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Passive head-up tilt positioning as an early mobilization strategy in neurocritical care: a prospective-retrospective controlled study

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Background: Early mobilization is recommended in neurocritical care, yet passive mobilization strategies for patients with impaired consciousness remain underexplored. This retrospective matched cohort study, incorporating prospectively collected intervention data, evaluates the clinical efficacy and physiological impact of passive head-up tilt positioning in patients with severe neurological injury.

Methods: We conducted a prospective-retrospective matched cohort study involving 58 patients with traumatic brain injury or hypertensive intracerebral hemorrhage. Twenty-nine patients received standardized passive verticalization using a motorized standing bed; 29 matched controls received standard care. Intracranial dynamics (ICP, CPP, and PRx), respiratory mechanics, intra-abdominal pressure (IAP), and neurological assessments (GCS, CRS-R, ICDSC) were measured at defined intervals. Primary outcomes included NSICU/hospital length of stay, duration of ventilation, complication rates, and long-term functional outcomes.

Results: Passive verticalization was well-tolerated and associated with a significant reduction in ICP (10.62 ± 2.13 vs. 8.38 ± 2.27 mmHg, $p < 0.05$) without affecting CPP or PRx. Neurological function improved significantly (GCS: $7.90 \rightarrow 10.07$; CRS-R: $8.17 \rightarrow 12.03$; all $p < 0.05$), and delirium severity declined (ICDSC: $5.97 \rightarrow 1.62$). Intervention patients had shorter NSICU and hospital stays, reduced mechanical ventilation duration, earlier enteral nutrition, lower DVT incidence, and superior 6-month ADL and DRS scores.

Conclusion: Passive head-up tilt positioning is a safe, feasible early mobilization strategy in neurocritical care. It improves neurological recovery, reduces complications, and supports long-term functional outcomes. These findings support the incorporation of passive verticalization into early rehabilitation protocols for patients unable to engage in active mobilization.

KEYWORDS

neurocritical care, early mobilization, passive head-up tilt positioning, intracranial pressure, delirium, mechanical ventilation, functional recovery, tilt table therapy

Introduction

Early mobilization is widely recognized as a fundamental aspect of critical care rehabilitation, strongly advocated by international guidelines for general intensive care unit (ICU) patients (1–3). Multiple studies have demonstrated its efficacy in reducing complications, shortening both ICU and overall hospital lengths of stay (LOS), enhancing functional recovery, and increasing patient satisfaction (4–8). For neurocritical care patients specifically, early mobilization holds particular importance due to their elevated risk of prolonged immobilization complications, impaired consciousness recovery, and neurological deficits, underscoring the need for tailored mobilization strategies to facilitate neurological improvement and reduce secondary complications. However, evidence specifically addressing the benefits of early mobilization in neurocritical care patients remains scarce and inconsistent (9–13). Patients in neurocritical care settings frequently present with impaired consciousness, which limits patient cooperation; heavy sedation and paralysis, reducing voluntary movement; mechanical ventilation, complicating patient handling and increasing risks during mobilization; and invasive intracranial monitoring, posing risks of device displacement or intracranial pressure instability (14–19). These factors collectively render conventional early mobilization particularly challenging or infeasible.

Given these constraints, passive head-up tilt positioning utilizing a tilt table has emerged as a viable alternative method for early mobilization. This technique addresses impaired consciousness by not requiring active patient cooperation, mitigates the impact of sedation and paralysis by passively supporting patients, reduces risks associated with mechanical ventilation by providing a stable and controlled posture, and accommodates invasive intracranial monitoring by minimizing the risk of device displacement or intracranial pressure fluctuations. Thus, passive verticalization potentially promotes circulation, decreases complications associated with prolonged immobilization, and supports neurological recovery through a feasible and controlled approach. While the efficacy of passive mobilization has been well-established in general ICU populations, its application and effectiveness in the neurocritical care environment have not been sufficiently investigated.

Therefore, this study aims to evaluate the clinical effectiveness of passive head-up tilt positioning using a tilt table in neurocritical patients, specifically examining impacts on intracranial pressure (ICP), delirium resolution, respiratory function, length of hospital stay, and overall patient outcomes.

Materials and methods

Study design and participants

This was a retrospective matched cohort study incorporating prospectively collected intervention data, conducted at the Department of Neurosurgery, Third Affiliated Hospital of Soochow University. We included critically ill patients admitted to the neurosurgical intensive care unit (NSICU) between July 2019 and June 2021 with a primary diagnosis of either traumatic brain injury or hypertensive intracerebral hemorrhage. During the intervention phase (July 2020 to June 2021), all patients who met the inclusion and

exclusion criteria were consecutively enrolled in the verticalization group without any exclusion based on prognosis, family preference, or anticipated outcomes. The control group consisted of matched patients from the prior year (July 2019 to June 2020), before the verticalization protocol was introduced, ensuring temporal separation between groups and avoiding treatment crossover or contamination.

Inclusion criteria were: (1) age ≥ 45 years; (2) diagnosis of traumatic brain injury or hypertensive intracerebral hemorrhage; (3) stable vital signs; and (4) Glasgow Coma Scale (GCS) score between 3 and 9 on admission.

Exclusion criteria included: (1) terminal illness; (2) unstable vital signs (e.g., blood pressure, heart rate, respiratory rate, or oxygen saturation); (3) elevated intracranial pressure (ICP ≥ 15 mmHg); (4) Richmond Agitation-Sedation Scale (RASS) $\geq +4$; (5) presence of deep vein thrombosis (DVT) in the lower extremities; (6) severe cardiac or pulmonary dysfunction; (7) multiple severe trauma; (8) active pneumothorax; (9) unstable fractures or spinal cord injury precluding mobilization; and (10) refusal or absence of informed consent from legal surrogates.

Between July 2020 and June 2021, 34 patients underwent passive verticalization. Of these, 5 were excluded due to incomplete physiological data ($n = 2$), loss to follow-up ($n = 2$), or early withdrawal from care based on family decision ($n = 1$). Thus, a total of 29 patients were included in the intervention group for final analysis.

Intervention protocol

The passive verticalization intervention was conducted by a multidisciplinary team consisting of 1–2 neurosurgeons, 1–2 nurses, 1–2 nursing assistants, and family members. A motorized standing bed (model Carelead a-1) was used to implement the intervention.

Intervention procedure:

1. Ensure airway security, suspend intravenous infusions temporarily, and confirm ventilator connections.
2. Clamp external drainage tubes (e.g., ventricular, thoracic) if applicable. Maintain continuous electrocardiogram (ECG) and ICP monitoring.
3. Transfer the patient to the standing bed and secure them using safety straps.
4. Elevate the bed in three sequential stages: 30° for 7 min, 60° for 6 min, and 80° for 7 min. A 1-min supine rest period was included prior to returning the patient to the hospital bed.
5. Vital signs and ICP were continuously monitored throughout. The session was terminated if the patient developed systolic blood pressure >200 mmHg or <90 mmHg, marked diaphoresis, tachycardia, respiratory distress, $SpO_2 < 80\%$, or ICP elevation >20 mmHg. This three-stage protocol (30° for 7 min, 60° for 6 min, and 80° for 7 min) was developed by adapting parameters from prior tilt-table mobilization studies in ICU and stroke rehabilitation settings (20–26). In the absence of a standardized neurocritical care protocol, our team refined this approach based on internal pilot experience, monitoring real-time changes in intracranial pressure, heart rate, and

blood pressure. This stepwise strategy was designed to balance postural effectiveness and patient safety and was ultimately adopted as an institutional standard of care.

Group allocation

Patients admitted between July 2020 and June 2021 who received passive verticalization and met the predefined inclusion/exclusion criteria were assigned to the intervention group. For the control group, matched patients were selected from the prior year (July 2019 to June 2020), before protocol implementation.

One-to-one matching was conducted based on five pre-specified variables:

- (1) age (± 5 years),
- (2) sex,
- (3) primary diagnosis (traumatic brain injury or hypertensive intracerebral hemorrhage),
- (4) admission Glasgow Coma Scale (GCS) score (± 1 point), and
- (5) APACHE II score (± 3 points).

These variables were chosen due to their established influence on neurocritical outcomes. The matching process was performed manually using a pre-specified algorithm by an independent investigator who was blinded to all clinical outcomes, in order to minimize selection bias and enhance methodological rigor.

The final matched pairs showed no significant differences in baseline clinical or demographic characteristics (Table 1), indicating successful group comparability.

Data collection

Demographic and baseline clinical variables included age, sex, body mass index (BMI), admission GCS score, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, primary diagnosis, etiology, lesion location, and comorbidities (e.g., hypertension, diabetes, cardiovascular disease, hematologic disorders).

Clinical and neurological outcomes

Clinical and neurological outcomes were assessed using the following standardized scales: Glasgow Coma Scale (GCS), Coma Recovery Scale-Revised (CRS-R), Levels of Cognitive Functioning (LCF), Intensive Care Delirium Screening Checklist (ICDSC), Functional Independence Measure (FIM), Activities of Daily Living (ADL), Glasgow Outcome Scale (GOS), and Disability Rating Scale (DRS).

Assessments were conducted at multiple time points, including baseline (at admission), post-intervention (2 h after verticalization), discharge, 3-month follow-up, and 6-month follow-up. APACHE II was used to assess baseline illness severity. GCS, CRS-R, and LCF were assessed at baseline and discharge; DRS, FIM, and ADL were measured at 6 months post-discharge; GOS was recorded at 3 months. ICDSC was assessed before and after each verticalization session to evaluate delirium dynamics. Detailed scoring results and timelines are presented in the Results section.

Physiological monitoring in the intervention group

Physiological parameters were systematically monitored in the intervention group to assess the safety and efficacy of passive verticalization. These included:

Intracranial dynamics: ICP, cerebral perfusion pressure (CPP), and pressure reactivity index (PRx)

Respiratory mechanics: static compliance (Cstat), inspiratory resistance (RI), and expiratory resistance (RE)

Neurological function: GCS, CRS-R, and ICDSC

Abdominal pressure: IAP.

All measurements were collected at standardized time points relative to each intervention session. Specifically, ICP, CPP, PRx, Cstat, RI, RE, GCS, CRS-R, and ICDSC were recorded at “Before” (2 h prior to verticalization) and “After” (2 h after verticalization). IAP was assessed at T0 (10 min before verticalization), T1 (10 min after initiation), and T2 (2 h post-intervention).

Neurological scores: GCS, CRS-R, and ICDSC before and after intervention.

Additional outcomes included NSICU length of stay (LOS), total hospital LOS, total hospitalization cost, intubation and mechanical ventilation duration, and incidence of complications (e.g., DVT and infections).

Statistical analysis

All statistical analyses were performed using SPSS version 26.0 and GraphPad Prism. Continuous variables were expressed as mean \pm standard deviation (SD) or median with interquartile range (IQR), and compared using Student’s t-test or Mann–Whitney U test based on distribution. Categorical variables were expressed as frequencies and percentages and compared using the chi-square test or Fisher’s exact test.

Multivariable logistic regression was conducted to assess the independent association between passive verticalization and infection outcomes, adjusting for potential confounders such as age, sex, APACHE II, and baseline neurological scores. A two-sided p -value < 0.05 was considered statistically significant.

Results

1. Baseline characteristics

A total of 58 patients were enrolled in the study, with 29 assigned to the intervention group and 29 to the control group. Three patients were lost to follow-up due to incorrect contact information. Baseline demographic and clinical characteristics, including age, sex, BMI, admission GCS and APACHE II scores, primary diagnosis, lesion location, and comorbidities, showed no statistically significant differences between groups ($p > 0.05$; Table 1).

2. Hospitalization metrics

Patients in the intervention group had significantly shorter NSICU length of stay (LOS) and overall hospital LOS compared to

TABLE 1 Demographic and clinical characteristics of neurocritical patients at admission.

| Item | Subcategory | Study group (n = 29) | Control group (n = 29) | p-value |
|----------------------------|--------------------------------|----------------------|------------------------|---------|
| Sex, n (%) | Male | 18 (62.07) | 19 (65.52) | 0.785 |
| | Female | 11 (37.93) | 10 (34.48) | |
| Age (years) | 45–75 | 25 (86.21) | 24 (82.76) | 0.717 |
| | >75 | 4 (13.79) | 5 (17.24) | |
| Weight (kg) | - | 65.48 ± 8.30 | 63.76 ± 7.83 | 0.419 |
| Height (cm) | - | 169.72 ± 5.40 | 169.76 ± 5.07 | 0.980 |
| BMI (kg/m ²) | - | 22.65 ± 1.87 | 22.04 ± 1.67 | 0.197 |
| Admission GCS | 3–5 | 6 (20.69) | 5 (17.24) | 0.738 |
| | 6–9 | 23 (79.31) | 24 (82.76) | |
| APACHE II score | - | 27.07 ± 4.28 | 25.55 ± 4.43 | 0.190 |
| Admission diagnosis, n (%) | TBI | 17 (58.62) | 15 (51.72) | 0.597 |
| | ICH | 12 (41.38) | 14 (48.28) | |
| Etiology, n (%) | Traffic accident | 8 (27.59) | 8 (27.59) | 0.764 |
| | Fall | 6 (20.69) | 6 (20.69) | |
| | High-altitude fall | 3 (10.34) | 1 (3.44) | |
| | Assault | 0 (0.00) | 0 (0.00) | |
| | Hypertension | 12 (41.38) | 14 (48.28) | |
| Lesion location, n (%) | Diffuse | 2 (6.90) | 3 (10.34) | 0.850 |
| | Right cerebral hemisphere | 13 (44.83) | 9 (31.03) | |
| | Left cerebral hemisphere | 9 (31.03) | 11 (37.93) | |
| | Bilateral cerebral hemispheres | 2 (6.90) | 3 (10.34) | |
| | Cerebellum | 1 (3.45) | 2 (6.90) | |
| | Brainstem | 2 (6.90) | 1 (3.45) | |
| Risk factors, n (%) | Hypertension | 13 (44.83) | 15 (51.72) | 0.853 |
| | Heart disease | 2 (6.90) | 3 (10.34) | |
| | Diabetes mellitus | 3 (10.34) | 4 (13.79) | |
| | Hematological disorder | 1 (3.44) | 0 (0.00) | |
| | Others | 2 (6.90) | 3 (10.34) | |

TBI, Traumatic brain injury; ICH, Intracranial hemorrhage; GCS, Glasgow Coma Scale; APACHE, Acute Physiology and Chronic Health Evaluation. Continuous variables presented as mean ± SD, categorical variables as n (%).

the control group ($p < 0.05$; Figure 1). Additionally, total hospitalization cost was lower in the intervention group (¥138,242.2 vs. ¥162,069.17), indicating improved cost-effectiveness.

3. Physiological monitoring during passive verticalization

Twenty-nine patients in the intervention group underwent standardized passive head-up tilt positioning, with each session lasting 20 min. Physiological parameters were collected at predefined intervals, as detailed in the Methods section.

- Intracranial hydrodynamics:** Among 21 patients with ICP monitoring, a significant reduction in mean ICP was observed after passive verticalization (10.62 ± 2.13 vs. 8.38 ± 2.27 mmHg, $p < 0.05$), while CPP and PRx showed no significant changes ($p > 0.05$; Figure 2).
- Respiratory mechanics:** Among 16 patients receiving mechanical ventilation, no significant differences were noted

in Cstat, RI, or RE before and after the intervention (all $p > 0.05$; Figure 3).

- Neurological status:** Marked improvements were observed in GCS (7.90 ± 1.11 to 10.07 ± 1.49 , $p < 0.05$) and CRS-R scores (8.17 ± 3.10 to 12.03 ± 2.54 , $p < 0.05$). Among 27 patients previously diagnosed with delirium, all demonstrated improvement based on ICDSC scores (5.97 ± 1.94 to 1.62 ± 0.82 , $p < 0.05$; Figure 4).
- Intra-abdominal pressure:** IAP increased significantly at T1 (38.14 ± 3.73 mmHg) compared to T0 (9.52 ± 2.68 mmHg) and T2 (9.07 ± 2.62 mmHg; all $p < 0.05$), indicating a transient rise during verticalization that returned to baseline thereafter (Table 2).

4. Airway management

Tracheostomy incidence did not significantly differ between groups (12 vs. 15, $p > 0.05$). Mechanical ventilation duration was also

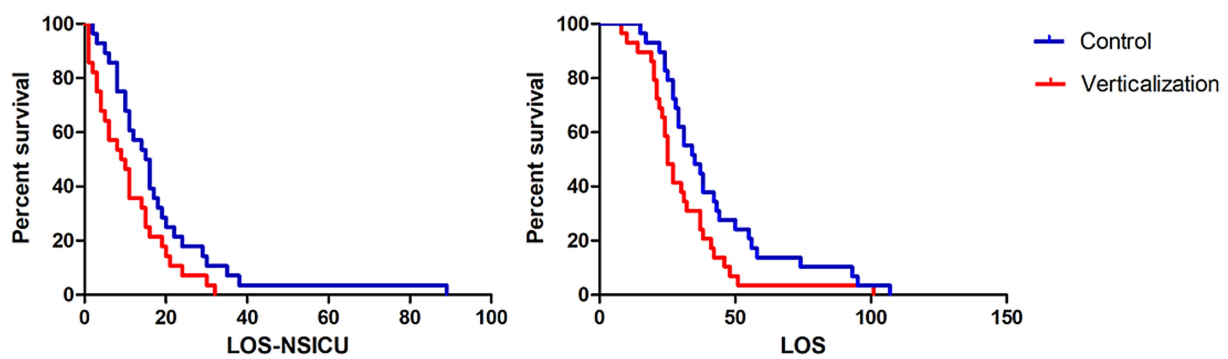


FIGURE 1

Comparison of NSICU and total hospital length of stay between groups. The intervention group receiving passive verticalization exhibited significantly shorter neurosurgical intensive care unit (NSICU) and total hospital length of stay compared to the control group ($p < 0.05$), indicating enhanced hospitalization efficiency associated with early mobilization.

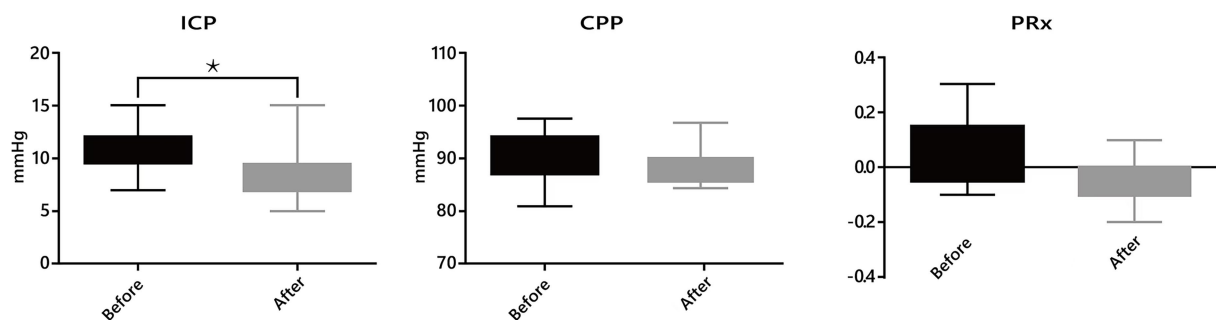


FIGURE 2

Changes in neurological and cognitive function following passive head-up tilt positioning. Scores on the Glasgow Coma Scale (GCS), Coma Recovery Scale-Revised (CRS-R), and Intensive Care Delirium Screening Checklist (ICDSC) were significantly improved after the intervention in the passive verticalization group ($p < 0.05$), indicating enhanced neurological recovery and reduced delirium severity.

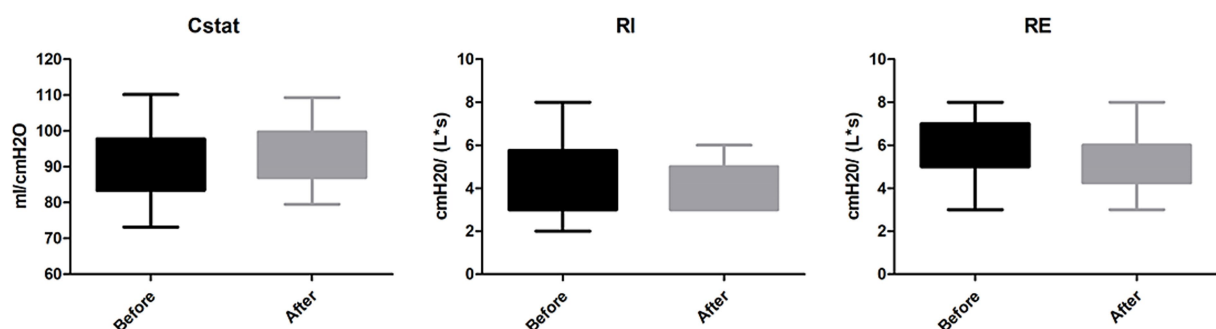


FIGURE 3

Effects of passive verticalization on intracranial dynamics. In patients with intracranial pressure (ICP) monitoring, a significant reduction in ICP was observed after passive verticalization ($p < 0.05$), while cerebral perfusion pressure (CPP) and pressure reactivity index (PRx) remained unchanged, suggesting maintained cerebral autoregulation.

significantly reduced (6.50 ± 5.53 vs. 12.71 ± 10.60 days, $p < 0.05$), while intubation rates and durations showed no statistical difference (Table 3).

To further assess the effect of passive verticalization on tracheostomy outcomes, Kaplan–Meier survival analysis was conducted using tracheostomy tube retention time as the event

variable. (Figure 5). The intervention group demonstrated a significantly shorter tube duration compared to the control group (log-rank test, $p < 0.05$), indicating that passive head-up tilt positioning may facilitate earlier decannulation in neurocritical care patients.

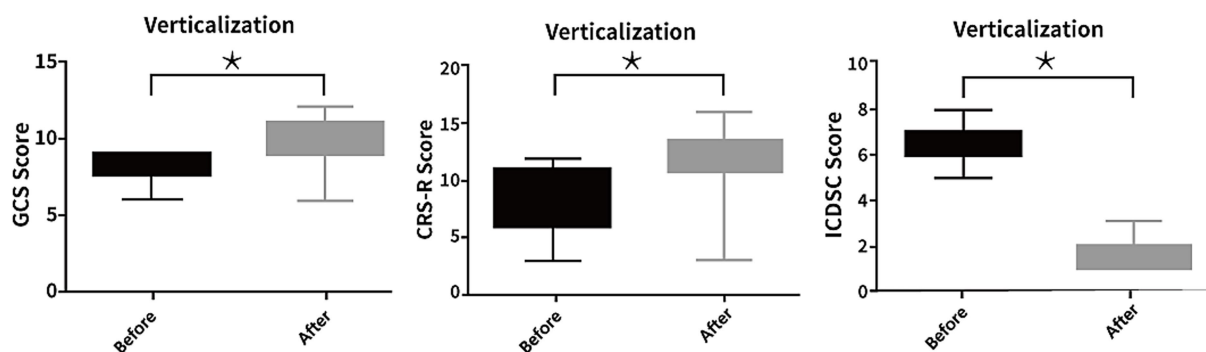


FIGURE 4

Impact of passive verticalization on mechanical ventilation and tracheostomy management. The intervention group exhibited a significantly shorter duration of mechanical ventilation and tracheostomy tube retention compared to controls ($p < 0.05$), indicating potential benefits of early passive mobilization for airway management in neurocritical care.

5. Complications

The intervention group exhibited significantly shorter delirium duration (2.48 ± 0.58 vs. 4.08 ± 1.72 days, $p < 0.05$), earlier initiation of enteral nutrition (4.45 ± 1.24 vs. 5.59 ± 1.55 days, $p < 0.05$), and no cases of DVT (vs. 4 in the control group, $p < 0.05$). No significant differences were observed in the incidence of pulmonary infections, fever, or refractory hyperglycemia ($p > 0.05$; Table 4).

6. Prognosis and follow-up

At discharge, patients in the intervention group showed significantly better GCS and LCF scores ($p < 0.05$). While 3-month follow-up revealed no significant differences in GOS, disability rate, or mortality, favorable trends were observed. At 6 months, ADL and DRS scores were significantly better in the intervention group ($p < 0.05$), suggesting enhanced long-term recovery (Table 5).

Discussion

This study provides clinical evidence supporting passive head-up tilt positioning as an effective early mobilization strategy for patients in neurocritical care. The intervention was associated with reduced lengths of stay in both the NSICU and hospital overall, as well as significant improvements in neurological function and reduced incidence of common ICU-related complications. These findings align with previous evidence from general ICU populations, highlighting the value of early mobilization in enhancing recovery and preventing functional deterioration.

The observed improvement in GCS and CRS-R scores indicates that passive verticalization may facilitate arousal and neurological responsiveness. This may be attributed to increased cortical activation and enhanced sensory input during upright positioning, which has been proposed to stimulate the reticular activating system and promote consciousness (27, 28). More over, all patients diagnosed with delirium before intervention experienced marked improvements, as evidenced by substantial decreases in ICDSC scores. These findings align with prior research highlighting the role of early mobilization in mitigating delirium and enhancing cognitive function (29, 30).

TABLE 2 Dynamic changes in IAP during passive orthostatic positioning.

| Item | T0 | T1 | T2 | <i>p</i> |
|---------|-----------------|------------------|-----------------|----------|
| IAP(29) | 9.52 ± 2.68 | 38.14 ± 3.73 | 9.07 ± 2.62 | |
| T0-T1 | | | | <0.001 |
| T0-T2 | | | | 0.514 |
| T1-T2 | | | | <0.001 |

IAP, Intra-abdominal pressure; T0, Baseline measurement (10 min before verticalization); T1, Early-phase measurement (10 min after initiation); T2, Delayed-phase measurement (2 h post-intervention).

TABLE 3 Comparative mechanical ventilation parameters and endotracheal tube duration between study cohorts.

| Item | Study group | Control group | <i>p</i> |
|-----------------|-----------------|-------------------|----------|
| T (n) | 12 | 15 | 0.597 |
| ETT (n) | 25 | 23 | 0.487 |
| ETT Duration(d) | 5.68 ± 3.79 | 8.22 ± 6.72 | 0.241 |
| MV (n) | 16 | 14 | 0.276 |
| MV Duration(d) | 6.50 ± 5.53 | 12.71 ± 10.60 | 0.048 |

T, Tracheostomy; ETT, Endotracheal tube; MV, Mechanical ventilation.

A key finding of this study was the significant reduction in ICP following passive verticalization. Elevated ICP is a known risk factor for poor neurological outcomes, and effective, non-invasive interventions remain limited (31–36). The observed reduction is likely attributed to posture-induced modulation of CSF dynamics and enhanced cerebral venous drainage (20–23). Previous studies have shown that head elevation improves intracranial compliance and reduces ICP without adversely affecting CPP (24–26). Importantly, CPP and the PRx remained stable after verticalization, indicating preserved cerebral perfusion and autoregulatory function. This supports the safety of passive verticalization, even in patients with impaired consciousness or invasive monitoring. Unlike pharmacologic interventions, this approach is non-invasive, bedside-accessible, and can be safely implemented in early neurocritical care. Given its simplicity and physiological benefits, passive verticalization may serve as an adjunct to conventional ICP management. However, further studies are needed to define optimal

TABLE 4 Comparative analysis of clinical complications between patient cohorts.

| Item | Study group | Control group | <i>p</i> -value |
|-------------------------|-------------|---------------|-----------------|
| Delirium (n) | 27 | 24 | 0.227 |
| Delirium Duration (d) | 2.48 ± 0.58 | 4.08 ± 1.72 | <0.001 |
| Pulmonary Infection (n) | 5 | 8 | 0.345 |
| Fever Cases (n) | 10 | 16 | 0.113 |
| Fever Duration (d) | 7.30 ± 3.59 | 9.13 ± 4.65 | 0.300 |
| DVT (n) | 0 | 4 | 0.038 |
| EN Compliance Time (d) | 4.45 ± 1.24 | 5.59 ± 1.55 | 0.004 |
| IH (n) | 2 | 5 | 0.227 |

DVT, Deep Vein Thrombosis; EN, Enteral Nutrition; IH, Intractable Hyperglycemia.

TABLE 5 Post-discharge prognosis and follow-up outcomes in the intervention and control groups.

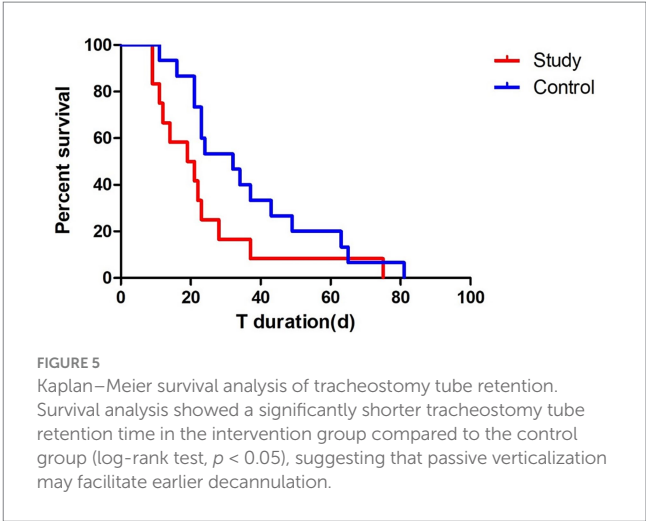
| Item | Study group | Control group | <i>p</i> |
|--------------------|---------------|---------------|----------|
| GCS | 12.03 ± 2.82 | 9.83 ± 4.11 | 0.020 |
| CRS-R | 15.48 ± 6.17 | 12.59 ± 7.22 | 0.106 |
| LCF | 5.24 ± 2.31 | 3.86 ± 2.72 | 0.042 |
| FIM | 86.03 ± 36.27 | 71.31 ± 41.25 | 0.154 |
| GOS (3 months) | 3.55 ± 1.30 | 2.90 ± 1.40 | 0.066 |
| 3-month Disability | 9(31.03) | 13(44.83) | 0.279 |
| 3-month Mortality | 2(6.90) | 5(17.24) | 0.227 |
| 6-month ADL | 66.21 ± 30.37 | 46.03 ± 36.73 | 0.026 |
| 6-month DRS | 7.38 ± 7.85 | 12.38 ± 10.03 | 0.039 |

Scoring systems: GCS, Glasgow Coma Scale; CRS-R, Coma Recovery Scale-Revised; LCF, Levels of Cognitive Functioning; FIM, Functional Independence Measure; GOS, Glasgow Outcome Scale; ADL, Activities of Daily Living; DRS, Disability Rating Scale. The scoring ranges are as follows: GCS: 3 (deep coma or death) to 15 (fully alert); CRS-R: 0 (no response) to 23 (normal consciousness); LCF: 1 (no response) to 8 (purposeful and appropriate); FIM: 18 (total dependence) to 126 (complete independence); GOS: 1 (death) to 5 (good recovery); ADL: 0 (complete dependence) to 100 (fully independent); DRS: 0 (no disability) to 29 (extreme disability).

positioning parameters and identify patients most likely to benefit from this intervention.

An intriguing physiological observation from our study was the transient increase in IAP during upright positioning, which returned to baseline upon resuming a supine position. This temporary elevation may stimulate gastrointestinal motility, potentially offering therapeutic benefits for neurogenic bowel dysfunction frequently encountered in neurocritical patients (37). Indeed, several patients reported relief from prolonged abdominal distension and improved bowel movements following intervention.

Additionally, regarding respiratory outcomes, the intervention significantly reduced the duration of mechanical ventilation and shortened tracheostomy tube retention. Although there was no difference in the number of patients requiring intubation or mechanical ventilation, shorter ventilation durations suggest that upright positioning may improve respiratory mechanics by optimizing lung volumes, reducing atelectasis, and enhancing diaphragmatic function, as supported by prior studies (38–42). These physiological improvements facilitate earlier restoration of airway protective reflexes, ultimately aiding earlier weaning from mechanical ventilation.



Importantly, a reduction in DVT incidence and faster attainment of enteral nutrition targets reflect the systemic benefits of early mobilization, even in patients unable to participate actively. These improvements may be due to enhanced venous return, improved hemodynamic stability, and reduced inflammatory response, all of which are known benefits of mobilization in critically ill patients (43, 44).

Long-term outcomes reinforced the benefits of passive verticalization, showing significantly better functional recovery as evidenced by improved GCS, Levels of LCF, ADL, and DRS scores at discharge and during follow-up evaluations. Although no statistically significant differences were observed in three-month disability and mortality rates, there was a consistent trend toward better outcomes in the intervention group. At 6 months post-discharge, the intervention group demonstrated superior functional independence and lower disability burden, highlighting the sustained impact of early passive mobilization on rehabilitation and quality of life.

This study provides novel clinical evidence supporting passive head-up positioning as a potentially effective adjunctive intervention in neurocritical care. Its integration into early rehabilitation protocols may contribute to improved neurological outcomes and reduced healthcare burden.

Nonetheless, this study has limitations, including a single-center, non-randomized design and relatively small sample size, which may affect generalizability and introduce selection bias. Future multicenter randomized controlled trials with larger cohorts are warranted to validate these findings and to establish standardized protocols for passive mobilization in neurocritical populations.

In addition, although we employed blinded manual matching and time-based group separation to minimize treatment selection bias, the inherent limitations of a retrospective design and non-randomized allocation remain. We acknowledge that future multicenter, prospective randomized trials are needed to validate these findings and confirm the safety and efficacy of passive verticalization under more controlled conditions.

Conclusion

Passive head-up tilt positioning is a safe and effective early mobilization strategy for neurocritical care patients. This intervention

was associated with reduced NSICU and hospital lengths of stay, shorter durations of mechanical ventilation and tracheostomy tube use, and improvements in neurological and cognitive recovery. It also lowered the incidence of complications such as delirium and DVT, contributing to better long-term functional outcomes. These findings highlight the potential of passive verticalization to support patients who are otherwise unsuitable for active mobilization due to impaired consciousness or invasive monitoring. By enhancing physiological stability and facilitating early functional recovery, this approach may improve care quality and resource utilization in neurocritical settings.

Further multicenter randomized controlled trials are needed to validate these findings and establish standardized protocols for passive verticalization in neurocritical care practice.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethics Committee of the First People's Hospital of Changzhou. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Informed consent was waived due to the retrospective nature of the analysis and full anonymization of all patient data.

Author contributions

GJ: Data curation, Visualization, Investigation, Writing – review & editing, Writing – original draft, Formal analysis. YF:

Writing – review & editing, Supervision, Funding acquisition, Conceptualization, Resources, Methodology. ZL: Visualization, Formal analysis, Data curation, Writing – review & editing. CY: Resources, Writing – review & editing, Investigation, Supervision. YP: Project administration, Supervision, Writing – review & editing. NS: Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Glossary

NICU - neurointensive care unit

GCS - Glasgow Coma Scale

ICP - intracranial pressure

T0 - 10 min before verticalization

T1 - 10 min after initiation

T2 - 2 h post-intervention

Before - 2 h prior to verticalization

After - 2 h after verticalization

CPP - cerebral perfusion pressure

PRx - pressure reactivity index

Cstat - static compliance

RI and RE - inspiratory and expiratory resistance

SD - standard deviation

LOS - lengths of stay

RASS - Richmond Agitation-Sedation Scale

DVT - deep vein thrombosis

ECG - electrocardiogram

BMI - body mass index

APACHE II - Acute Physiology and Chronic Health Evaluation II

CRS-R - Coma Recovery Scale-Revised

LCF - Cognitive Functioning

ICDSC - Intensive Care Delirium Screening Checklist

DRS - Disability Rating Scale

FIM - Functional Independence Measure

ADL - Activities of Daily Living

GOS - Glasgow Outcome Scale

IQR - interquartile range