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Early mobilization in postoperative glioma patients real world impact on recovery and long term prognosis

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The implementation of early mobilization in postoperative care has been shown to expedite patient recovery. However, its widespread use among patients undergoing glioma resection is not firmly established. This study aimed to implement an early mobilization protocol in glioma patients and evaluate its effects on early recovery and long-term prognosis. Patients who underwent craniotomy for glioma treatment between January 2018 and December 2019 were enrolled in a randomized controlled trial comparing conventional perioperative care (control group) with conventional care plus a structured early mobilization protocol (experimental group). We collected data on early recovery and long-term prognosis from patients' electronic health records. Means and frequencies were evaluated using the Mann-Whitney U test, T-test, and chi-square test. The research team conducted standardized assessments in advance to ensure consistency. Postoperative primary outcomes revealed that the experimental group showed improvements of 39.06 points in activities of daily living and 0.86 points in numerical rating scale scores for pain, a 2.02 day shorter mean length of hospital stay (95% confidence interval [CI] 91.099–100.596, 0.403–1.691, 9.754–15.060, $P<0.001$). Secondary outcomes also indicated that the experimental group had a 4.2 day shorter mean time to ambulation, a 3.48 day shorter mean duration of central venous catheter use, a 4.15 day shorter mean duration of gastric tube use, and a 3.64 day shorter mean duration of urethral catheter use. Furthermore, the experimental group demonstrated a significantly lower incidence of postoperative complications and reduced hospitalization expenses ($P<0.05$). However, no statistically significant differences with secondary outcomes were observed in intraoperative blood loss or three-year prognosis between the two groups. Our findings show that an early mobilization protocol can promote early recovery in patients undergoing glioma resection without adversely affecting long-term prognosis. The protocol demonstrated both safety and cost-effectiveness, supporting its clinical implementation to improve postoperative functional recovery.

Gliomas constitute the most prevalent primary brain tumors in adults, representing 70% of primary malignant brain neoplasms based on data from the American Brain Tumor Registry[1,2]. Recent epidemiological surveys in China report an annual incidence of 5–8 per 100,000 person-years. Surgical resection remains the preferred initial treatment, but it carries significant risks, including neurological injury, physiological and psychological stress, and perioperative complications, which may adversely affect prognosis[3–5].

First pioneered by Henrik Kehlet in 1997, the enhanced recovery after surgery (ERAS) protocol framework revolutionized perioperative management through standardized multidisciplinary collaboration among neurosurgeons, anesthesiologists, and rehabilitation specialists[6]. Evidence-based ERAS protocols have demonstrated benefits such as shortened hospital stays, reduced surgical stress, decreased complication rates, and decreased demand for postoperative rehabilitation services[7]. The ERAS Association, established in 2010, has released guidelines for multiple surgical specialties, showing reduced treatment costs without compromising outcomes[8]. Both domestic and international guidelines emphasize the critical role of early mobilization in accelerating recovery and reducing postoperative complications[9,10].

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ERAS protocols have been increasingly applied in neurosurgery, demonstrating advantages such as reduced postoperative length of stay (LOS) and faster recovery without increased complications[11–13]. Studies, including a 2022 report, confirm that ERAS enhances postoperative recovery in glioma patients while maintaining safety[14]. As a core ERAS component, early mobilization effectively mitigates complications associated with prolonged immobilization, though its operational criteria remain inconsistently defined across neurosurgical practice[15]. Its specific impact on glioma patients' recovery and long-term prognosis remains unclear. This study aims to determine whether early mobilization accelerates recovery and influences long-term outcomes in glioma resection patients. Primary outcomes were postoperative ADL and NRS within 3 days, incidence of postoperative complications, LOS, total hospitalization costs, and 3-year clinical outcomes. Secondary outcomes comprised intraoperative blood loss, time to ambulation, and duration of indwelling catheters (UC, GT, and CVC).

Materials and methods

Study population

We performed a single-center RCT with consecutive enrollment undergoing craniotomy for glioma resection at a tertiary neurosurgical center from January 2018 to December 2019. The inclusion criteria were as follows: (1) glioma confirmed by computed tomography (CT), magnetic resonance imaging (MRI), and histopathological confirmation; (2) availability of complete medical records; (3) age $\geq$ 18 years; (4) no history of prior surgical treatment; and (5) provision of signed informed consent. Exclusion criteria included: (1) diagnosis of other malignant tumors or evidence of distant metastasis; (2) preoperative limb dysfunction muscle strength $<$ Grade 4 (Medical Research Council [MRC] scale); (3) preexisting neurological deficits such as neurological deficits, consciousness impairment, ataxia, apraxia, neglect and visual deficits, aphasia, or myasthenia; (4) a history of cardiac, cerebrovascular, or hepatic diseases; and (5) presence of mental illness or severe psychological disorders, clinically diagnosed per International Classification of Diseases (ICD-10) criteria, with clinical interviews conducted to confirm eligibility.

A total of 115 patients met the inclusion criteria and were enrolled in the study. Participants were randomly assigned via block randomization (1:1 ratio) to either the experimental group or the observed group. The final analysis included 59 patients in the experimental group and 56 in the observed group. The study protocol was approved by the hospital's ethics committee, and written informed consent was obtained from all participants.

Data sources

The primary data sources included diagnostic reports, pathological reports, progress notes, hospital discharge records, mortality data, nursing assessments, and nursing records, as well as laboratory test results. The data reported in this study were not derived from representative samples or large-scale case studies; instead, they reflect the real-world data (RWD) of patients who underwent glioma resection surgery between 2018 and 2019. Consequently, variables were not pre-selected but are described as they naturally occurred in the clinical setting.

Early mobilization protocol

The structured early mobilization protocol (Fig. 1) was developed in accordance with ERAS Society Neurosurgical Guidelines[16–23]. When the patient returned to the ward on the day of surgery, the head of the bed was raised 30° once the patient regained normal consciousness, and the patient was assisted in turning over and performing back percussion every two hours. On the first day after surgery, the patient was instructed to actively exercise their limbs and sit up for 20 min twice a day in bed. The patient was encouraged to take deep breaths and practice effective coughing. If the patient experienced intolerance, the activity mode was adjusted to shorten the duration of each activity and increase the frequency of activities. The responsible nurse evaluated the patient's lower extremity muscle strength on the second and third days after surgery. For patients with muscle strength $\geq$ grade 3, the nurse guided the patient to perform core training based on the previous day's exercises (e.g., bridge exercise, straight leg elevation, etc.), sit at the bedside for 20 min twice a day, and then stand at the bedside for 20 min twice a day with the assistance of family members. The cumulative activity time was at least 1 h per day, and patients with muscle strength $<$ grade 3 continued with the previous training goals. On the fourth and fifth days after surgery, the responsible nurse evaluated the patients' muscle strength. For patients with muscle strength $\geq$ 4, the nurse instructed the patients to walk with the assistance of their family members for 20 min twice a day based on the previous training, with the total activity time reaching at least 1.5 h per day. Patients with muscle strength $<$ 4 continued with the previous training goals. On the sixth and seventh days after surgery, the responsible nurse evaluated the patient's muscle strength. For patients with muscle strength = grade 5, based on the training from the previous days, the patient was instructed to ambulation at 0.8 m/s independently for 20 min twice a day under the supervision of family members, with the total activity time reaching at least 2 h per day. Patients with muscle strength $<$ grade 5 continued with the previous training goals. In the later stages, the activity time and frequency should be gradually increased based on previous activities, ensuring that the patient does not experience excessive fatigue.

Standard postoperative care included: Positioning: Patients should remain in a head-elevated position while awake to ensure optimal intracranial venous drainage. Airway Maintenance: Caregivers must ensure a patent airway by clearing respiratory secretions and administering oxygen if needed to prevent aspiration. Vital Sign Monitoring: Within the first 24 h post-surgery, vital signs—including respiratory rate, blood pressure, heart rate, oxygen saturation, and electrolyte levels—should be actively monitored to detect abnormalities[24]. Diet: Depending on their condition, patients may begin with a clear or semi-liquid diet enriched with high-protein and high-vitamin foods (e.g., milk, eggs, meat) to promote nutritional recovery and physical rehabilitation[25] (see Supplementary Table S1). Routine care is tailored to each patient's condition and medical requirements, with caregivers remaining vigilant for potential complications.

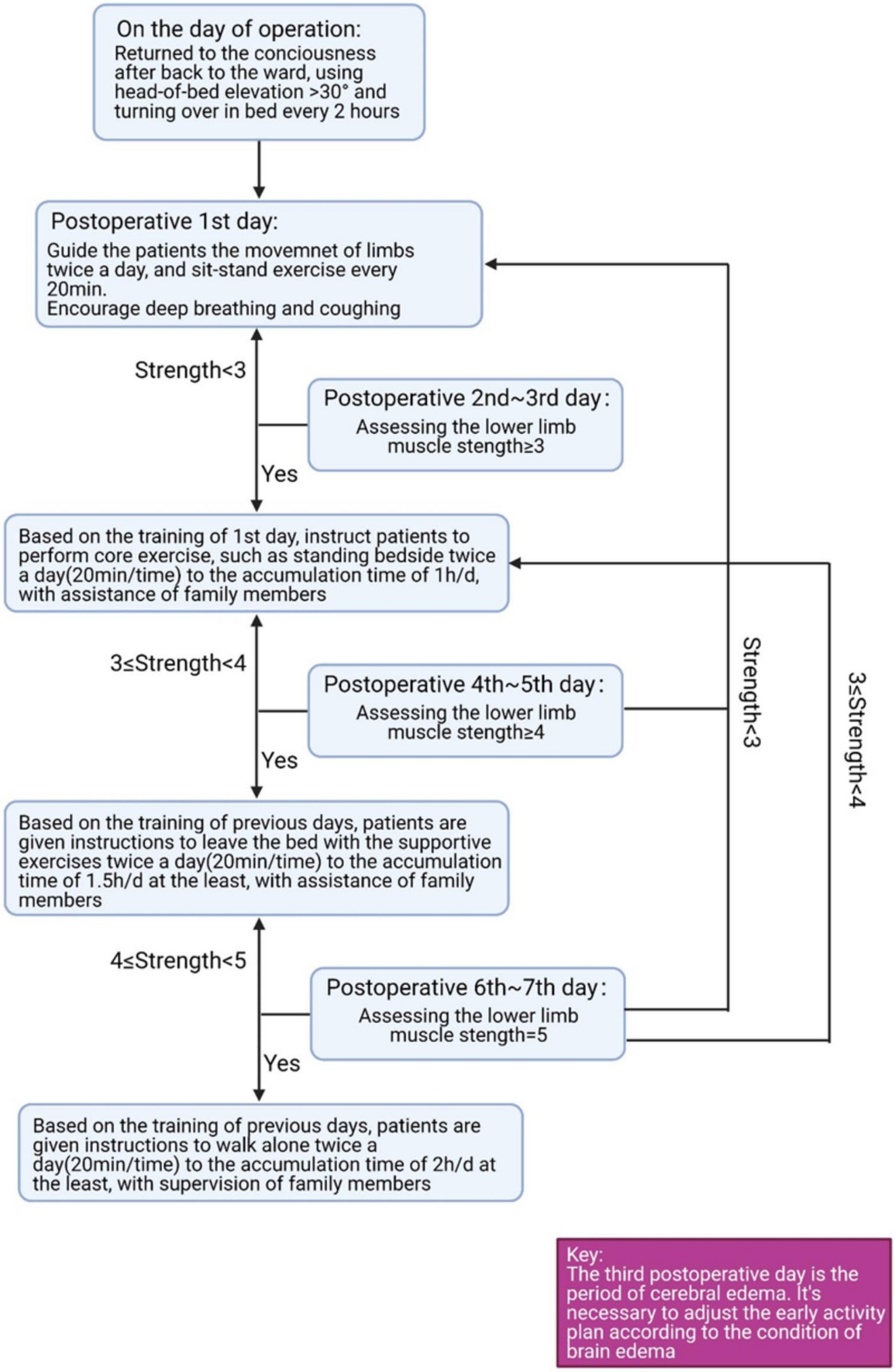

Fig. 1. Flow chart of early mobilization protocol. Multidisciplinary standardized nursing process flowchart. Nursing process for early mobilization after surgery, taking into consideration the patient's condition and postoperative characteristics. This process involves mobilization on the second postoperative day, seventh postoperative day, and for patients with muscle strength levels of < 3, 3–4, 4–5, and 5.

To enhance pain management, multimodal analgesia was implemented, including preoperative and preemptive analgesia, central sensitization management, and diverse anesthesia techniques[26,27]. Daily pain assessments were conducted by nurses, and patients reporting a pain score ≥ 2 were encouraged to notify their attending physician for medication intervention and relaxation training. Psychological support was also provided to alleviate anxiety and enhance comfort.

To facilitate safe and independent mobility, the hospital implemented infrastructure upgrades, including the installation of handrails along corridors, auxiliary equipment in bathrooms, and provision of mobile infusion stands and walking aids. Educational resources, such as early mobilization health education manuals and instructional videos, were created to guide patients. Communication groups specifically for glioma patients were established to address concerns and reduce anxiety related to early mobilization. Health education bulletin boards with motivational phrases, such as "Victory belongs to the most persevering!" were placed throughout the ward to encourage adherence to the mobilization protocol. Nurses actively engaged with patients to motivate them and reinforce daily goals.

The early mobilization protocol was implemented as part of a departmental quality improvement initiative. Emergency response plans were developed to address incidents arising during mobilization. Senior nurses submitted daily reports to the head nurse, documenting adherence to the protocol and any challenges encountered. Random inspections were conducted by the head nurse to ensure compliance. Additionally, interdisciplinary discussions involving doctors and nurses were held to address challenges and propose actionable solutions. These measures ensured the standardization and effectiveness of the mobilization protocol.

Outcome variables

Primary outcomes included ADL and NRS scores within three days postoperatively, as well as the occurrence of postoperative complications, LOS, hospitalization expenses, and three-year clinical prognosis. Secondary outcomes encompassed intraoperative blood loss, time to ambulation, and the timing of drainage tube removal.

ADLs were used to assess the self-care abilities of inpatients, serving as crucial indicators of their overall health and functional status. LOS referred to the duration from patient admission to discharge, while hospitalization expenses covered various categories, including medications, consumables, diagnostics, treatments, comprehensive medical services, blood and blood products, rehabilitation services, and other associated costs. The three-year prognosis was defined by survival rates, recurrence, and mortality outcomes.

The ADL score was evaluated based on the completion of six activities outlined in the Katz's Activities of Daily Living Index[28]: bathing, dressing, eating, indoor activities, toileting, and bladder/bowel continence. If a patient could independently perform all six tasks, their ADL was classified as "independent"; otherwise "dependent". The NRS score assessed patients' pain intensity using a numerical scale from 0 to 10, where 0 represented no pain and 10 indicated the most severe pain. Patients were instructed to select a number between 0 and 10 to reflect their pain level, with the following categories: no pain (0 points), mild pain (1 to 3 points), moderate pain (4 to 6 points), and severe pain (7 to 10 points).

Data collection and statistical analysis

Data were prospectively recorded using standardized case report forms to document baseline characteristics and provide valuable references for subsequent statistical analysis. Information recorded included sex, age, body mass index (BMI), albumin (ALB) levels, prothrombin time (PT), NRS scores, tumor location, number of tumors, tumor volume, and tumor grade. Continuous variables are presented as means ± standard deviations (SDs), while categorical variables are presented as percentages or frequencies. Differences between two groups were assessed using Student's t-test or the Mann-Whitney U test for continuous variables, and the X^2 test or Fisher's exact test for categorical variables. A database was constructed using EpiData version 3.5.2, with double-entry verification by independent data managers to ensure accuracy to minimize potential entry errors. Statistical analyses were performed using GraphPad Prism (version 7.0; GraphPad Software, San Diego, CA, USA) and SPSS version 23.0; SPSS, Inc.). A significance level of $P < 0.05$ was considered statistically significant. To control for the family-wise error rate in multiple comparisons, Bonferroni correction was applied. Given that 22 independent comparisons were conducted, the adjusted significance threshold was set at 0.05/22. During data analysis, each comparison's p-value was compared against this adjusted threshold. If the p-value was less than the adjusted significance threshold, the comparison was deemed statistically significant.

Results

Demographic characteristics of the glioma patients

From January 2018 to December 2019, 133 consecutive patients underwent glioma resection at our institution. After excluding 18 cases (12 screening failures, 6 withdrawals), 115 eligible patients underwent block randomization (1:1 ratio) to either the observed group ($n = 56$, receiving conventional care) or the experimental group ($n = 59$, receiving conventional care plus early mobilization). Upon comparison, no significant differences were observed between the two groups in terms of sex, age, education level, BMI, ALB levels, PT, NRS scores, tumor location, tumor size, tumor number, tumor resection extent, or tumor grade. All craniotomies were performed by the same experienced surgical team. Baseline characteristics between the groups were comparable (Table 1 and Table S2), and tumor-specific information is summarized in Table 2 (Table S2). With no significant differences were found in any of the aforementioned characteristics at baseline ($p > 0.05$).

Comparison of primary outcomes related to patient rehabilitation indicators

On the third day after surgery, the experimental group demonstrated superior outcomes compared with the observed group in terms of NRS and ADL scores ($p < 0.001/22$) (see Table 3; Fig. 2, and Table S4). Furthermore, the incidence of postoperative complications was significantly lower in the experimental group ($p = 0.049$) (see

Factors	Observed group	Experimental group	t/z/χ^2	*P*
Sex [frequency (male/female)]	56(33/23)	59(38/21)	0.047(χ^2	0.828
Age [year (mean ± SD)]	52.41 ± 13.69	52.64 ± 11.76	0.098(t)	0.922
Education [Frequency (below junior high school/middle school–high school/above high school)]	56(16/20/20)	59(17/16/26)	1.180(χ^2)	0.554
BMI [kg/m^2(mean ± SD)]	23.29 ± 2.39	23.02 ± 3.24	0.527(t)	0.599
ALB [g/L (mean ± SD)]	39.87 ± 3.88	38.80 ± 2.97	−1.567(z)	0.117
PT [s (mean ± SD)]	11.18 ± 1.28	11.08 ± 0.71	−0.563(z)	0.574
NRS [score (mean ± SD)]	1.79 ± 1.50	1.59 ± 1.12	−0.087(z)	0.931

Table 1. Comparison of general information between the two groups. *SD* standard deviations, *BMI* body mass index, *ALB* albumin, *PT* prothrombin time, *NRS* numerical rating scale.

Factors	Observed group	Experimental group	t/z/χ^2	*P*
Lesion area [frequency (central/non-central)]	56(5/51)	59(6/53)	0.051(χ^2)	0.821
Tumor hemisphere[frequency (left/right/bilateral)]	56(25/23/8)	59(28/22/9)	0.173(χ^2)	0.917
Tumor localization				
Frontal (n/%)	16(21.9%)	18(30.5%)	0.015(χ^2)	0.784
Parietal (n/%)	4(5.4%)	9(15.2%)		
Temporal (n/%)	11(15%)	6(10.1%)		
Occipital (n/%)	3(4.1%)	2(3.3%)		
Insula (n/%)	1(1.3%)	2(3.3%)		
Temporal-parietal (n/%)	5(6.8%)	1(1.6%)		
Temporal-occipital (n/%)	2(2.7%)	1(1.6%)		
Frontal-parietal (n/%)	2(2.7%)	5(8.4%)		
Frontal-temporal (n/%)	3(4.1%)	3(5.0%)		
Parieto-occipital	1(1.3%)	2(3.3%)		
Brainstem (n/%)	1(1.3%)	3(5.0%)		
Cerebellum (n/%)	1(1.3%)	1(1.3%)		
Third ventricle (n/%)	2(2.7%)	1(1.3%)		
Sellar region (n/%)	1(1.3%)	1(1.3%)		
Basal ganglia (n/%)	1(1.3%)	1(1.3%)		
Thalamus (n/%)	1(1.3%)	1(1.3%)		
Paracele (n/%)	1(1.3%)	2(3.3%)		
Lesion Number[frequency (1/2 or above)]	56(46/10)	59(49/10)	0.016(χ^2)	0.898
Tumor volume [cm^3(mean ± SD)]	37.47 ± 31.92	37.82 ± 36.71	0.277(z)	0.782
Tumor resection extent(total resection/subtotal resection/partial resection)	56(44/8/4)	59(45/8/6)	0.336(χ^2)	0.845
Tumor grade [frequency(I-II/III-IV)]	56(50/6)	59(53/6)	0.009(χ^2)	0.924

Table 2. Summary of tumor related details. *SD* standard deviations.

Factors	Observed group	Experimental group	z	*P*
Number	56	59	–	–
Intraoperative blood loss (mean ± SD, ml)	372.50 ± 247.47	276.49 ± 203.77	−1.783	0.075
NRS on third day (mean ± SD)	1.50 ± 1.18	0.64 ± 1.04	−4.898	<0.001
ADL score on third day (mean ± SD)	56.79 ± 7.10	95.85 ± 4.75	−9.399(z)	<0.001
Time to ambulation (mean ± SD, day)	6.45 ± 1.13	2.25 ± 0.44	−9.577(z)	<0.001
Postoperative central venous catheter indwelling time (mean ± SD, day)	10.50 ± 7.89	7.02 ± 4.33	−2.535(z)	0.011
Postoperative gastric tube indwelling time(mean ± SD, day)	6.52 ± 0.69	2.37 ± 0.58	0.949(z)	<0.001
Postoperative urinary catheter indwelling time (mean ± SD, day)	7.59 ± 7.56	3.95 ± 4.16	−3.516(z)	<0.001
Three-year prognosis	56(28/12/16)	59(40/5/14)	5.059(χ^2)	**0.08**

Table 3. Comparison of rehabilitation-related indicators between the two groups. *SD* standard deviations, *NRS* numerical rating scale, *ADL* activity of daily living. Three-year prognosis: survival/relapse/die.

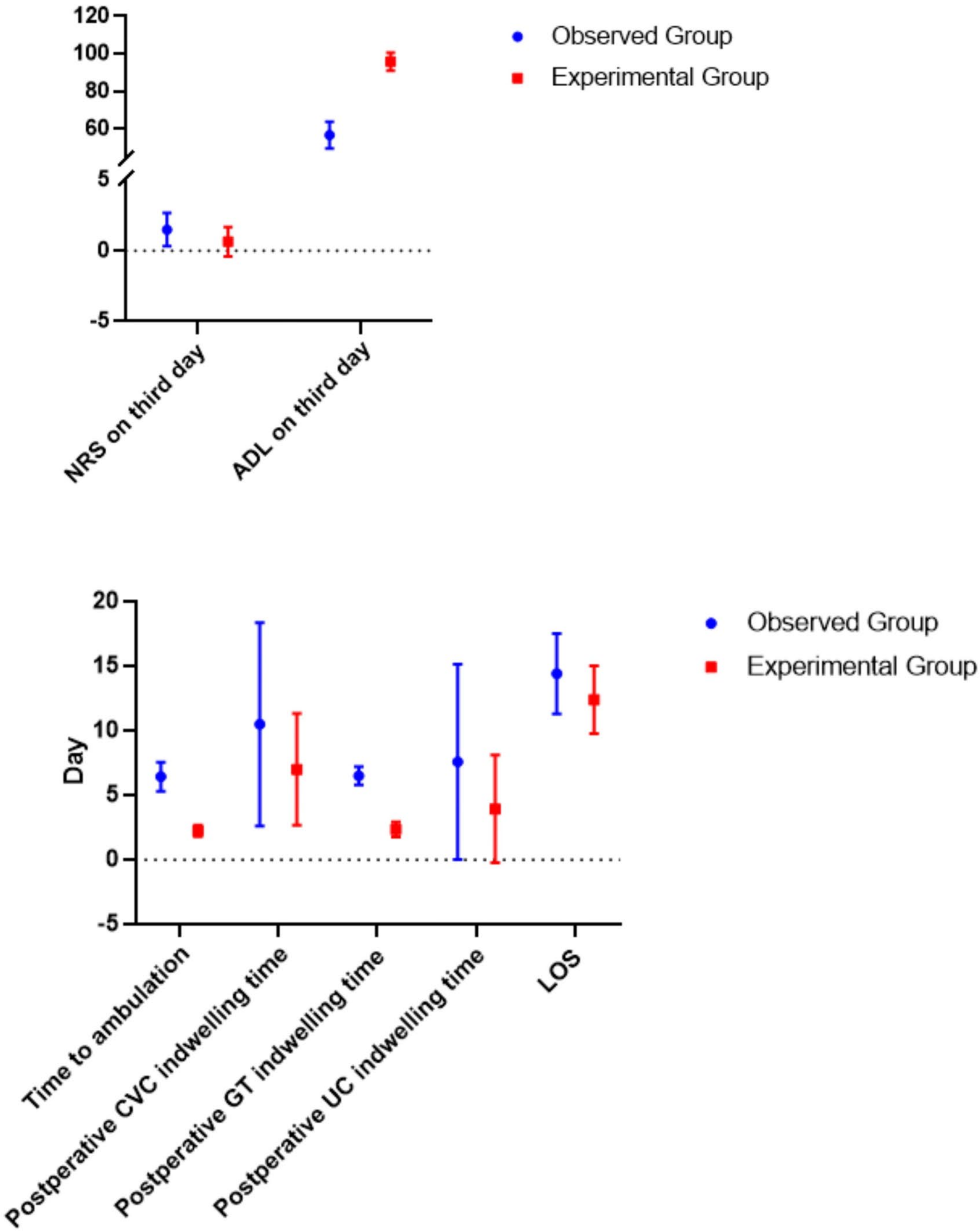

Fig. 2. Changes of rehabilitation-related indicators between the two groups. *NRS* Numerical rating scale, *ADL* activity of daily living, *CVC* central venous catheter, *GT* gastric tube, *UC* urethra catheter.

Table 4 and Table S3). LOS was both statistically and clinically significantly shorter in the experimental group, with a mean reduction of 2.02 days ($p < 0.001/22$) (see Table 5; Fig. 2, and Table S4). Hospitalization expenses were also lower in the experimental group compared to the observed group (see Table 5). In summary, the experimental group exhibited both a shorter LOS and lower costs. However, there was no significant difference in the three-year prognosis between the two groups ($p = 0.08$) (see Table 3).

Number of complications	0	1	2	≥ 3
Observed group (number)	41	12	3	0
Experimental group (number)	51	8	0	0
X^2	4.330			
P	0.049			

Table 4. Comparison of postoperative complications between the two groups.

Group	LOS (mean ± SD, day)	Hospitalization expenses (mean ± SD, ¥)
Observed group	14.43 ± 3.14	39824.59 ± 11698.58
Experimental group	12.41 ± 2.65	32883.06 ± 2635.64
z	−3.587(z)	−5.411
P	<0.001	<0.001

Table 5. Comparison of LOS and hospitalization expenses between the two groups. *SD* standard deviations.

Comparison of secondary outcomes related to patient rehabilitation indicators

The results showed no significant difference in intraoperative blood loss between the experimental and observed groups ($P > 0.05$) (see Table 3; Fig. 2). Notably, the experimental group demonstrated earlier ambulation compared to the observed group. The average time to ambulation in the experimental group was 2.25 ± 0.44 days, which was significantly shorter than the observed group's average of 6.45 ± 1.13 days, with a mean difference of 4.2 days ($P < 0.001/22$) (see Table 3; Fig. 2). Additionally, the experimental group exhibited significantly shorter postoperative indwelling times for CVC, GT, and UC compared to the observed group, with mean day differences of 3.48 days for CVC, 4.15 days for GT, and 3.64 days for UC. The p-values for GT and UC were both < 0.001/22, while the p-value for CVC was 0.011 (see Table 3; Fig. 2).

Discussion

This study demonstrates that an early mobilization protocol significantly improved early recovery outcomes in glioma patients, including reduced pain (NRS), enhanced functional independence (ADL), shorter time to ambulation, and decreased LOS and hospitalization costs. However, no significant differences were observed in long-term prognosis or intraoperative blood loss between groups. Glioma, a common primary brain tumor, is highly malignant, difficult to treat, and associated with high mortality and postoperative recurrence rates[29]. The ERAS protocol facilitates recovery through comprehensive patient assessment, progress monitoring, timely extubation, and promoting early ambulation and oral feeding[30,31]. According to ERAS guidelines, early and structured mobilization is crucial for accelerating recovery. Early mobilization, as part of the ERAS protocol, represents an innovative nursing approach that enhances recovery.

Effective pain management is a core component of the ERAS protocol and is essential for successful recovery following glioma surgery. Uncontrolled postoperative pain can activate the pituitary-adrenal axis, resulting in immunosuppression, elevated risk of wound infections, and impaired wound healing[32]. Inadequate pain control may also restrict mobility, increasing the likelihood of complications such as deep vein thrombosis, pulmonary embolism, and pneumonia[33]. Additionally, effective pain management has been demonstrated to reduce postoperative nausea and vomiting in most patients and promote early mobilization[34]. In this study, multimodal analgesia was utilized to minimize dependence on anesthetics and ensure stable, effective pain control. Pain levels were evaluated using NRS scores, revealing a significant reduction in postoperative pain in the experimental group compared to the observed group. These findings underscore the importance of effective perioperative pain management in alleviating postoperative pain and enhancing recovery outcomes.

Early mobilization is crucial for enhancing systemic blood circulation. Studies indicate that initiating ambulation on the first postoperative day significantly improves recovery and facilitates earlier discharge compared to delaying mobilization until the third day[27]. These findings underscore the importance of early mobilization protocols in accelerating rehabilitation and improving patient outcomes. In our study, the experimental group demonstrated better ADL scores, fewer complications, earlier postoperative mobilization, faster extubation times, and shorter LOS compared to the observed group, consistent with previous research. As a patient-centered perioperative model, the ERAS protocol provides clinical benefits such as reducing surgical stress, promoting faster recovery, lowering LOS and hospitalization costs, and increasing patient satisfaction[35–37]. These results reaffirm the critical role of early mobilization in active rehabilitation for glioma surgery patients. The early mobilization protocol involves nursing interventions from the day of surgery through the first seven postoperative days. Although these steps may increase clinical nurses' workload, their efforts are vital for optimizing patient recovery and well-being.

Gliomas, characterized by their invasive nature, present significant challenges for complete surgical resection, increasing the risk of recurrence and adversely impacting patient survival. According to the latest neurological cancer guidelines, maximal safe resection combined with adjuvant chemoradiation can improve both progression-free survival and overall survival in glioma patients[38]. Several factors influence glioma patient survival, including surgery, adjuvant therapy, patient age, Karnofsky performance status (KPS) score, tumor grade, and molecular characteristics. While histological type correlates with WHO grade, it is not an independent prognostic factor[39]. In our study, no between-group differences were observed in age or WHO classification between the two groups. Despite the experimental group undergoing an early mobilization protocol to enhance recovery, no significant differences in long-term prognosis were identified.

The disease and treatment side effects often result in functional impairments and limitations in daily activities for glioma patients. Effective rehabilitation interventions are crucial for significantly enhancing their functional outcomes. Rehabilitation strategies for glioma patients are generally divided into cognitive rehabilitation and exercise rehabilitation[38].

Cognitive rehabilitation for glioma patients frequently incorporates programs like the tablet-based ReMind, which integrates psychoeducation, strategy training, and attention retraining games[39]. Home-based iPad programs also provide a convenient platform for cognitive rehabilitation[40]. Another notable example is the computer-based CogMed Working Memory Training (CWMT), demonstrated to enhance working memory in individuals with cognitive deficits[41].

In contrast, evidence on the effectiveness of exercise-based rehabilitation programs specifically designed for glioma patients remains limited[42]. However, studies have investigated the feasibility and benefits of resistance and aerobic training across various settings, including outpatient clinics, hospitals, homes, and virtual reality environments[4]. While research on virtual reality applications for brain tumor patients is still scarce, meta-analyses indicate that physiotherapy incorporating augmented reality can enhance balance, gait, upper limb function, muscle mass, physical performance, and exercise self-efficacy, while reducing fall risk in other patient populations[43–45].

The most effective rehabilitation interventions for brain tumor patients generally include personalized exercise plans, individualized training, and adherence-enhancing strategies, such as close monitoring of training data and regular physiotherapist guidance[46]. Both cognitive and motor rehabilitation programs are crucial for supporting post-discharge recovery and represent a promising area for future research.

Univariate analysis revealed no statistically significant difference in education level between the two groups (Table 1), and linear regression analysis confirmed that education level did not significantly influence the study's primary outcomes (Table S2). We hypothesize that this lack of effect may stem from the short duration of the early mobilization protocol, which was primarily nurse-supervised, leaving insufficient time for education level to impact results. However, with a longer intervention, education level could play a more pronounced role in shaping patients' understanding and engagement with health information, potentially influencing their participation in postoperative early mobilization. Patients with higher education levels may better comprehend the importance of early mobilization and adhere more effectively to recovery protocols, benefiting from improved self-care skills and confidence. Conversely, those with lower education levels may require additional support, such as simplified educational materials, to ensure proper understanding and implementation of mobilization strategies.

The use of early mobilization in neurosurgery for glioma patients remains in its early stages of exploration. While ERAS principles have been safely applied to various neurosurgical procedures, early mobilization is still an underexplored aspect of ERAS for postoperative rehabilitation in glioma patients[47]. Nonetheless, early mobilization protocols have been established as safe, simple, and effective[48,49].

Limitations
Firstly, to ensure patient safety, patients under 18 years, those with other malignant tumors or distant metastases, significant preoperative organ dysfunction, muscle strength < Grade 4, or severe heart, brain, or liver injuries were excluded from the study. Secondly, one of the limitations of this study is the potential presence of the Hawthorne effect. This refers to the phenomenon where individuals alter their behavior because they are aware of being observed. In our study, patients may have demonstrated better recovery outcomes due to the awareness that they were participating in a research study and receiving additional attention and care. This effect could introduce bias into the results, requiring careful interpretation of the findings. Although efforts were made to maintain standardized clinical conditions, we cannot entirely eliminate the influence of the Hawthorne effect. Future research should explore strategies to mitigate this bias and improve the reliability and validity of study outcomes. Finally, while our research demonstrates the effectiveness and safety of the early mobilization protocol, variations in medical environments, healthcare systems, and socioeconomic factors necessitate further investigation. A multicenter study with a larger sample size is needed to assess the generalizability of our findings across diverse healthcare settings and patient populations.

Future directions
In recent years, there has been a growing interest in the implementation of early mobilization programs for glioma patients, with promising outcomes. Moving forward, it is crucial to explore patient-reported outcomes and health-related quality of life (HRQoL) metrics to better understand the full impact of these programs. Furthermore, there is a need to investigate whether compliance with early mobilization protocols varies by age and how this may correlate with different patient outcomes. Such research will provide valuable insights into optimizing early mobilization strategies, ultimately enhancing the well-being and recovery of glioma patients.

Conclusions
In conclusion, the early mobilization protocol has proven to be safe, reliable, and cost-effective, making it a valuable addition to clinical practice. It effectively decreased catheter duration (UC, GT, and CVC), as well as shortening LOS and lowering hospitalization costs. Additionally, the protocol reduces the incidence of complications, improved functional independence, alleviates postoperative pain, and promotes earlier ambulation. However, it showed no significant improvement in 3-year overall survival on long-term prognosis.

Data availability
All the data supporting the conclusions of this article are included in the article and its supplementary information files.

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Author contributions

Xiaohang Chen and Lei Wan were responsible for study conception and design and aims. Xiaohang Chen and Lei Wan were responsible for data analysis and interpretation. Bei Wang was responsible for verifying the overall replication of the results and other research outputs. Xiaohang Chen and Lei Wan were responsible for explicitly writing the initial draft. Xiaohang Chen and Lei Wan were responsible for critical review, commentary, and revision, including the pre- and postpublication stages. Bei Wang were responsible for supervision, oversight and leadership responsibility for the planning and execution of the research activity, including mentorship external to the core team.

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval

This study was complied with the ethical principles the Declaration of Helsinki (2000) of the World Medical Association. The research protocol was ethical clearance by the Institutional Review Board of Zhongnan Hospital of Wuhan University (Approval No. 2019258). Written informed consent was obtained from all participants prior to enrollment.

Additional information

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