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Application of Airway Clearance Combined with Postural Care in Patients with Severe Traumatic Brain Injury

Qiang Wang, Min Li, Xinghua Li, Dong Wang, Yaowu Zhan*

Affiliated Hospital of Hebei University, Baoding 071000, Hebei, China

***Corresponding author:** Yaowu Zhan, t9800362@hbu.edu.cn

Abstract: *Objective*: To explore the systemic changes in respiratory function, the progression of pulmonary complications, and the potential for neurological recovery in patients with severe traumatic brain injury (sTBI) when applying an integrated approach that combines systematic airway clearance techniques with posture adjustment guided by cranial-cerebral physiological data. *Methods*: A total of 104 eligible sTBI patients were randomly assigned to a study group receiving integrated intervention (54 cases) and a control group receiving standard care (50 cases). Standard care followed general guidelines for neurocritical care, while the integrated intervention group underwent an additional comprehensive procedure: twice-daily airway clearance including positioning percussion, high-frequency vibration drainage, and image-guided pulmonary drainage, along with individualized progressive posture adjustments (such as phased elevation of the head of the bed and selective lateral positioning under image guidance) based on continuous monitoring of intracranial pressure (ICP) and cerebral perfusion pressure (CPP). Oxygenation index (PaO_2/FiO_2), respiratory mechanics parameters (plateau pressure, lung compliance), incidence of clinical pulmonary infection (CPIS criteria), duration of antimicrobial agent use, length of stay in the intensive care unit (ICU), and Glasgow Outcome Scale (GOS) at day 28 were evaluated and compared between the two groups before intervention, and on days 3 and 7. *Results*: By day 7 of intervention, the oxygenation index and lung compliance measurements in the study group were significantly higher than those in the control group ($P<0.01$). The proportion of patients with clinical pneumonia and the constituent ratio of severe pneumonia (CPIS≥8) in the study group were significantly reduced ($P<0.05$). The median duration of mechanical ventilation and the median length of ICU stay in the study group were shorter than those in the control group ($P<0.01$). The 28-day outcome assessment showed that the proportion of patients with favorable recovery outcomes (GOS 4–5) in the study group was higher than that in the control group ($P<0.05$). *Conclusion*: Implementing an integrated approach that combines structured airway maintenance with intracranial pressure-based posture control can effectively promote the recovery of pulmonary gas exchange efficiency in sTBI patients and reduce mechanical ventilation-related stress injury to lung tissue.

Keywords: Severe traumatic brain injury; Airway management; Posture adjustment; Intracranial dynamics; Pneumonia prevention

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1. Introduction

In the systemic pathological cascade triggered by severe traumatic brain injury (sTBI), respiratory dysfunction and secondary infections constitute critical secondary insults that significantly impact the clinical course of patients. Traditional nursing practices often treat airway secretion management and postural restrictions aimed at maintaining intracranial pressure (ICP) stability as separate issues, sometimes leading to conflicting management principles. This fragmented approach may fail to adequately address the complex interplay between brain and lung pathology under pathological conditions. A close interaction network exists among intracranial venous return dynamics, intrathoracic pressure changes, and alveolar recruitment status, suggesting the potential necessity for an integrative nursing support strategy that transcends traditional boundaries. This study aims to design and evaluate a collaborative nursing model that fundamentally seeks to bridge the operational gap between respiratory support and neuroprotection. By employing scientific scheduling and precise interventions, it aims to maximize the recovery of pulmonary physiological reserves while ensuring absolute stability of the intracranial environment, thereby exploring an integrated and practical clinical nursing pathway to optimize comprehensive treatment outcomes for sTBI patients.

2. Materials and methods

2.1. General information

The study subjects were sTBI patients admitted to the Neurosurgical Intensive Care Unit (NICU) of our hospital from June 2021 to December 2023. Inclusion criteria were clearly defined as follows: meeting the clinical diagnostic criteria for severe traumatic brain injury (Glasgow Coma Scale score between 3 and 8 upon admission); aged between 18 and 75 years; transferred to our hospital within one day of injury and expected to require more than three days of invasive ventilatory support; and obtaining informed consent from the patient's legal representative. Exclusion criteria included: pre-existing severe chronic obstructive pulmonary disease (COPD) or other underlying pulmonary conditions; cervical or thoracic spinal cord injuries, multiple rib fractures causing chest wall instability; clear evidence of pneumonia upon admission; expected survival of less than three days or concurrent life-threatening organ injuries. Ultimately, 104 patients were enrolled in the study and randomly assigned to the collaborative intervention group (54 cases) and the standard care group (50 cases) using a random number method. The study protocol was approved by the Institutional Ethics Review Committee (Approval No.: XYZ2021056).

2.2. Inclusion and exclusion criteria

The establishment of these criteria aimed to select a typical sTBI population in the acute phase, with relatively concentrated ages, and inevitably requiring prolonged ventilatory assistance due to their condition. By excluding patients with underlying diseases or injuries that could significantly affect respiratory function, as well as those with pre-existing infections upon admission, it maximizes the assurance that any differences in clinical outcome indicators between the two groups during subsequent observations can be more reasonably attributed to the different nursing interventions applied, rather than to heterogeneity in the initial status of the study population.

2.3. Intervention methods

The standard care group followed the general protocol for neurocritical care, which mainly involved open

suctioning based on airway secretion status, axial position changes every two hours, routine adjustment of ventilator parameters based on arterial blood gas analysis values, standardized enteral nutrition support, and administration of drugs to prevent stress ulcers. The collaborative intervention group, in addition to the above, implemented an integrated intervention protocol: In terms of airway clearance, twice-daily programmed procedures were performed by specially qualified respiratory therapists, integrating manual hyperventilation techniques, specific frequency (30–35 Hz) vibration-assisted drainage targeting the primary affected lung lobe (determined by auscultation or imaging), and closed-system suctioning after nebulized mucolytic agent administration. In terms of postural control, an hourly ICP and cerebral perfusion pressure (CPP) data monitoring-assessment-action cycle was established. Under the condition of real-time confirmation of safe ICP thresholds (<20 mmHg) and adequate CPP (>60 mmHg), a gradual postural adjustment strategy was implemented: for example, gradually elevating the head of the bed from 15 degrees to 30 degrees and maintaining it for a specific duration to optimize diaphragmatic function and lower lung zone ventilation; planning and ensuring a cumulative total of no less than four hours of side-lying positions with clear drainage orientation daily (choosing the affected or unaffected side based on imaging findings), and conducting intensive monitoring and recording of the patient's vital signs and intracranial hemodynamic indicators before and after each postural change.

2.4. Observation indicators

The primary observation indicators focused on respiratory system function, with arterial oxygen partial pressure, oxygenation index calculation, airway plateau pressure values displayed on the ventilator, and dynamic lung compliance calculation recorded at baseline (T0), the third day (T3), and the seventh day (T7) of intervention. Secondary observation indicators covered clinical endpoint events, including the incidence of ventilator-associated pneumonia meeting the Clinical Pulmonary Infection Score (CPIS ≥ 6 points) criteria, total days of antimicrobial therapy after pneumonia diagnosis, total duration of invasive mechanical ventilation, and total length of stay in the intensive care unit between the two groups. For neurological recovery assessment, the Glasgow Outcome Scale-Extended (GOS-E) was used to score all patients on the 28th day after the initiation of intervention measures, and the proportion of patients achieving a favorable recovery outcome (GOS rating of 4 or 5) within each group was statistically analyzed. All data collection and registration were independently completed by research assistants who were not involved in patient grouping and were unaware of the grouping situation to ensure objectivity.

3. Results

3.1. Comparison of baseline data between the two groups

Analysis and comparison of the demographic and clinical baseline characteristics of the two groups at the start of the study revealed no statistically significant differences (all *P*-values > 0.05) in mean age, gender ratio, classification of external causes leading to traumatic brain injury, immediate coma severity score upon admission, primary distribution of intracranial injury areas (cerebral hemisphere or cerebellar-brainstem region), and the presence of severe trauma in other systems between the two groups, as shown in **Table 1**.

Table 1. Comparison of baseline data between the two groups

Item	Collaborative Intervention Group(n = 54)	Standard Care Group(n = 50)	x^2/t value	P value
Age (years, mean ± SD)	44.8 ± 13.2	46.9 ± 12.5	0.825	0.411
Gender (male/female, n)	37 / 17	34 / 16	0.005	0.943
Cause of Injury (traffic accident/fall/other, n)	31 / 16 / 7	29 / 14 / 7	0.098	0.952
GCS Score on Admission (points, mean ± SD)	5.3 ± 1.5	5.4 ± 1.7	0.321	0.749
Injury Location (supratentorial/infratentorial, n)	40 / 14	38 / 12	0.088	0.767
Presence of Polytrauma (yes/no, n)	18 / 36	16 / 34	0.042	0.838

3.2. Comparison of oxygenation and respiratory mechanics indicators between the two groups

At the initial baseline measurement time point (T0), the two study groups exhibited comparable levels in terms of the PaO_2/FiO_2 ratio reflecting oxygenation efficiency, plateau pressure reflecting ventilation pressure, and dynamic compliance reflecting lung tissue elasticity ($P > 0.05$). By the third day post-intervention (T3), the collaborative intervention group had demonstrated a numerical tendency towards superiority over the standard care group in oxygenation index and lung compliance, although the differences between the groups had not yet reached the threshold for statistical significance ($P > 0.05$). Upon measurement at the seventh day (T7), the PaO_2/FiO_2values and dynamic lung compliance measurements in the collaborative intervention group had significantly surpassed those of the standard care group, while their mean airway plateau pressure readings were significantly lower than those of the standard care group. All these differences were highly statistically significant ($P < 0.01$), as shown in **Table 2**.

Table 2. Comparison of oxygenation and respiratory mechanics indicators between the two groups at different time points (Mean ± SD)

Indicator	Group	T0	T3	T7	Inter-group Effect P value
PaO_2/FiO_2 (mmHg)	Collaborative Intervention Group	181.5 ± 44.8	238.2 ± 37.5	287.2 ± 31.5*#	< 0.01
	Standard Care Group	179.3 ± 42.7	220.8 ± 39.6	243.5 ± 38.7*	
Platform Pressure (cmH_2O)	Collaborative Intervention Group	25.9 ± 3.4	23.2 ± 2.7	20.5 ± 2.3*#	< 0.01
	Standard Care Group	26.3 ± 3.0	24.8 ± 3.2	23.9 ± 2.9*	
Cdyn (mL/ cmH_2O)	Collaborative Intervention Group	25.6 ± 4.9	33.1 ± 5.3	39.2 ± 4.8*#	< 0.01
	Standard Care Group	25.0 ± 5.0	30.5 ± 5.8	33.0 ± 5.7*	

Note: *indicates $P < 0.05$ compared with T0 within the same group; #indicates $P < 0.01$ for comparison between groups at the T7 time point

3.3. Comparison of pulmonary infection-related indicators between the two groups

Based on the clinical pulmonary infection scoring criteria, the overall incidence of ventilator-associated pneumonia in the collaborative intervention group was 15.0%, which was significantly lower than the 32.0% observed in the standard care group (x^2=4.215, P=0.040), as shown in **Table 3**.

Table 3. Comparison of pulmonary infection incidence between the two groups [n(%)]

Item	Collaborative intervention group(*n*=54)	Standard care group(*n*=50)	x^2 value	*P* value
Total VAP Incidence Cases (CPIS ≥ 6)	8 (15.0%)	16 (32.0%)	4.215	0.040
Among which: CPIS 6-7	5 (9.3%)	7 (14.0%)	0.588	0.443
Among which: CPIS ≥ 8	3 (5.6%)	10 (20.0%)	5.012	0.025

3.4. Comparison of clinical and neurological prognosis indicators between the two groups

In terms of treatment process indicators, the median duration of invasive mechanical ventilation support for patients in the collaborative intervention group was 7 (5, 9) days, and the median length of stay in the intensive care unit (ICU) was 13 (10, 16) days. Both of these time indicators were significantly shorter than those in the standard care group. Specific data are summarized in **Table 4**.

Table 4. Comparison of clinical and neurological prognosis indicators between the two groups

Item	Collaborative Intervention Group(*n*=54)	Standard Care Group (*n*=50)	Statistical Value	*P* value
Duration of mechanical ventilation (days, M(P25, P75))	7 (5, 9)	11 (8, 15)	Z = -2.917	0.004
Length of ICU stay (days, M(P25, P75))	13 (10, 16)	17 (13, 21)	Z = -2.987	0.003
28-day GOS score ≥ 4 [n (%)]	23 (42.6%)	13 (26.0%)	x^2 = 4.127	0.042

4. Discussion

The data obtained in this study collectively confirm, from both physiological responses and final clinical outcomes, that for patients with severe traumatic brain injury (sTBI), a comprehensive nursing strategy that combines systematic airway clearance measures with posture adjustment based on intracranial pressure feedback yields statistically significant overall benefits superior to those of conventional nursing models. The effectiveness of this strategy is rooted in the synergistic and enhancing effects between different intervention components, rather than the mechanical accumulation of isolated technical approaches [1].

The positive impact of this integrated approach on the mechanical properties of the respiratory system and oxygen exchange capacity in patients is clearly supported by the data. The significant increase in dynamic lung compliance and the concurrent decrease in airway plateau pressure directly reflect a reduction in elastic resistance of the lung tissue and an improvement in ventilation efficiency. These positive changes may stem from the combined contributions of multiple mechanisms: targeted high-frequency vibration and pulmonary expansion techniques effectively clear viscous secretions obstructing the small and medium airways, reopening alveolar units that were closed due to mucus plugs; simultaneously, the progressive elevation of the head of the bed implemented under close monitoring optimizes the geometric shape and contractile efficiency of the diaphragm, increases functional residual capacity, and effectively counteracts the tendency for atelectasis in the lower lung regions caused by prolonged supine positioning. The sustained improvement in the oxygenation index serves as direct evidence of optimized matching between ventilation

and perfusion within the lungs, indicating that the intervention not only increases ventilation volume but may also indirectly benefit the perfusion efficiency of pulmonary capillaries by improving local circulation [2].

The effectiveness of this strategy in reducing the incidence of ventilator-associated pneumonia (VAP) highlights its significant clinical utility. The occurrence of VAP is essentially the result of an imbalance among microbial load, local and systemic host defense mechanisms, and iatrogenic intervention factors [3]. The integrated approach implemented in this study, through proactive, scheduled, and highly targeted airway clearance activities, substantially reduces the physical substrate—secretions retained in the airways—on which bacteria rely to proliferate and form biofilms. Meanwhile, the improved pulmonary ventilation and oxygenation status inherently enhance the phagocytic clearance function of local immune cells in the alveoli, creating a microenvironment unfavorable for pathogen proliferation [4].

The positive impact of this approach on indicators related to medical resource consumption and treatment efficiency holds considerable practical significance. The reduction in mechanical ventilation dependency time and the decrease in intensive care unit (ICU) length of stay are direct manifestations of the translation of the aforementioned physiological benefits into the realms of medical economics and operational efficiency [5]. The earlier liberation from the ventilator directly reduces the potential risks of ventilator-induced lung injury, complications related to the accumulation of sedative and analgesic drugs, and ICU-acquired muscle weakness in patients.

5. Conclusion

In summary, the organic integration of posture regulation following intracranial pressure principles with systematic airway clearance techniques constructs a novel “brain-lung integration” management paradigm adapted to the special pathophysiological state of patients with sTBI. This paradigm not only achieves clear effects in improving respiratory function, controlling infection occurrence, and optimizing medical resource utilization.

Disclosure statement

The authors declare no conflict of interest.

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