、改善通气/血流灌注比例。既往俯卧位通气在治疗急性呼吸窘迫综合征(acute respiratory distress syndrome，ARDS)的患者中有较多研究[2-4]，但对于重症肺炎患者研究较少，神经外科重症患者合并重症肺炎中的研究则更少，可能原因为神经外科疾病多表现为颅内高压且行手术治疗，对于俯卧位的实施及治疗过程颅内压的评估有困难，且容易导致颅内病情加重。本研究分析神经外科重症病房中收治的神经系统疾病合并重症肺炎41例患者的临床资料，评估俯卧位通气在神经外科重症病房中的应用价值。

1 对象与方法

1.1 *研究对象* 回顾性分析2023年1月至2024年10月南京大学医学院附属鼓楼医院神经外科重症病房收治的经常规治疗无法改善且进行性加重的重症肺炎患者41例的临床资料。所有患者实施俯卧位前均告知患者家属并签署知情同意书。本研究经南京医科大学附属鼓楼医院审核批准。

1.2 *纳入与排除标准* 纳入标准：(1) 符合重症肺炎相关诊断标准[5]；(2) 常规抗感染等治疗无效且肺部炎症进行性加重并出现低氧血症；(3) 经头颅影像学检查评估无显著颅内高压患者。排除标准：(1) 循环不稳定；(2) 多发肋骨骨折；(3) 伴胸腹腔脏器损伤。

1.3 *数据收集* 收集患者临床资料，包括性别、年龄、身体质量指数(body mass index，BMI)、既往史(高血压病、糖尿病病史)、治疗措施(抗生素、鼻饲饮食)、神经外科重症监护室住院时长等。记录俯卧位通气治疗前，治疗1、3、5及7 d的血气分析[pH值、氧分压(PaO_2)、二氧化碳分压($PaCO_2$)、吸入氧浓度(fraction of inspired oxygen，FiO_2)、氧合指数(PaO_2/FiO_2)]、血流动力学[心率(HR)、平均动脉压(MAP)]的变化情况。在患者进行俯卧位通气治疗前、治疗3天及7天后完善胸部CT检查，对比肺部炎症改善情况。

1.4 *监测指标* 所有患者均留置人工气道，持续机械通气，采用SIMV(synchronized intermittent mandatory ventilation)容量+压力控制通气模式，潮气量(tidal volume，VT)8～10 mL/kg，呼吸频率15～20次/min，FiO_2 0.40～1.00，呼气末正压(PEEP)≥5 cmH_2O。实施俯卧位前常规留置鼻肠管，俯卧位期间经鼻肠管持续营养支持保证营养摄入，烦躁患者适量镇静，每2小时调整患者头部及受压部位，防止下垂部位的压迫及水肿，俯卧位时间大于7 d，每次俯卧位通气时间6~8 h，注意关注人工气道有无分泌物堵塞，及时清理。俯卧位通气过程中予持续心电监测，注意血压、血氧饱和度波动情况，如生命体征不稳，需立即停止。

1.5 *统计学方法* 应用SPSS 27.0统计软件对所有数据进行分析。符合正态分布的计量资料以$\bar{x}±s$表示，比较采用单样本重复测量方差分析；不符合正态分布的计量资料以$M(Q_1, Q_3)$表示，比较采用Kruskal-Wallis H检验；计数资料用例(%)表示。$P<0.05$为差异有统计学意义。

2 结　果

2.1　一般情况　41例患者中男28例，女13例；年龄20~88(64.98±13.91)岁。疾病类型包括脑出血24例（基底节区、小脑、脑干、脑叶、脑室），颅脑外伤7例，重症蛛网膜下腔出血6例，颈髓出血1例，脑积水1例，慢性硬膜下血肿1例，吉兰-巴雷综合征1例。除颈髓出血及吉兰-巴雷综合征2例患者外，其余39例均有不同程度意识障碍，其中格拉斯哥昏迷评分(GCS)3~8分34例，9~11分5例。手术治疗33例，保守治疗8例。BMI为18.52~37.87(26.05±4.11)kg/m^2。有高血压病史33例，有糖尿病病史7例。住院天数11~33(20.49±5.14)d。所有患者均留置人工气道，其中气管切开35例、气管插管6例。

2.2　俯卧位通气各时间点血气分析指标比较　俯卧位治疗前，治疗1 d、3 d、5 d及7 d的PaO_2、氧合指数逐渐升高，FiO_2逐渐降低，差异有统计学意义(P<0.05)；$PaCO_2$、pH值各时间点间差异无统计学意义(P>0.05)。见表1。

2.3　血流动力学指标变化情况　所有患者行俯卧位前血压均控制在正常范围内，对于有高血压患者予降压药物控制血压平稳。俯卧位通气前后HR、MAP比较差异均无统计学意义(P>0.05)。见表2。

2.4　肺部炎症改善情况　在患者进行俯卧位通气治疗前、治疗3 d及7 d后完善胸部CT检查，对比肺部炎症呈现逐渐吸收好转状态(图1、图2)。

表1　俯卧位前后动脉血气比较　(n=41)

Tab.1　Comparison of arterial blood gas before and after prone position　(n=41)

时间	PaO_2(mmHg, $\bar{x}\pm s$)	FiO_2[$M(Q_1,Q_3)$]	$PaCO_2$(mmHg, $\bar{x}\pm s$)	pH($\bar{x}\pm s$)	氧合指数(mmHg, $\bar{x}\pm s$)
治疗前	79.63±4.81	0.75(0.70, 0.83)	43.12±6.41	7.39±0.07	104.12±11.09
治疗1 d	89.90±6.83	0.70(0.70, 0.80)	42.20±8.23	7.40±0.08	118.67±18.58
治疗3 d	106.98±12.26	0.70(0.70, 0.80)	39.78±7.41	7.42±0.06	148.20±29.17
治疗5 d	130.40±12.03	0.60(0.50, 0.60)	40.23±9.23	7.41±0.07	237.21±56.91
治疗7 d	135.68±13.95	0.40(0.40, 0.50)	39.89±3.89	7.41±0.06	303.26±66.78
F/H值	219.963	71.063	1.790	0.661	164.657
P值	< 0.001	< 0.001	0.132	0.524	< 0.001

表2　俯卧位前后血流动力学变化　(n=41, $\bar{x}\pm s$)

Tab.2　Hemodynamic changes before and after prone position　(n=41, $\bar{x}\pm s$)

指标	治疗前	治疗1 d	治疗3 d	治疗5 d	治疗7 d	F值	P值
HR(次/min)	97.63±24.00	95.76±21.96	88.41±20.41	87.68±17.24	89.98±19.92	1.923	0.108
MAP(mmHg)	92.49±7.65	90.66±9.15	89.71±10.72	89.02±8.26	89.44±10.68	0.889	0.471

注：患者70岁老年男性，因颅内动脉瘤介入术后脑积水，病程中并发肺部炎症，经常规治疗无法缓解后，予实施俯卧位通气。A为俯卧位通气前；B为俯卧位3天后；C为俯卧位7天后。

图1　一例70岁老年男性俯卧位通气治疗前后肺部影像

Fig.1　Lung images of a 70-year-old man before and after prone ventilation

注：患者72岁老年男性，因脑出血行血肿清除，病程中并发肺部感染，常规治疗无效后，予行俯卧位通气。A为俯卧位通气前；B为俯卧位通气3天后；C为俯卧位通气7天后。

图2　一例72岁老年男性俯卧位通气治疗前后肺部影像

Fig.2　Lung images of a 72-year-old man before and after prone ventilation

2.5　不良事件发生率　本研究所有患者治疗过程中未出现脑出血、颅内压增高、脑梗死等影像学表现；未出现循环不稳、误吸、人工气道脱落等情况，仅部分患者出现头面部皮肤受压肿胀，仰卧位后均改善。

3 讨　论

神经外科重症患者多为经手术治疗的神经系统危重症患者，表现为意识障碍、呛咳反射减弱或消失，同时留置人工气道机械通气，容易导致不同程度肺部感染。颅内高压导致的恶心呕吐、抗生素使用以及仰卧状态下患者深部痰难以有效引流，可导致吸入性肺炎、肺不张、肺实变等并发症[6-7]；神经外科重症患者由于机体消耗常处于负氮平衡，免疫功能降低，感染的风险加重。重症肺炎是肺部炎症发展的危重阶段，即使在重症监护病房，仍存在较高的病死率[8-9]，住院时间延长。本研究41例患者住院时长(20.49±5.14)天，远超普通病房住院时间，患者的经济负担加重。目前临床上治疗方案为氧疗、抗感染、化痰及支持疗法等[10]，支持疗法多采用机械通气，仰卧位机械通气在一定程度上可改善患者的氧合状态，缓解临床症状，但其对纠正严重低氧血症、改善通气血流方面具有局限性[11-12]。传统的机械通气技术可能难以恢复肺泡功能，有时甚至会导致正常肺泡过度扩张和气压损伤[13]。俯卧位机械通气属于一种治疗性的辅助干预方法，该体位可改变膈肌的运动方式和位置，改善肺非重力依赖区的肺血流分布及气体交换，不仅有利于塌陷肺泡的重新开放，减少肺表面活性物质的损失，同时显著降低肺水肿的发生率，加快自主呼吸的恢复，缩短ICU的住院时间[14]。同时改善心脏及纵隔对肺脏的压迫，调整胸廓顺应性，进而改善氧合，纠正顽固性低氧血症，降低患者病死率[15-17]。汤睿等[18]研究发现，俯卧位通气对于纠正颅脑损伤患者的低氧血症有一定的效果。相比仰卧位，俯卧位在配合拍背的情况下，能够将痰液引流出肺外，促进气道分泌物引流，有效控制感染，且很少出现误吸[19]。既往也有研究表明住院期间实施俯卧位通气可以降低C反应蛋白等炎症因子的水平，从而有效控制感染[20]。

目前俯卧位通气在治疗ARDS的患者中已有较多的研究，均取得不错的结果[21-22]，在重症肺炎患者中的研究较少，在神经外科重症患者中的研究则更少。由于俯卧位通气因体位改变可能导致颅内压增高加重病情，神经外科重症患者多表现意识障碍及躁动、需留置人工气道，特别是气管切开，存在人工气道脱落的风险，同时神经外科相关疾病如高血压脑出血、重症蛛网膜下腔出血等多数为肥胖患者，本研究41例患者BMI值为(26.05±4.11)kg/m^2，因此行俯卧位操作时需耗费大量人力，导致部分单位对俯卧位依从性不高，因而对于这方面研究报道较少。笔者选取了治疗前病程均超过一周且颅内情况稳定，头颅影像检查排除严重的颅高压、脑水肿等，且经抗感染、支气管镜、振动排痰等常规治疗仍无法改善的重症肺炎患者实施俯卧位通气，均取得很好的效果。同时部分患者留置颅内压监测，实时的颅内压监测能及时调整治疗，降低因俯卧位导致的颅高压引起的不良结果。关于俯卧位通气治疗的时长及频率，目前尚无统一标准，既往一些研究表明，每日持续行俯卧位通气12 h或更长时间的患者，氧合改善更高，获益更大[23-27]。因神经外科患者的特殊性，为减少因长时间俯卧位导致的颅内压增高风险，本研究41例患者，每日俯卧位时间固定为6~8 h，俯卧位持续时间7 d以上。Demir等[28]研究提示俯卧位期间足量镇痛镇静并采取机械通气对于颅内压影响较小。本研究对于俯卧位患者依据生命体征采取个体化镇痛镇静治疗，对于躁动患者，采取合适的镇痛镇静方案尤为重要。所有患者监测俯卧位治疗前，治疗1 d、3 d、5 d及7 d动脉血气提示PaO_2、氧合指数均明显升高，FiO_2逐渐降低，动态复查头颅CT未见颅内出血及脑水肿加重；俯卧位通气治疗前、治疗3 d及7 d后完善胸部CT检查提示肺部炎症明显改善；监测俯卧位前后血流动力学指标未出现循环不稳等不良反应；部分患者可能出现头面部皮肤压迫肿胀，因本研究俯卧位时间短且每隔2小时改变患者头部与四肢的位置，仰卧位后均得到改善。所有患者治疗期间未出现脱管等严重不良反应。既往文献报道俯卧位后暂停肠内营养支持，本研究患者常规留置鼻肠管，俯卧位期间正常予肠内营养支持未出现呕吐误吸等，治疗期间仍能得到有效的营养支持，有利于降低不良预后。

综上所述，对于神经外科重症病房重症肺炎患者，在无严重的颅内高压情况下，俯卧位通气可改善肺部氧合指数及肺部通气，改善肺部炎症，对血流动力学无明显影响。但本研究也存在不足之处，首先本研究为单中心研究，样本量少。针对神经外科重症患者，未来是否有更有效的无创监测颅内压方法，比如能否通过超声引导下颈静脉压力间接估算等，以及在不增加颅内压或对颅内压影响最小情况下的最佳俯卧位时间及俯卧频次，未来仍需进一步大样本、多中心的研究。

利益冲突　无

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