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# Effect of a physician-nurse integrated lung protection care model in neurocritical patients

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ABSTRACT

*Background:* Lung injury resulting from diffuse pulmonary interstitial and other lung-related complications is a significant contributor to poor prognosis and mortality in patients with critical neurological diseases. To enhance patient outcomes, it is essential to investigate a lung protection model that involves the collaboration of doctors, nurses, and other medical professionals.

*Methods:* Patients receiving different care styles were divided into two groups: routine care (RC) and lung function protection care (LFPC). The LFPC group included airway and posture management, sedation and analgesia management, positive end-expiratory pressure titration in ventilation management, and fluid volume management, among others. Statistical analysis methods, such as chi-square, were used to compare the incidence of acute lung injury (ALI), neurogenic pulmonary edema (NPE), ventilator-associated pneumonia (VAP), acute respiratory distress syndrome (ARDS), and length of stay between the RC and LFPC groups.

*Results:* The RC group included 68 patients (33 males; 34–74 years of age). The LFPC group included 60 patients (29 males; 37–73 years of age). Compared with the RC group, the LFPC group had lower occurrence rates of ALI (20.0 % vs. 38.2 %, $P = 0.024$), NPE (8.3 % vs. 23.5 %, $P = 0.021$), VAP (8.3 % vs. 25.0 %, $P = 0.013$), and ARDS (1.7 % vs. 16.2 %, $P = 0.015$). The length of hospital stay was shorter in the LFPC group than in the RC group ($11.3 \pm 3.5$ vs. $14.3 \pm 4.4$ days, $P = 0.0001$).

*Conclusion:* The physician-nurse integrated lung protection care model proved to be effective in improving outcomes, reducing complications, and shortening the hospital stay length for neurocritical patients.

## 1. Introduction

Neurocritical patients refer to individuals with severe nervous system conditions, including acute cerebrovascular diseases, craniocerebral injury, and intracranial tumors. These patients are identified by a Glasgow Coma Scale (GCS) score of less than 12 points (Kramer & Couillard, 2020; Kuroda, 2016; Oddo et al., 2019). The most common admission diagnosis is subarachnoid hemorrhage, and the majority of patients are male with at least two complications, such as traumatic brain and spinal cord injury, myasthenia, epilepsy, and irreversible hypoxic brain injury (Broessner et al., 2007; Suarez et al., 2020; Venkatasubba Rao et al., 2020; Zacharia et al., 2012). However, neurocritical illness can be caused by various diseases, each with its own specific epidemiology and prognosis. Generally, these conditions have a poor prognosis and high mortality rate (Broessner et al., 2007; Kramer & Zygun, 2013).

According to the 'brain-lung double-hit theory', the interaction and action of brain-lung function can result in various factors such as increased intracranial pressure and catecholamine release. These factors can lead to the development of neurogenic pulmonary edema (NPE), respiratory system injury (e.g., ARDS), and hypercapnia. Additionally, these diseases cause systemic changes in both pulmonary and systemic circulation, which in turn affect the brain tissue. This aggravates the symptoms of nervous system ischemia and hypoxia, creating a vicious cycle that further impacts the prognosis of patients (Mascia, 2009; Mrozek, Constantin, & Geeraerts, 2015; Mrozek, Gobin, Constantin, Fourcade, & Geeraerts, 2020). Impairment of lung function (respiratory failure, pulmonary edema, pendant pneumonia, septicemia, etc.) is the most common complication in many neurocritical patients during hospitalization (Hoesch et al., 2012; Lee & Rincon, 2012). For critically ill patients, lung diseases can aggravate brain injury, and respiratory failure and pendulous pneumonia are independent prognostic risk factors

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for brain injury patients (Chinese Neurosurgical Society of Chinese Medical Association & China Collaborative Group of Neurosurgical Intensive Care Management, 2020).

Therefore, treatment and protection of the lungs in neurocritical patients is crucial to improve their prognosis. At the same time, effective measures should be taken to protect the lungs of neurocritical patients during the treatment and care process. This is crucial to reduce the mortality rate and associated complications and improve the recovery rate (Tao et al., 2019). Mechanical ventilation is an invasive intervention associated with pneumonia, cognitive dysfunction and prognosis in neurocritical patients (Bilotta, Giordano, Sergi, & Pugliese, 2019; Kamuf et al., 2018), emphasizing the importance of adequate patient monitoring and care. Therefore, an appropriate and optimized ventilation management protocol is essential to avoid further neurological damage.

New diagnostic and treatment methods are a blessing for patients with critical neurological diseases, as a large number of complications lead to a poorer prognosis. Compared to other care models (Corradi et al., 2018a), we not only have a multidisciplinary care team, but also increased and improved fluid management, an information-integrated lung injury risk assessment system, early individualized analgesia and sedation, balloon pressure detection and airway humidification through the three directions of “early warning-treatment-rehabilitation”. With this in mind, this study aims to explore a model of lung protection in neurocritical care patients that involves collaboration between physicians, nurses and caregivers, and the impact of this model on the incidence of pulmonary complications and hospitalisation.

## 2. Methods

### 2.1. Study design and patients

In this study, retrospective data collection and prospective design analyses were performed on patients with severe neurocritical patients admitted to the Department of Neurosurgery at the First Affiliated Hospital of the Air Force Military Medical University from March 2018 to April 2020.

Patients enrolled between May 2018 and January 2019 were included in the RC group due to insufficient testing devices and indicators to assess lung function. Since February 2019, a collaborative lung protection strategy for doctors, nurses and healthcare staff has been introduced for patients with neurocritical illnesses. Patients admitted after this date received more sophisticated care to protect lung function based on the RC group and were included in the LFPC group. The main differences between the RC and LFPC groups are shown in Supplementary Table 1.

The inclusion criteria were 1) inpatients in the neurosurgery ward, 2) diagnosed with acute and severe neurological disease such as cerebrovascular disease, traumatic brain injury, and intracranial tumor by computed tomography (CT) and cerebral angiography, 3) mechanical ventilation lasted longer than 12 h, and 4) GCS was 3–12 points (Bodien et al., 2021). The exclusion criteria were 1) patients with primary cardiac and pulmonary disease or 2) patients who had been in the intensive care unit (ICU) for less than 24 h.

### 2.2. Routine care

The patients in the RC group were diagnosed and treated by the doctors in the neurosurgical care unit. They received oxygen therapy, ventilation therapy, lung recruitment and medication. The nurses followed the doctors’ instructions for routine care. Interventions that were part of the monitoring and treatment of lung injuries included airway management and postural management. Airway management required a balloon pressure monitor to monitor balloon pressure, timely inhalation of a nebulizer, and assessment of aspiration risk in combination with traditional intra-abdominal pressure monitoring. Postural management required the patient to lie supine and on their side and to aspirate sputum independently. No additional attention was paid to the monitoring and treatment of pulmonary function impairment (Ntoumenopoulos et al., 2018; Oddo et al., 2018; Qin et al., 2019).

Doctors were responsible for examining and diagnosing patients, administering oxygen therapy, ventilation therapy, lung recruitment and drug therapy, giving medical orders and monitoring the situation after implementation. For patients with no contraindications, nurses raised the head of the bed 45°, turned patients over and patted them on the back every two hours, and had them inhale nebulized oxygen six times a day (tracheal intubation and intratracheal infusion for patients using a ventilator). The healthcare staff carried out the relevant examinations on the instructions of the doctors and reported the results.

### 2.3. Lung function protection care

To reduce the incidence of lung-related injuries in severe neurocritical patients, a multidisciplinary cooperative intervention team was formed with the head of the neurosurgical intensive care unit and the head nurse as team leaders (Fig. 1) (Laopoulou et al., 2019). Under the leadership of the Director of the Neurosurgical Intensive Care Unit, the team, in collaboration with physicians, nurses and medical professionals, performed early screening of the risk of lung function injury and appropriate treatment of patients to improve patient outcomes, reduce the incidence of acute lung injury (ALI), neurogenic pulmonary edema (NPE), ventilator-associated pneumonia (VAP), respiratory distress syndrome (ARDS) and average length of hospital stay.

The multidisciplinary team consisted of 15 members: four doctors from the neurosurgery department, eight nurses from the critical neurosurgery department, one nurse from the respiratory department, one doctor from the ultrasound department and one healthcare specialist from the radiology department.

### 2.4. Admission patient risk evaluation

All patients were mechanically ventilated for at least 12 h prior to admission. All patients were assessed for risk of lung injury on admission. Risk screening was performed using the Murray Lung Injury Score (Murray, Matthay, Luce, & Flick, 1988) and the Lung Injury Prediction Score (LIPS score) (Gajic et al., 2011; Mikkelsen et al., 2013; Trillo-Alvarez et al., 2011). The two scores were evaluated within 2 h of the patient’s admission to the emergency department (scoring results were not recorded). The Murray lung injury score $> 0$ points indicates lung injury, and the LIPS score $> 4$ indicates high risk. In these patients, blood gas analysis was performed twice a day, patients were turned over and patted on the back once an hour (compared to 2 h in the low-risk patients), and the expectoration device was used three times a day. Lung injury treatment improvement rate = (number of people who have improved lung injury treatment/number of people who have suffered lung injury) $\times$ 100 %. Improved mechanical ventilation rate was calculated as: (number of people successfully extubation/total patients) $\times$ 100 %. All data were collected from patient’s medical records.

### 2.5. Integrated lung protection strategy

The implementation of the integrated lung protection strategy was based on the cooperation of several medical care departments. The lung protection mode referred to the proactive prevention and treatment of acute lung injuries that may occur or have occurred due to various causes and risk factors in order to prevent pulmonary complications, preserve patients’ lung function and promote early recovery (Nieman et al., 2020). In the pulmonary protective care model, more comprehensive diagnosis and treatment were provided through the collaboration of physicians, nurses and healthcare professionals to reduce the incidence of lung-related injuries. During rehabilitation, medications, physical therapy and equipment were used to improve the final outcome.

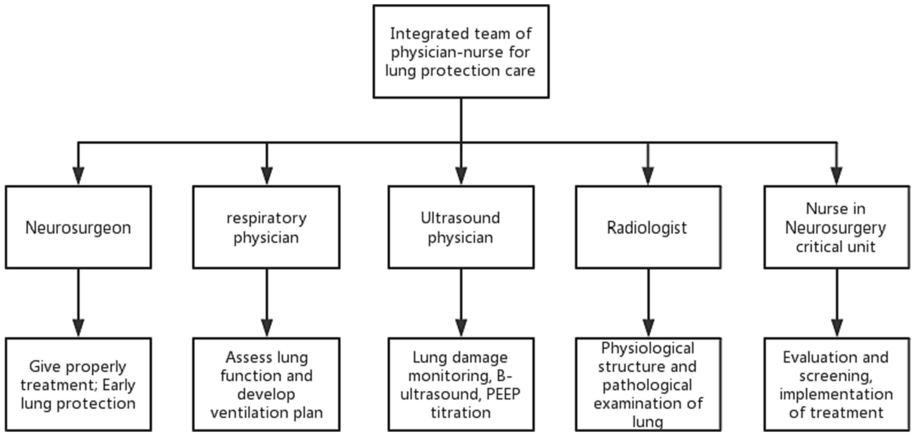


**Fig. 1.** Schematic representation of the integrated team of physicians, nurses, and healthcare professionals for lung protection care.

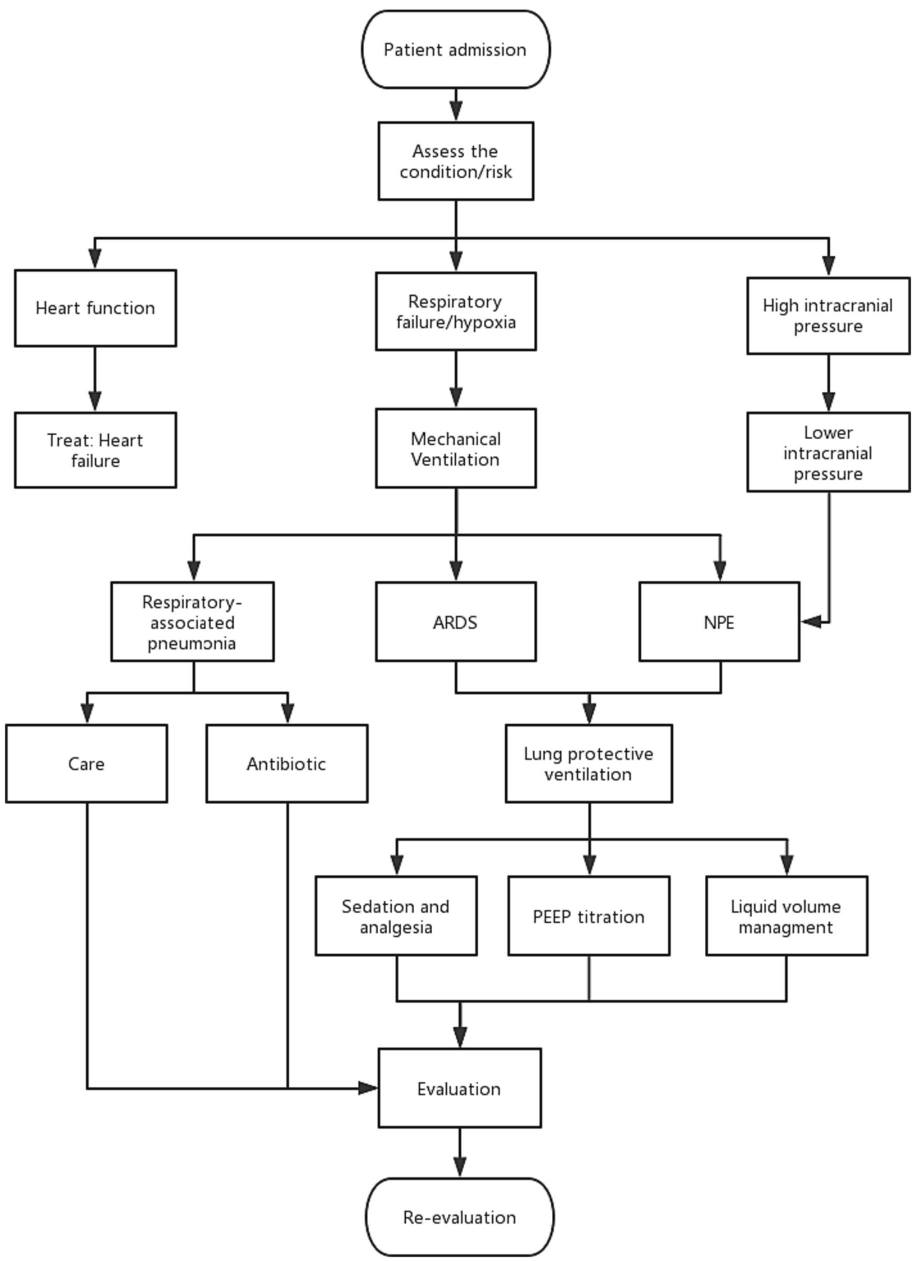


**Fig. 2.** Schematic representation of the process of the lung protection ventilation strategy.

Respiratory and postural management was led by the nurses. The doctors were involved in postural management. Sedation, analgesia and volume management were led by the physicians. Ventilator management was led by the physicians and involved the medical officers and nurses. Airway management included reduction of airbag leaks and airway injury, continuous nebulization as needed, an improved method of monitoring intra-abdominal pressure, nasal insertion of jejunal tube feeding, alternating cold and warm oral care, and training in swallowing function.

Postural management required positioning the patient in the prone position and integrating auscultation of mucus sounds, changing body position, tapping on the back and suctioning.

### 2.6. Sedation and analgesia management

The process of lung protection ventilation strategy also included sedation and analgesia (Fig. 2). The patients with a Richmond Agitation-Sedation Scale (RASS) (Sessler et al., 2002) score $\geq 2$ received sedation and analgesia. The patients who required sedation were reassessed every 1 to 2 h. If necessary, the interval between assessments could be shortened to determine whether to continue sedation. The ideal light sedation state was evaluated by a RASS of 0–2 points. For patients with agitation, physical restraint, drug sedation, and analgesia were combined. Commonly used drugs included dexmedetomidine injection and midazolam injection. After reaching the sedation goal, the nurse evaluated the patients every 2 h and waked up the patient every day. The nursing staff closely monitored the vital signs and adverse drug reactions.

### 2.7. PEEP titration management

The ventilation strategy process for lung protection included positive end-expiratory pressure (PEEP) titration and volume management (Fig. 2). Continuous arterial blood gas monitoring was performed for PEEP titration, and the optimal oxygenation method, P-V curve and other methods were combined to titrate the best PEEP. Intracranial oxygenation had to be maintained while preventing alveolar hyperventilation and avoiding exacerbation of lung injury. The air was warmed and humidified. Nurses received increased training in understanding the meaning of an alarm for each baseline parameter and initiating an appropriate emergency response, reporting and acting in a timely manner.

### 2.8. Fluid volume management

A non-invasive blood flow variability detector was used to dynamically monitor the plethrogen variability index (PVI) in real time to guide fluid volume; >14 % indicated the need for active fluid infusion. Indications for blood transfusion were based on the total hemoglobin indicator (SpHb). When administering fluid therapies, infusion pumps were used to tightly control the flow rate (Oddo et al., 2018).

### 2.9. Statistical analysis

The categorical data are presented as n (%) and were analyzed using the chi-square test. The continuous data were tested for normal distribution using the Kolmogorov-Smirnov test. Those with a normal distribution are presented as means ± standard deviations and were analyzed using Student's *t*-test; otherwise, they are presented as medians (interquartile ranges) and were analyzed using the Mann-Whitney *U* test. P-values $< 0.05$ are considered statistically significant. The data were managed and analyzed using SPSS 22.0 (IBM Corp., Armonk, NY, USA).

## 3. Results

### 3.1. Characteristics of the patients

Finally, 68 patients were included in the RC group according to the exclusion criteria. Of these, 33 (48.5 %) were male and 35 (51.5 %) were female. There were 31 patients with acute cerebrovascular disease, 14 with intracranial tumor, 23 with head injury, 53 with surgical treatment and 15 with non-surgical treatment. Sixty patients with neurocritical illnesses were included in the LFPC group. Among them, 29 (48.3 %) were male and 31 (51.7 %) were female. There were 26 patients with acute cerebrovascular disease, 13 with intracranial tumor, 21 with head injury, 47 with surgical treatment and 13 with non-surgical treatment. There were no significant differences in age, sex, GCS score, diagnosis, heart function, comorbidities, intracranial hypertension, and surgery between the two groups (all $P > 0.05$) (Table 1). Therefore, the comparison of the assessment of lung function impairment between the RC and LFPC groups could be performed using inclusion and exclusion criteria.

### 3.2. Medical care and intervention on lung-related injuries between routine care and the multidisciplinary lung protection model

Compared with the RC group, the LFPC group showed lower frequencies of LIPS > 4 (15.00 % vs. 32.35 %, $P = 0.029$) and Murray score > 0 (20.00 % vs. 38.23 %, $P = 0.039$); sedation and analgesia (40.00 % vs. 17.65 %, $P = 0.009$), individualized PEEP (53.33 % vs. 20.59 %, $P < 0.001$); fluid volume management (100 % vs. 30.88 %, and higher volume of IV infusion during night (1226.8 ± 189.6 vs. 657 ± 110.9 ml,

**Table 1**
Characteristics of patients with brain injury in the RC and LFPC groups from 2018 to 2020 in Xijing Hospital (n = 128).

| Characteristics | Total n = 128 | RC group n = 68 | LFPC group n = 60 | P* |
|---|---|---|---|---|
| Sex, n (%) | | | | 0.562 |
| Male | 62 | 33 (53) | 29 (47) | |
| Female | 66 | 35 (53) | 31 (47) | |
| Age (years), n (%) | | | | 0.398 |
| ≥55 | 77 | 40 (52) | 33 (48) | |
| <55 | 55 | 28 (51) | 27 (49) | |
| GCS, n (%) | | | | 0.430 |
| Mild/Moderate | 64 | 35 (55) | 29 (45) | |
| Severe | 64 | 33 (52) | 31 (48) | |
| Diagnosis | | | | |
| Cerebrovascular disease, n (%) | | | | 0.469 |
| Yes | 57 | 31 (54) | 26 (46) | |
| No | 71 | 37 (52) | 34 (48) | |
| Intracranial tumor, n (%) | | | | 0.526 |
| Yes | 27 | 14 (52) | 13 (48) | |
| No | 101 | 54 (53) | 47 (47) | |
| Craniocerebral injury, n (%) | | | | 0.237 |
| Yes | 54 | 23 (43) | 31 (57) | |
| No | 74 | 45 (61) | 29 (39) | |
| Diabetes, n (%) | | | | 0.573 |
| Yes | 30 | 16 (53) | 14 (47) | |
| No | 98 | 52 (53) | 46 (47) | |
| Hypertension, n (%) | | | | 0.491 |
| Yes | 46 | 25 (54) | 21 (46) | |
| No | 82 | 43 (52) | 39 (48) | |
| Surgery, n (%) | | | | 0.565 |
| Yes | 100 | 53 (53) | 47 (47) | |
| No | 28 | 15 (54) | 13 (46) | |

**Abbreviations:** lung function protection care (LFPC); routine care (RC); Glasgow coma scale (GCS) (Mehta & Chinthapalli, 2019):Mild (13–15); Moderate (9–12); Severe (3–8). Diabetes: No diabetes-related complications (diabetic ketoacidosis, etc.); Hypertension: No hypertension-related complications (myocardial infarction, cerebral infarction, etc.); Surgery: No tumor-related surgery.

* Note: Chi-square test is used as a statistical method to obtain the *P*-values.

$P < 0.001$), and lower volume of IV infusion during day (2088.8 ± 322.8 vs. 262804 ± 443.6 ml, $P < 0.001$). Compared with the RC group, the LFPC group had lower occurrence rates of ALI (20.0 % vs. 38.2 %, $P = 0.024$), NPE (8.3 % vs. 23.5 %, $P = 0.021$), VAP (8.3 % vs. 25.0 %, $P = 0.013$), and ARDS (1.7 % vs. 16.2 %, $P = 0.015$). The length of hospital stay was shorter in the LFPC group than in the RC group (11.3 ± 3.5 vs. 14.3 ± 4.4 days, $P = 0.0001$). From the above results, we found that the time to diagnose lung injury ($P < 0.001$) and the mortality related to lung injury ($P < 0.01$) could be significantly shortened by improving the detection indicators and improving the diagnosis and treatment methods (Table 2).

## 4. Discussion

Neurocritical patients have a high risk of suffering a lung injury during hospitalization, which would worsen their condition (Hoesch et al., 2012; Lee & Rincon, 2012; Mascia, 2009; Mrozek et al., 2015; Mrozek et al., 2020). This study aims to investigate a lung protection model for neurocritical patients, which involves collaboration among physicians, nurses, and healthcare professionals. The study also aims to assess the impact of this model on the occurrence of pulmonary complications and length of hospital stay. The results suggest that compared to conventional routine care, the physician-nurse integrated lung protection model was effective in improving outcomes by reducing related complications and shortening the length of hospital stay for neurocritical patients.

In the treatment of neurocritical patients, a patient-centered multidisciplinary approach should be used to provide holistic treatment and nursing care. This approach aims to prevent the oversight of overall organ functions while focusing on the disease development at specific locations (Glass, Rogers, Peloquin, & Bonifacio, 2014; Kramer & Zygun, 2013; Tao et al., 2019). Western countries such as the United Kingdom and the United States have implemented a "lung protection" strategy that prioritizes prevention, professional diagnosis and treatment, and multidisciplinary collaboration (Hu, Pittet, Kerby, Bosarge, & Wagener, 2017). In China, there is a greater focus on treatment rather than prevention, which often results in missed opportunities for preventing and treating lung injuries, leading to poor outcomes such as dependence on ventilators and even death. Currently, the negative impact of pulmonary complications on the outcomes of neurocritical patients is well known (Wang, 2019), but the specific pathogenesis of these diseases remains to be further studied. This study has demonstrated that implementing a lung protection strategy can reduce lung-related injuries to some extent, warranting clinical application and ongoing improvement.

**Table 2**
Monitoring and treatment of lung-related injuries in the two groups from 2018 to 2020 in Xijing Hospital (n = 128).

| Medical care | RC group (n = 68) | LFPC group (n = 60) | P* |
|---|---|---|---|
| Time from the patient's admission to the diagnosis of lung injury (days) | 3.32 ± 1.19 | 2.37 ± 0.95 | 0.00 |
| Time (days) from the patient's admission to the start of treatment of lung injury | 3.51 ± 1.30 | 2.40 ± 0.93 | 0.00 |
| Lung injury treatment improvement rate, n (%) | 57 (83.8) | 55 (91.7) | 0.28 |
| Lung injury mortality, n (%) | 11 (16.2) | 1 (1.7) | 0.01 |
| Lung injury monitoring: Murray Score | 1.16 ± 0.34 | 0.74 ± 0.21 | 0.00 |
| Lung injury monitoring: LIPS | | | 0.04 |
| >4, n (%) | 22 (32.4) | 9 (15) | |
| <4, n (%) | 46 (67.6) | 51 (85) | |
| Airway management: airbag leakage and airway injury, n (%) | 11 (16.2) | 5 (8.3) | 0.28 |
| Sedation and analgesia, n (%) | 12 (17.6) | 24 (40) | 0.01 |
| RASS > 2, n (%) | 8 (11.8) | 2 (3.3) | 0.15 |
| Individualized PEEP, n (%) | 14 (20.59) | 32 (53.33) | <0.001 |
| Liquid volume management, n (%) | | | 0.00 |
| IV infusion at day time, ml | 2628.4 ± 443.6 | 2088.8 ± 322.8 | |
| IV infusion at nigh time, ml | 657.1 ± 110.9 | 1226.8 ± 189.6 | |
| Acute lung injury, n (%) | 26 (38.2) | 12 (20.0) | 0.024 |
| Neurogenic pulmonary edema, n (%) | 16 (23.5) | 5 (8.3) | 0.021 |
| Ventilator-associated pneumonia, n (%) | 17 (25.0) | 5 (8.3) | 0.013 |
| Acute respiratory distress syndrome, n (%) | 11 (16.2) | 1 (1.7) | 0.015 |
| Average length of in-hospital (day) | 14.3 ± 4.4 | 11.3 ± 3.5 | 0.0001 |

**Abbreviations:** LFPC: lung function protection care; RC: routine care; LIPS: lung injury prediction score; RASS: Richmond agitation-sedation scale; PEEP: positive end-expiratory pressure.

* Note: The continuous variable *P*-value comes from the weighted student *t*-test; The categorical variable *P*-value is derived from the weighted chi-squared test.

In this study, lung protection for critically ill patients was implemented through three phases: early warning, rescue, and rehabilitation. The early warning stage involves early identification of lung injury using the lung injury assessment scale, an improved method for monitoring intra-abdominal pressure, and a convenient operation. It also includes the implementation of graded early warning management for critically ill patients, high injury risk hanging signs, and key transfers for each class.

The treatment stage involved controlling the source of stress through sedation and analgesia. Patients with severe neurological illnesses may exhibit poor cooperation and intense agitation. Nociceptive pain stimulation can lead to the body remaining in a heightened state of stress by activating the sympathetic-adrenal medulla system, which can result in lung function damage and increased oxygen consumption (Aubanel, Bruiset, Chapuis, Chanques, & Payen, 2020; Gelinas, Klein, Naidech, & Skrobik, 2013). Therefore, the Richmond Agitation-Sedation Scale (RASS) was used to evaluate the effect of sedation. Furthermore, the treatment involved maintaining a stable circulation of body fluids. The patients were monitored for a week to create a 24-hour patient intake curve. There was a noticeable correlation between the amount of fluid infusion and nursing work: the volume was sufficient during the day and decreased during the night. For this reason, the following enhancements have been implemented. The nurse utilized the infusion pump to administer the liquid at a consistent rate, adjusted the infusion speed based on the physician's instructions, and dynamically monitored the perfusion variation index (PVI) and other indicators. In this study, the concept of neurocritical nursing was transformed by shifting from a passive response to instrument alarms to an active observation and evaluation. The nurses were trained to interpret blood gas analysis and other monitoring parameters, and they also participated in medical rounds. The medical team utilized various indicators and nursing feedback, along with guidance from the respiratory department, to dynamically adjust the parameters of the ventilator and implement prone ventilation when necessary.

In the rehabilitation stage, continuous humidification of the airway was performed. The benefits of continuous humidification include consistent delivery, minimal use of humidification liquid, reduced risk of coughing, and nebulization to offset the ongoing loss of water in the patients' airways due to ventilation. The airway is consistently humidified, which reduces the viscosity of sputum, ensures an unobstructed airway, and enhances patient comfort. In addition, swallowing training was performed to prevent aspiration.

The prevention strategy proposed in this study achieved good outcomes, as supported by other strategies developed elsewhere on the globe (Beuret et al., 2002; Corradi et al., 2018b; Lee & Rincon, 2012; Mrozek et al., 2015). The advantages of the strategy proposed here are that it requires no additional tools and equipment besides those already used in neurocritical care, and it favors the active participation of the whole neurocritical care team.

Nevertheless, this study has limitations. The sample size is small and from a single hospital. In addition, the two groups of patients are from two different time periods, which could induce bias due to possible differences in practice, but it also ensured that the control group was not influenced and biased by the changes in practice due to the lung protection strategy in the other group. Nevertheless, additional studies are necessary to optimize the strategy.

In conclusion, the physician-nurse integrated lung protection care model effectively reduces lung injury-related complications and improves the prognosis of patients with critical neurological conditions.

## 5. Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Xijing Hospital of the Fourth Military Medical University (approval No: KY20212086).

## 6. Consent for publication

Not Applicable.

## 7. Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due to the protection of the privacy of consulting experts but are available from the corresponding author on reasonable request.

## 8. Authors' contributions

Xuan Li, Yu Wang contributed equally to this study. Qian Zhang contributed to the conception and design and analysis and interpretation of data, drafting the article, and final approval of the version to be published. Xuan Li contributed to the acquisition of data, analysis, and interpretation of data, conception, and design. Yu Wang contributed to revising the manuscript critically for important intellectual content. All of them agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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## CRediT authorship contribution statement

**Xuan Li:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yu Wang:** Conceptualization, Writing – original draft, Visualization, Investigation, Validation, Formal analysis, Methodology, Software. **Qian Zhang:** Conceptualization, Data curation, Writing – review & editing, Visualization, Formal analysis, Methodology, Supervision, Resources, Project administration and Software..

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2024.102637.

## References

Aubanel, S., Bruiset, F., Chapuis, C., Chanques, G., Payen, J.F., 2020. Therapeutic options for agitation in the intensive care unit. Anaesth Crit Care Pain Med 39 (5), 639–646. https://doi.org/10.1016/j.accpm.2020.01.009.

Beuret, P., Carton, M.J., Nourdine, K., Kaaki, M., Tramoni, G., Ducreux, J.C., 2002. Prone position as prevention of lung injury in comatose patients: a prospective, randomized, controlled study. Intensive Care Med. 28 (5), 564–569. https://doi.org/10.1007/s00134-002-1266-x.

Bilotta, F., Giordano, G., Sergi, P.G., Pugliese, F., 2019. Harmful effects of mechanical ventilation on neurocognitive functions. Crit. Care 23 (1), 273. https://doi.org/10.1186/s13054-019-2546-y.

Bodien, Y., Barra, A., Temkin, N., Barber, J., Foreman, B., Vassar, M., Edlow, B., 2021. Diagnosing Level of Consciousness: The Limits of the Glasgow Coma Scale Total Score. J. Neurotrauma 38 (23), 3295–3305. https://doi.org/10.1089/neu.2021.0199.

Broessner, G., Helbok, R., Lackner, P., Mitterberger, M., Beer, R., Engelhardt, K., Schmutzhard, E., 2007. Survival and long-term functional outcome in 1,155 consecutive neurocritical care patients. Crit. Care Med. 35 (9), 2025–2030. https://doi.org/10.1097/01.ccm.0000281449.07719.2b.

Chinese Neurosurgical Society of Chinese Medical Association, & China Collaborative Group of Neurosurgical Intensive Care Management, 2020. Chinese expert consensus of neurosurgical intensive care management (2020). Natl Med J China 100 (19), 1443–1458.

Corradi, F., Robba, C., Tavazzi, G., Via, G., 2018. Combined lung and brain ultrasonography for an individualized "brain-protective ventilation strategy" in neurocritical care patients with challenging ventilation needs. Crit. Ultrasound J. 10 (1), 24. https://doi.org/10.1186/s13089-018-0105-4.

Gajic, O., Dabbagh, O., Park, P.K., Adesanya, A., Chang, S.Y., Hou, P., Injury Trials Group: Lung Injury Prevention Study, I, 2011. Early identification of patients at risk of acute lung injury: evaluation of lung injury prediction score in a multicenter cohort study. Am. J. Respir. Crit. Care Med. 183 (4), 462–470. https://doi.org/10.1164/rccm.201004-0549OC.

Gelinas, C., Klein, K., Naidech, A.M., Skrobik, Y., 2013. Pain, sedation, and delirium management in the neurocritically ill: lessons learned from recent research. Semin. Respir. Crit. Care Med. 34 (2), 236–243. https://doi.org/10.1055/s-0033-1342986.

Glass, H.C., Rogers, E.E., Peloquin, S., Bonifacio, S.L., 2014. Interdisciplinary approach to neurocritical care in the intensive care nursery. Semin. Pediatr. Neurol. 21 (4), 241–247. https://doi.org/10.1016/j.spen.2014.10.003.

Hoesch, R.E., Lin, E., Young, M., Gottesman, R.F., Altaweel, L., Nyquist, P.A., Stevens, R.D., 2012. Acute lung injury in critical neurological illness. Crit. Care Med. 40 (2), 587–593. https://doi.org/10.1097/CCM.0b013e3182329617.

Hu, P.J., Pittet, J.F., Kerby, J.D., Bosarge, P.L., Wagener, B.M., 2017. Acute brain trauma, lung injury, and pneumonia: more than just altered mental status and decreased airway protection. Am. J. Physiol. Lung Cell. Mol. Physiol. 313 (1), L1–L15. https://doi.org/10.1152/ajplung.00485.2016.

Kamuf, J., Garcia-Bardon, A., Ziebart, A., Thomas, R., Folkert, K., Frauenknecht, K., Hartmann, E.K., 2018. Lung injury does not aggravate mechanical ventilation-induced early cerebral inflammation or apoptosis in an animal model. PLoS One 13 (8), e0202131.

Kramer, A.H., Couillard, P., 2020. Neurocritical Care: A Growing International Collaborative. Neurocrit. Care 32 (1), 80–83. https://doi.org/10.1007/s12028-019-00858-6.

Kramer, A.H., Zygun, D.A., 2013. Declining mortality in neurocritical care patients: a cohort study in Southern Alberta over eleven years. Can. J. Anaesth. 60 (10), 966–975. https://doi.org/10.1007/s12630-013-0001-0.

Kuroda, Y., 2016. Neurocritical care update. J Intensive Care 4, 36. https://doi.org/10.1186/s40560-016-0141-8.

Laopoulou, E., Papagiorgis, P., Chrysovitsanou, C., Tsiou, C., Plakas, S., Fouka, G., 2019. Nurses' knowledge about perioperative care of patients with neurological diseases. J. Perioper. Pract. 29 (4), 87–93. https://doi.org/10.1177/1750458918788984.

Lee, K., Rincon, F., 2012. Pulmonary complications in patients with severe brain injury. Crit Care Res Pract 2012, 207247. https://doi.org/10.1155/2012/207247.

Mascia, L., 2009. Acute lung injury in patients with severe brain injury: a double hit model. Neurocrit. Care 11 (3), 417–426. https://doi.org/10.1007/s12028-009-9242-8.

Mehta, R., Chinthapalli, K., 2019. Glasgow coma scale explained. BMJ (Clin. Res. Ed.) 365, l1296. https://doi.org/10.1136/bmj.l1296.

Mikkelsen, M.E., Shah, C.V., Meyer, N.J., Gaieski, D.F., Lyon, S., Miltiades, A.N., Christie, J.D., 2013. The epidemiology of acute respiratory distress syndrome in patients presenting to the emergency department with severe sepsis. Shock 40 (5), 375–381. https://doi.org/10.1097/SHK.0b013e3182a64682.

Mrozek, S., Constantin, J.M., Geeraerts, T., 2015. Brain-lung crosstalk: Implications for neurocritical care patients. World J Crit Care Med 4 (3), 163–178. https://doi.org/10.5492/wjccm.v4.i3.163.

Mrozek, S., Gobin, J., Constantin, J.M., Fourcade, O., Geeraerts, T., 2020. Crosstalk between brain, lung and heart in critical care. Anaesth Crit Care Pain Med 39 (4), 519–530. https://doi.org/10.1016/j.accpm.2020.06.016.

Murray, J.F., Matthay, M.A., Luce, J.M., Flick, M.R., 1988. An expanded definition of the adult respiratory distress syndrome. Am. Rev. Respir. Dis. 138 (3), 720–723. https://doi.org/10.1164/ajrccm/138.3.720.

Nieman, G.F., Al-Khalisy, H., Kollisch-Singule, M., Satalin, J., Blair, S., Trikha, G., Habashi, N.M., 2020. A Physiologically Informed Strategy to Effectively Open, Stabilize, and Protect the Acutely Injured Lung. Front. Physiol. 11, 227. https://doi.org/10.3389/fphys.2020.00227.

Ntoumenopoulos, G., Hammond, N., Watts, N.R., Thompson, K., Hanlon, G., Paratz, J.D., New Zealand Intensive Care Society Clinical Trials, G, 2018. Secretion clearance strategies in Australian and New Zealand Intensive Care Units. Aust. Crit. Care 31 (4), 191–196. https://doi.org/10.1016/j.aucc.2017.06.002.

Oddo, M., Poole, D., Helbok, R., Meyfroidt, G., Stocchetti, N., Bouzat, P., Citerio, G., 2018. Fluid therapy in neurointensive care patients: ESICM consensus and clinical practice recommendations. Intensive Care Med. 44 (4), 449–463. https://doi.org/10.1007/s00134-018-5086-z.

Oddo, M., Bracard, S., Cariou, A., Chanques, G., Citerio, G., Clerckx, B., Taccone, F.S., 2019. Update in Neurocritical Care: a summary of the 2018 Paris international conference of the French Society of Intensive Care. Ann. Intensive Care 9 (1), 47. https://doi.org/10.1186/s13613-019-0523-x.

Qin, Y., Yin, W.H., Zeng, X.Y., Zou, T.J., Li, Y., Zhou, R., Wang, X.T., 2019. Influence of Critical Care Ultrasound Oriented Fluid Management in Different Stages of Shock to the Outcome. Sichuan Da Xue Xue Bao Yi Xue Ban 50 (6), 803–807.

Sessler, C.N., Gosnell, M.S., Grap, M.J., Brophy, G.M., O'Neal, P.V., Keane, K.A., Elswick, R.K., 2002. The Richmond Agitation-Sedation Scale: validity and reliability in adult intensive care unit patients. Am. J. Respir. Crit. Care Med. 166 (10), 1338–1344. https://doi.org/10.1164/rccm.2107138.

Suarez, J.I., Martin, R.H., Bauza, C., Georgiadis, A., Venkatasubba Rao, C.P., Calvillo, E., Investigators, P.S., 2020. Worldwide Organization of Neurocritical Care: Results from the PRINCE Study Part 1. Neurocrit. Care 32 (1), 172–179. https://doi.org/10.1007/s12028-019-00750-3.

Tao, L., Zhang, B.Q., Huang, Y.Z., Zhao, X.M., Zhang, Y.Q., Yang, Z.X., 2019. Practice and effects of multidisciplinary collaboration and precision management model in the prevention and control of multi-drug resistant bacteria infection in neurosurgical intensive care unit. Comtemp Med 25 (32), 121–124.

Trillo-Alvarez, C., Cartin-Ceba, R., Kor, D.J., Kojicic, M., Kashyap, R., Thakur, S., Gajic, O., 2011. Acute lung injury prediction score: derivation and validation in a population-based sample. Eur. Respir. J. 37 (3), 604–609. https://doi.org/10.1183/09031936.00036810.

Venkatasubba Rao, C.P., Suarez, J.I., Martin, R.H., Bauza, C., Georgiadis, A., Calvillo, E., Investigators, P.S., 2020. Global Survey of Outcomes of Neurocritical Care Patients: Analysis of the PRINCE Study Part 2. Neurocrit. Care 32 (1), 88–103. https://doi.org/10.1007/s12028-019-00835-z.

Wang, Y.L., 2019. Research progress on risk factors of ventilator-associated lung injury and perioperative precise lung protective ventilation strategy. J Precision Med 34 (06), 471–474.

Zacharia, B.E., Vaughan, K.A., Bruce, S.S., Grobelny, B.T., Narula, R., Khandji, J., Sander Connolly, E., 2012. Epidemiological trends in the neurological intensive care unit from 2000 to 2008. J. Clin. Neurosci. 19 (12), 1668–1672. https://doi.org/10.1016/j.jocn.2012.04.011.