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The influence of enhanced recovery after surgery protocol adherence in patients undergoing elective neuro-oncological craniotomies

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ABSTRACT

Objectives: Enhanced recovery after surgery (ERAS) protocols have reduced the length of hospital stay (LOS) and healthcare costs without increasing adverse outcomes. We describe the impact of adherence to an ERAS protocol for elective craniotomy among neuro-oncology patients at a single institution.
Methods: This retrospective study enrolled adult patients who underwent elective craniotomy and the ERAS protocol at our institute between January 2020 and April 2021. The patients were divided into high- and low-adherence groups depending on their adherence to $\geq$9 or <9 of the 16 items, respectively. Inferential statistics were used to compare group outcomes, and multivariable logistic regression analysis was used to examine factors related to delayed discharge (LOS>7 days).
Results: Among the 100 patients assessed, median adherence was 8 items (range, 4–16), and 55 and 45 patients were classified into the high- and low-adherence groups, respectively. Age, sex, comorbidities, brain pathology, and operative profiles were comparable at baseline. The high-adherence group showed significantly better outcomes, including shorter median LOS (8 days vs. 11 days; p = 0.002) and lower median hospital costs (131,657.5 baht vs. 152,974 baht; p = 0.005). The groups showed no differences in 30-day postoperative complications or Karnofsky performance status. In the multivariable analysis, high adherence to the ERAS protocol (>50%) was the only significant factor preventing delayed discharge (OR = 0.28; 95% CI = 0.10 to 0.78; p = 0.04).
Conclusions: High adherence to ERAS protocols showed a strong association with short hospital stays and cost reductions. Our ERAS protocol was feasible and safe for patients undergoing elective craniotomy for brain tumors.

1. Introduction

Enhanced recovery after surgery (ERAS) is a perioperative protocol that uses various evidence-based treatments or care to control surgery-related stress and increase the rate of functional capacity recovery.[1] The protocol concept was proposed by Professor Henrik Kehlet and has continued to evolve, primarily in Europe.[2,3] Professor Olle Ljungqvist and Professor Ken Fearon established the ERAS Society in 2001.[1] Subsequently, an ERAS guideline was created to care for patients who underwent colonic surgery,[4] and the program began to be implemented worldwide. More than 20 related ERAS guidelines covering major surgery in many subspecialties such as gynecologic,[5] urologic,[6] thoracic,[7] head and neck,[8] and orthopedic surgery, including surgery for degenerative spine diseases,[9] have evolved as a result of this process.

The results of previous studies showed that ERAS is helpful, in principle, because patients show a rapid rate of recovery, which has been found to reduce the response to inflammatory processes through reductions in the systemic inflammatory response,[10] insulin resistance,[11] and nitrogen breakdown.[12] In addition, ERAS showed a clear benefit in the clinical context by resulting in reduced hospital stay, hospital costs, and postoperative complications and mortality rates.[13,14,15]

The adoption of ERAS for neuro-oncologic surgery is currently in its

Abbreviations: ATB, Antibiotic; BMI, Body mass index; DVT, Deep vein thrombosis; ERAS, Enhanved recovery after surgery; ICU, Intensive care unit; IQR, Interquartile range; KPS, Karnofsky performance status; LOS, Length of hospital stay; RCT, Randomized controlled trial.

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Table 1
Enhanced Recovery After Surgery protocol in the study.

Items	Definition of protocol adherence (each item)
Preoperative bundle	
Preoperative counseling and patient's education	1. Comprehensive preoperative evaluation and counseling conducted by neurosurgeon. 2. Abstinent from smoking and alcohol consumption at least four weeks. 3. Nutritional assessment and dietary advise. 4. Deep breathing exercise
Oral preparation	Apply mouthwash with chlorhexidine solution after admission till discharge.
Scalp preparation	Washing hair with chlorhexidine scrub during admission and postoperative day 2^{nd}.
Short NPO time	Fasting solid food for 8 h before surgery.
Preoperative carbohydrate loading	Oral intake clear carbohydrate drink, volume 150 mL, in the morning of operational day (2–4 h preoperative).
Intraoperative bundle	
Multimodal analgesia	1. Acetaminophen 500–1000 mg per oral in the morning of operational day (2–4 h preoperative). 2. The scalp block use bupivacaine injection for ipsilateral side in unilateral scalp incision or both sides for bicoronal incision. 3. Local anesthesia uses 1% Xylocaine with adrenaline 1:200,000 infiltrated along subcutaneous scalp incision.
PONV risk assessment and prophylaxis	1. Risk assessment with institute's protocol which use simplified risk factor from Apfel's score (female, smoking, history of PONV/motion sickness, intraoperative opioid use) - if score 2–3, use two antiemetic prophylaxis (Dexamethasone and ondansetron IV). - if score = 4, use three antiemetic prophylaxis. (Dexamethasone, ondansetron, and dimenhydrinate IV)
Antibiotic prophylaxis	Cefazolin administration within 1 h prior to scalp incision.
Minimize scalp shaving	Hair shaving about 2 cm over the incision line.
Absorbable scalp suture	Subcutaneous and skin are sutured by absorbable suture.
No drainage tube placement	Do not place the drainage tube.
Postoperative bundle	
Early water intake	Water intake within 8 h after extubation.
Early solid diet	Normal solid diet within 24 h after extubation.
Early urinary catheter removal	Early removal of the urinary catheter within 24 h after surgery.
Early rehabilitation program	Start bed exercises and/or ambulation program within 24 h after surgery
DVT screening and prophylaxis	1. VTE risk assessment with Autar DVT Risk Assessment Scale. 2. Ultrasound leg vein for screening DVT during admission (once a week). 3. Used intermittent pneumatic calf compression prophylaxis.

DVT = deep vein thrombosis; IV = intravenous; NPO = nothing per oral; PONV = postoperative nausea vomiting; VTE = venous thromboembolism.

Table 2
Patients characteristics.

Parameter	Total (*n* = 100)	Low adherence (*n* = 45)	High adherence (*n* = 55)	*p*-value
Female	69	32 (71%)	37 (67%)	0.828
Median of age in years (range)	53 (15,86)	51 (17,86)	55 (15,78)	0.440
Median BMI in kg/m^2 (range)	24.1 (17.6,39.1)	24.4 (17.6, 39.1)	23.8 (18.0, 34.2)	0.457
Median preoperative KPS (range)	80 (40, 100)	80 (40, 100)	80 (60, 100)	0.730
ASA classification				
I, no. (%)	27	11 (24%)	16 (29%)	0.656
II, no. (%)	73	34 (76%)	39 (71%)	
Concomitant diseases, no. (%)				
Hypertension	31	13 (29%)	18 (33%)	0.828
Dyslipidemia	30	16 (36%)	14 (26%)	0.284
Smoker	22	9 (20%)	13 (24%)	0.809
Diabetes	16	5 (11%)	11 (20%)	0.280
Cancer	9	4 (9%)	5 (9%)	1.000
Recurrent brain tumor	8	4 (9%)	4 (7%)	1.000
Pathology				
Intra-axial tumor	43	19 (42%)	24 (44%)	
Metastasis	14	7 (15.6)	7 (12.7)	0.776
Low grade astrocytoma	5	1 (2%)	4 (7%)	0.375
Anaplastic astrocytoma	13	5 (11%)	8 (15%)	0.768
Glioblastoma	11	6 (13%)	5 (9%)	0.536
Extra-axial tumor	57	26 (58%)	31 (56%)	1.000
Meningioma	50	24 (53%)	26 (47%)	0.688
CPA tumor	4	1 (2%)	3 (6%)	0.625
Craniopharyngioma	2	0	2 (4%)	0.500
Germinoma	1	1 (2%)	0	0.450
Tumor location				
Supratentorial	95	44 (98%)	51 (93%)	0.375
Infratentorial	5	1 (2%)	4 (7%)	

ASA = The American Society Anesthesiologist; BMI = body mass index; KPS = Karnofsky Performance Status scale.

initial stages. The first randomized controlled trial (RCT) comparing ERAS therapy with traditional treatment in patients undergoing elective craniotomy surgery to treat brain tumors was conducted in 2018. It showed that the implementation of ERAS was as safe and clinically beneficial as using ERAS in another subspecialty.[16] Subsequent studies evaluated the usefulness of ERAS in the neurosurgical field.[1718,19] However, these studies showed substantial variety in patient characteristics and study protocols.[20,21] As a result, the conclusions obtained from the data for elective craniotomy data are quite limited at present. Furthermore, none of the studies on patients undergoing elective craniotomy surgery have discussed the importance of evaluating adherence to the ERAS protocol.[22–24]

This study was conducted at Songklanagarind Hospital, a university hospital and neurologic disease referral center in southern Thailand. In 1984, the hospital established a unit for neurological surgery. The ERAS protocol was implemented in this unit in 2019, and the criteria were periodically updated in accordance with the released evidence base. Therefore, this study also reflects the institutions' ERAS protocol audits for assessing the sustainability of protocol adherence. In addition, this study evaluated the influence of ERAS protocol adherence in patients undergoing elective brain tumor surgery at our institute.

2. Patients and methods

Patients with brain tumors who underwent an elective craniotomy at Songklanagarind Hospital between January 2020 and April 2021 were included in this study. We included all patients aged ≥15 years who presented with single brain lesions and were managed with the ERAS protocol in the study. Patients with profound weakness, dependent status, uncontrolled cardiovascular diseases, severe metabolic diseases, sepsis, a history of neuropsychiatric disease, severe cognitive impairment, or pregnancy were excluded.

The patients' characteristics were reported, including their age, sex, body mass index (BMI), preoperative Karnofsky performance status (KPS), ASA classification, concomitant diseases, type of brain tumor according to the WHO 2016 classification, and location. In addition, anesthetic data were presented in terms of operative times, estimated blood loss, volume of fluid, and blood transfusion.

3. Enhanced recovery after elective craniotomy protocol and outcome

Our protocol consisted of 16 items, including pre-, intra-, and postoperative bundles, based on the recommendations of previous studies.[16] Patients were admitted to the intensive care unit for at least one night after the operation and underwent a CT scan with or without contrast on

Table 3
Operative data (n = 100).

Parameter	Total (n = 100)	Low adherence (n = 45)	High adherence (n = 55)	p value
Median operative time in minutes (min, 1stQ, 3rdQ, max)	312.5 (125,245,425,885)	320 (125,255,420,830)	305 (150,240,435,885)	0.897
Median of estimate blood loss in mL (min, 1stQ, 3rdQ, max)	400 (50,200,800,7500)	500 (50,200,1000,7500)	400 (50,200,700,6800)	0.760
Median intraoperative RBC transfusion in mL, n = 31 (min, 1stQ, 3rdQ, max)	561 (206,271,1132,3199)	701 (247,402,1063.5,2760)	519 (206,228,1157,3199)	0.129
Median intraoperative FFP transfusion in mL, n = 25 (min, 1stQ, 3rdQ, max)	607 (359,522,1093,2600)	583 (359,514,1106,2600)	616.5 (471,558,1093,2567)	0.453
Median intraoperative crystalloid in mL (min, 1stQ, 3rdQ, max)	2200 (300,1625,3000,6250)	2300 (300,1700,3000,6250)	2200 (755,1600,3000,5880)	0.570
Median intraoperative colloid in mL, n = 26 (min, 1stQ, 3rdQ, max)	500 (150,500,1000,1400)	500 (300,500,900,1400)	500 (150,500,1000,1000)	0.908
Median intraoperative urine output in mL (min, 1stQ, 3rdQ, max)	957.5 75,545,1360,4970	930 75,590,1360,4970	985 125,500,1420,4570	0.955

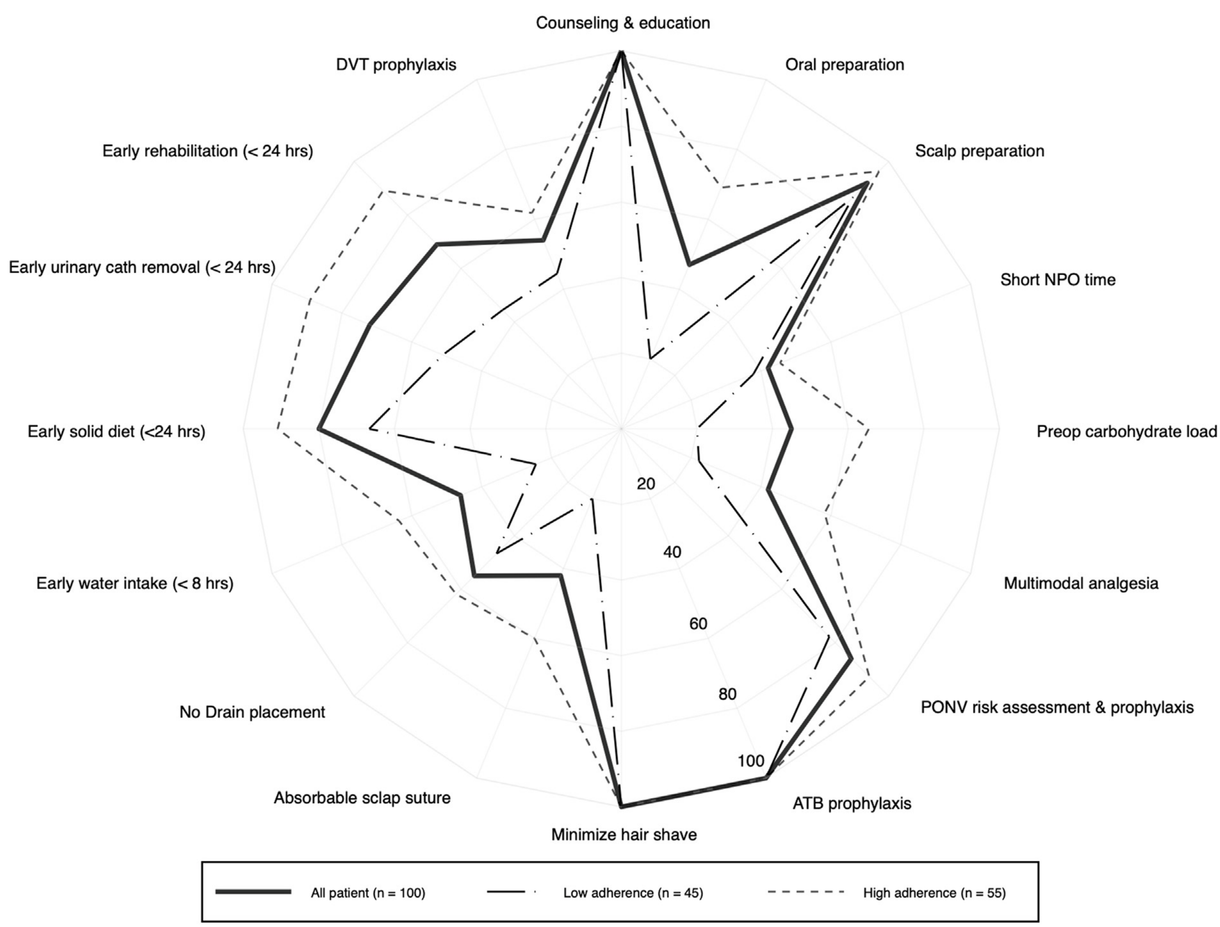

Fig. 1. Percentage of adherence to each ERAS protocol item among all patients (solid line), those with low adherence (solid and dashed line), and those with high adherence (dashed line).

the first postoperative day. Eligible patients were expected to receive all 16 items, and the protocol details are listed in Table 1.

Adherence to the protocol was defined as the number of items fulfilled by each patient. Patients were divided into two groups according to their adherence to the protocol items.[25] The first group, called the "high-adherence group," consisted of patients who fulfilled at least nine protocol items (more than 50% adherence). Thus, patients who fulfilled fewer than nine protocol items were classified into the "low-adherence group."

Length of hospital stay (LOS), hospitalization cost, reoperation rate, and requirement for readmission within 30 days postoperative were the primary outcomes. The secondary outcomes included postoperative complications within 30 days, including death, intracranial complications (surgical site infection, seizure, intracranial hemorrhage), and systemic complications (respiratory or cardiovascular events, urinary tract infection, pneumonia, venous thromboembolism, and postoperative nausea and vomiting [PONV]).

4. Statistical analysis

Continuous variables are presented as medians and interquartile ranges (IQR), whereas categorical variables are presented as numbers and proportions. Appropriate non-parametric tests were used to analyze discrete or non-normal continuous data. Univariate logistic regression

Table 4
The adherence to ERAS program.

Items	Total (n = 100)	Low adherence (n = 45)	High adherence (n = 55)	p value
Preoperative counseling and patient's education	100	45 (100)	55 (100)	
Oral preparation	47	9 (20.0)	38 (69.1)	<0.001
Scalp preparation	92	39 (86.7)	53 (96.4)	0.135
Short NPO time	42	17 (37.8)	25 (45.5)	0.542
Preoperative carbohydrate loading	45	9 (20.0)	36 (65.5)	<0.001
Multimodal analgesia	42	10 (22.2)	32 (58.2)	<0.001
PONV risk assessment and prophylaxis	86	35 (77.8)	51 (92.7)	0.043
Antibiotic prophylaxis	100	45 (100)	55 (100)	
Minimize scalp shaving	100	45 (100)	55 (100)	
Absorbable scalp suture	42	9 (20.0)	33 (60.0)	<0.001
No drainage tube placement	55	21 (46.7)	34 (61.8)	0.159
Early water intake	46	11 (24.4)	35 (63.6)	<0.001
Early solid diet	80	30 (66.7)	50 (90.9)	0.005
Early urinary catheter removal	72	23 (51.1)	49 (89.1)	<0.001
Early rehabilitation program	69	20 (44.4)	49 (89.1)	<0.001
DVT screening and prophylaxis	54	20 (44.4)	34 (61.8)	0.107

Table 5
Primary outcome.

Parameter	Total (n = 100)	Low adherence (n = 45)	High adherence (n = 55)	p-value
Median of length of hospital stay				
Admission to discharge in days (min, 1stQ, 3rdQ, max)	9 3,7,12,[26]	11 4,9,15,[26]	8 3,6,12,18	0.002
ICU stays in hour (min, 1stQ, 3rdQ, max)	20 (0,9,55,99)	21 (0,18,23,99)	20 (7,15,25,47)	0.075
Postop to discharge in days (min, 1stQ, 3rdQ, max)	7 3,5,10,[27]	9 3,6,12,[27]	7 3,4,7,16	0.004
Readmission rate within 30 days after surgery	0	0	0	
Reoperation rate within 30 days after surgery	0	0	0	
Median of hospital cost in baht (min, 1stQ, 3rdQ, max)	138,287 (84,178, 118,518, 178,995, 349,507)	152,974 (103,532, 126,605, 200,853, 349,507)	131657.5 (84,178, 113,661, 163,326, 241,779)	0.005

ICU = Intensive care unit.

was used to identify variables independently associated with the primary and secondary outcomes. The variables with p values < 0.20 in the univariable analysis were further analyzed using the stepwise backward method in multivariable logistic regression. All statistical tests were two-sided, and significance was defined as $p < 0.05$. Data analysis was performed using STATA® version 17 (StataCorp LLC., Texas, USA, 1985–2021.)

5. Results

The total cohort included 100 consecutive patients (31 men and 69 women) with a median age of 53 years (range, 15–86 years) and a median BMI of 24.1 kg/m^2 (range, 17.6–39.1 kg/m^2). The two primary brain tumors were meningiomas (50%) and astrocytic tumors (43%), and most of the tumors were located in the supratentorial region (95%). We classified 55 and 45 patients in the high- and low-adherence groups, respectively. The differences in patient characteristics between these two groups were not statistically significant. The patient details are listed in Table 2.

Table 6
Secondary outcome.

Secondary outcome	Total (n = 100)	Low adherence (n = 45)	High adherence (n = 55)	p-value
Surgical complication				
Death	1	1 (2%)	0	0.450
Surgical site infection	0	0	0	
Intracranial infection	0	0	0	
Epilepsy	11	3 (7%)	8 (15%)	0.336
Intracranial hemorrhage (conservative treatment)	36	16 (36%)	20 (36%)	1.000
Intracranial hemorrhage (surgical treatment)	0	0	0	
Non-surgical complication				
Respiratory	0	0	0	
Cardiovascular	1	0	1 (2%)	1.000
UTI	2	1 (2%)	1 (2%)	1.000
Pneumonia	2	2 (4%)	0	0.200
DVT	1	0	1 (2%)	1.000
PONV	23	9 (20%)	14 (26%)	0.635
Hyperglycemia 48 h	28	14 (31%)	14 (26%)	0.655
Functional recovery				
Median of discharge KPS (min, 1stQ, 3rdQ, max)	80 (0,80,90,100)	80 (0,80,90,100)	80 (60,80,90,100)	0.696
Median of 30-day postop KPS (min, 1stQ, 3rdQ, max)	100 (0,90,100,100)	100 (0,90,100,100)	100 (60,90,100,100)	0.792

KPS = Karnofsky Performance Status scale.

Elective craniotomy was performed in all the patients with supratentorial lesions (95%). The remaining five patients with infratentorial tumors were treated with suboccipital craniectomy. We used minimally invasive approaches, such as limited craniotomy or keyhole craniotomy, to operate on all patients. The median operating time was 312.5 min (range, 125–885 min), and the median estimated blood loss was 400 mL (range, 50–7500 mL). Colloid fluids were used in 26 patients to optimize volume status. Only 31% of the patients required red blood cell transfusion, with a median red blood cell transfusion volume of 561 mL (206–3199 mL). Intraoperative data were not significantly different between the high- and low-adherence groups (Table 3).

The patients adhered to a median number of 8 (range, 4–16) ERAS items (Fig. 1 and Table 4). The compliance rates for half of the items were more than 50%. However, the rates for the other eight items were below 50%. In comparisons between the patient groups, statistically significant differences in ERAS protocol adherence were found for nine items, namely, oral preparation, preoperative carbohydrate loading, multimodal analgesia, PONV management, use of absorbable sutures, early water and solid diet intake, early urinary catheter removal, and early start of the rehabilitation program.

The median LOS was nine days (range, 3–27 days). Patients with high adherence had a lower median overall LOS (8 days vs. 11 days, $p = 0.002$) and postoperative LOS (7 days vs. 9 days, $p = 0.004$). The length of intensive care unit (ICU) stay did not differ between the high- and low-adherence groups (20 h vs. 21 h, $p = 0.075$). However, the median

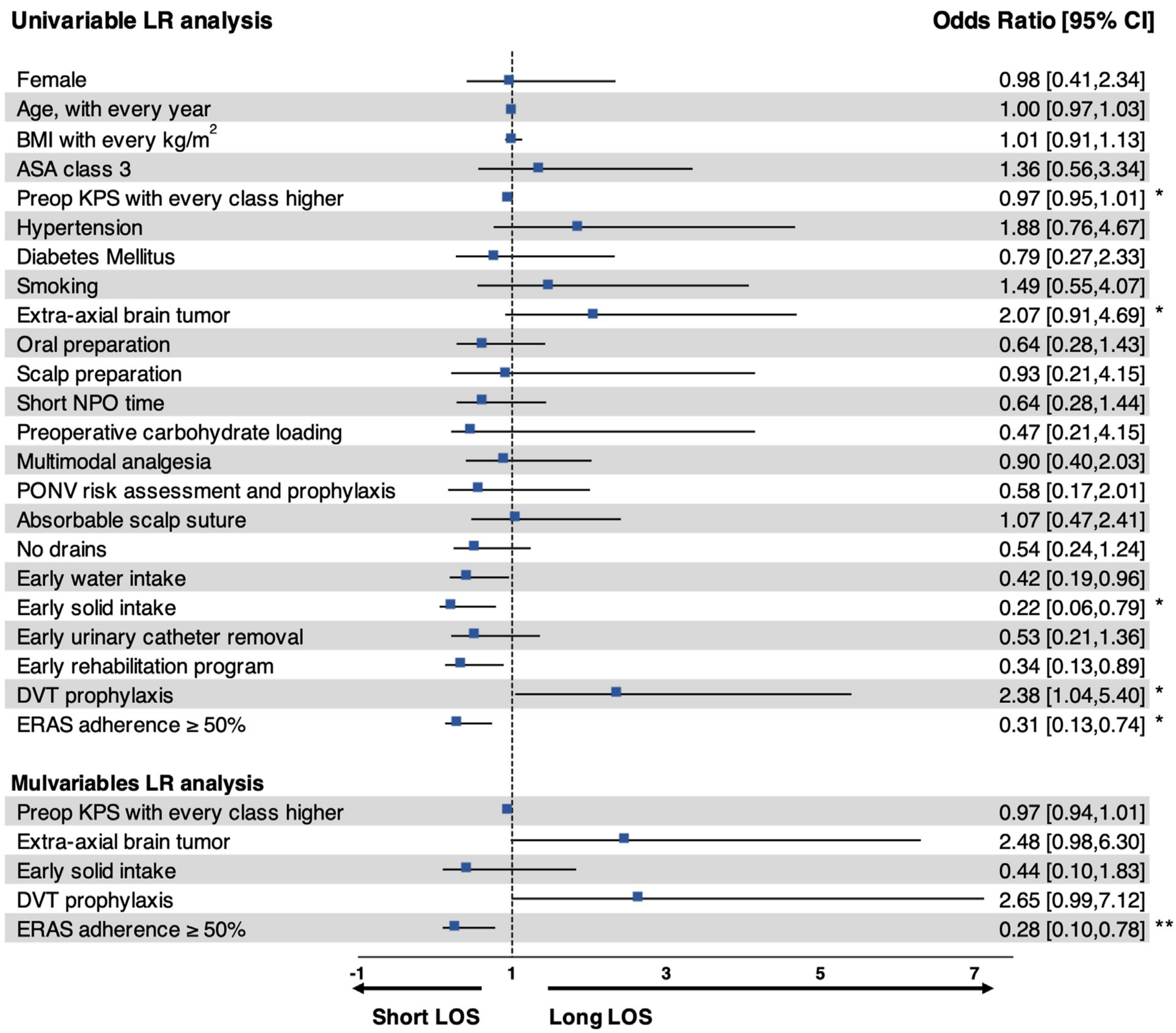

Fig. 2. The Forest plot illustrates the odds ratio derived from univariable and multivariable logistic regression analysis. In the univariable analysis, factors with a *p*-value 0.20 were denoted by a single asterisk (*). The double asterisk (**) indicated statistical significance in the multivariable analysis with a *p*-value <0.05.

hospital cost was lower in the high-adherence group (131657.5 baht vs. 152,974 baht, p = 0.005). The primary outcomes are presented in Table 5. Overall, the intracranial and systemic complication rates were 41% and 33%, respectively. The most common complication observed was intracranial hemorrhage along the tumor base (36%), which was detected through early postoperative CT scans. Follow-up clinical and CT scans were required, but no further surgical managemtn or reoperation was necessary. Another surgery-related complication within the 30 days postoperative periodwas the postoperative seizure, which was observed within 24 h postoperatively in 11 patients. The most frequent systemic complications were hyperglycemia (28%) and postoperative nausea, and PONV (23%) (Table 6). One patient with a glioblastoma multiforme died from a massive pulmonary embolism on postoperative day 7 while receiving early ambulation and showed no other complications from surgery. Most of the remaining patients achieved a 30-day favorable outcome with a KPS of 100 (60–100) after surgery. In addition, none of the patients required reoperation or readmission in our study.

6. Discussion

ERAS refers to the process of caring for patients undergoing major surgery using two essential strategies: the use of multiple methods (items) to promote patient recovery and the prescription of treatments that cover all processes that patients will receive, including preoperative, perioperative, and postoperative care.[1] Each ERAS item introduced in the protocol is based on evidence showing its usefulness in stimulating patient recovery after surgery. However, this evidence is often evaluated item-by-item rather than as a whole protocol.[22] As a result of this strategy, the authors hypothesize that patients treated with the same ERAS protocol but adhering to an unequal number of items may have different therapeutic outcomes. The study results confirmed the dose–response hypothesis,[25,26] with the patients who followed more than 50% of the ERAS items, known as high-adherence patients, showing a shorter length of hospitalization and fewer medical expenses than those with low adherence.

Although studies related to caring for patients undergoing brain tumor surgery have been conducted earlier, they used different terms, such as "Early discharge after surgery" [27], "Fast track recovery program" [28], and ambulatory care (outpatient craniotomy, same-day craniotomy, and day-surgery craniotomy).[29–31] Unfortunately, the previous literature was based on observational methods, and some studies did not cover the entire process of the ERAS protocol. Hagan et al conducted a systematic review in 2016[22] and found that some ERAS items were used in patients with brain tumors to stimulate recovery after surgery, with the items showing a high level of evidence, including deep vein thrombosis (DVT) prophylaxis, antibiotic prophylaxis, PONV prophylaxis, avoidance of hypothermia, and early mobilization. When evaluated with the GRADE recommendations, these items are classified as solid recommendations that should be included in the ERAS protocol.[32] Subsequently, Wang et al conducted an RCT in 2018 and introduced the first and complete ERAS protocol covering the entire process of surgical care (pre-, intra-, and postoperative bundles) for patients with brain tumor undergoing elective craniotomy surgery.[16] Their study compared patients receiving the ERAS protocol ($n = 70$) to those receiving traditional care ($n = 70$) and found that the benefits in the ERAS group included a reduced hospital stay (4 days vs. 7 days, $p < 0.0001$) and lower medical expenses (52,930 RMB vs. 64,316 RMB, $p = 0.001$). However, no statistically significant differences were found in the complication and mortality rates between the groups. The authors also reported the results of adopting the ERAS protocol in subsequent studies. They found that the ERAS protocol relieved postoperative pain,[33] increased patient satisfaction,[34] and improved health-related quality of life in patients with gliomas.[35]

The ERAS protocol has been introduced for patients with brain tumors, but there is no generally accepted standard protocol or guideline.[20,36] This is partly due to the limited data; therefore, further clinical studies are needed. Furthermore, studies on the importance of adherence to protocols have not yet been reported. To our knowledge, this is the first study to report such results and arrive at this preliminary conclusion. In our study, high adherence to the protocol significantly affected a short hospital stay (less than seven days) after multivariable analysis (Fig. 2).

Audits play an important role, especially in detailed and procedural analyses, because implementing new protocols is often problematic over time,[37–39] and these problems can encourage a return to traditional or familiar practices. For example, in this study, the ERAS items that showed good adherence were usually items that were already being practiced before starting the protocols, such as advising patients and providing antibiotic prophylaxis before scalp incision. Newer practice items, such as oral preparation, preoperative carbohydrate loading, and multimodal analgesia, such as scalp block, often have low practice rates. Therefore, when implementing the protocol, periodic audits by multidisciplinary teams to review patient and practitioner team data can facilitate assessments of the strengths and weaknesses of the protocols, resulting in better treatment outcomes.[40]

This study was subject to several limitations. Firstly, due to its retrospective nature, retrospective bias was unavoidable. This includes the lack of information on the indication for surgery in each patient, as well as specific discharge criteria. Second, the number of cases was small, and the results were based on data from a single institution. Third, no comparisons were performed with patients that did not undergo the ERAS protocol. Fourth, some familiar items of the ERAS protocol, such as pre-habilitation programs, and systematic monitoring of patients after discharge, were not included in this study. Fifth, some items, such as the effects of oral preparation and absorbable sutures, have never been directly studied. Lastly, in this early phase of protocol implementation, we used some items differently from their usage in the ERAS protocols reported in previous studies, such as limiting oral carbohydrate consumption 2 h before surgery to only 150 mL due to concerns about aspiration pneumonitis.

7. Conclusions

Our study demonstrated that high ERAS adherence was associated with favorable outcomes. In addition, patients with high adherence showed a decreased LOS and lower hospital costs. Therefore, a protocol audit after ERAS implementation may be needed to maintain the effectiveness of the protocol in patients undergoing brain tumor surgery.

Credit author statement

Anukoon Kaewborisutsakul: Conceptualization and method design, Data collection and preparation, Statistic analysis, Draft manuscript and final version approved. **Chanatthee Kitsiripant:** Conceptualization and method design, Draft manuscript and final version approved. **Sukanya Kaewsridam:** Data collection and preparation, Manuscript approved. **Wilairat Kankuan Kaewborisutsakul:** Statistic analysis, Draft manuscript and final version approved. **Chaitong Churuangsuk:** Conceptualization and method design, Manuscript approved.

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.

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References

1. Ljungqvist O, Scott M, Fearon KC. Enhanced recovery after surgery: a review. *JAMA Surg*. 2017;152:292–298. https://doi.org/10.1001/jamasurg.2016.4952.
2. Møiniche S, Dahl JB, Rosenberg J, Kehlet H. Colonic resection with early discharge after combined subarachnoid-epidural analgesia, preoperative glucocorticoids, and early postoperative mobilization and feeding in a pulmonary high-risk patient. *Reg Anesth*. 1994;19:352–356.
3. Bardram L, Funch-Jensen P, Jensen P, Crawford ME, Kehlet H. Recovery after laparoscopic colonic surgery with epidural analgesia, and early oral nutrition and mobilisation. *Lancet*. 1995;345:763–764. https://doi.org/10.1016/s0140-6736(95)90643-6.
4. Fearon KC, Ljungqvist O, Von Meyenfeldt M, et al. Enhanced Recovery after Surgery: a consensus review of clinical care for patients undergoing colonic resection. *Clin Nutr*. 2005;24:466–477. https://doi.org/10.1016/j.clnu.2005.02.002.
5. Nelson G, Bakkum-Gamez J, Kalogera E, et al. Guidelines for perioperative care in gynecologic/oncology: enhanced Recovery after Surgery (ERAS) Society recommendations-2019 update. *Int J Gynecol Cancer*. 2019;29:651–668. https://doi.org/10.1136/ijgc-2019-000356.
6. Cerantola Y, Valerio M, Persson B, et al. Guidelines for perioperative care after radical cystectomy for bladder cancer: enhanced Recovery after Surgery (ERAS®) society recommendations. *Clin Nutr*. 2013;32:879–887. https://doi.org/10.1016/j.clnu.2013.09.014.
7. Batchelor TJP, Rasburn NJ, Abdelnour-Berchtold E, et al. Guidelines for enhanced recovery after lung surgery: recommendations of the enhanced recovery after surgery (ERAS®) society and the European society of thoracic surgeons (ESTS). *Eur J Cardio Thorac Surg*. 2019;55:91–115. https://doi.org/10.1093/ejcts/ezy301.
8. Dort JC, Farwell DG, Findlay M, et al. Optimal perioperative care in major head and neck cancer surgery with free flap reconstruction: a consensus review and recommendations from the Enhanced Recovery after Surgery Society. *JAMA Otolaryngol Head Neck Surg*. 2017;143:292–303. https://doi.org/10.1001/jamaoto.2016.2981.
9. Debono B, Wainwright TW, Wang MY, et al. Consensus statement for perioperative care in lumbar spinal fusion: enhanced Recovery after Surgery (ERAS®) Society recommendations. *Spine J*. 2021;21:729–752. https://doi.org/10.1016/j.spinee.2021.01.001.
10. Peng J, Dong R, Jiao J, et al. Enhanced Recovery after Surgery impact on the systemic inflammatory response of patients following gynecological oncology surgery: a prospective randomized study. *Cancer Manag Res*. 2021;13:4383–4392. https://doi.org/10.2147/CMAR.S294718.
11. Noba L, Wakefield A. Are carbohydrate drinks more effective than preoperative fasting: a systematic review of randomised controlled trials. *J Clin Nurs*. 2019;28:3096–3116. https://doi.org/10.1111/jocn.14919.
12. Liu B, Wang Y, Liu S, et al. A randomized controlled study of preoperative oral carbohydrate loading versus fasting in patients undergoing elective craniotomy. *Clin Nutr*. 2019;38:2106–2112. https://doi.org/10.1016/j.clnu.2018.11.008.
13. Lohsiriwat V, Lertbannaphong S, Polakla B, Riansuwan W. Implementation of enhanced recovery after surgery and its increasing compliance improved 5-year overall survival in resectable stage III colorectal cancer. *Updates Surg*. 2021;73:2169–2179. https://doi.org/10.1007/s13304-021-01004-8.
14. Zaed I, Bossi B, Ganau M, Tinterri B, Giordano M, Chibbaro S. Current state of benefits of Enhanced Recovery after Surgery (ERAS) in spinal surgeries: a systematic review of the literature. *Neurochirurgie*. 2022;68:61–68. https://doi.org/10.1016/j.neuchi.2021.04.007.
15. Dietz N, Sharma M, Adams S, et al. Enhanced Recovery after Surgery (ERAS) for spine surgery: a systematic review. *World Neurosurg*. 2019;130:415–426. https://doi.org/10.1016/j.wneu.2019.06.181.
16. Wang Y, Liu B, Zhao T, et al. Safety and efficacy of a novel neurosurgical enhanced recovery after surgery protocol for elective craniotomy: a prospective randomized controlled trial. *J Neurosurg*. 2019;130:1680–1691. https://doi.org/10.3171/2018.1.JNS171552.

17. Wang L, Cai H, Wang Y, et al. Enhanced recovery after elective craniotomy: a randomized controlled trial. *J Clin Anesth*. 2022;76, 110575. https://doi.org/10.1016/j.jclinane.2021.110575.
18. Elayat A, Jena SS, Nayak S, Sahu RN, Tripathy S. Enhanced recovery after surgery - ERAS in elective craniotomies-a non-randomized controlled trial. *BMC Neurol*. 2021;21:127. https://doi.org/10.1186/s12883-021-02150-7.
19. Neville IS, Ureña FM, Quadros DG, et al. Safety and costs analysis of early hospital discharge after brain tumour surgery: a pilot study. *BMC Surg*. 2020;20:105. https://doi.org/10.1186/s12893-020-00767-y.
20. Stumpo V, Staartjes VE, Quddusi A, et al. Enhanced Recovery after Surgery strategies for elective craniotomy: a systematic review. *J Neurosurg*. 2021;135:1857–1881. https://doi.org/10.3171/2020.10.JNS203160.
21. Peters EJ, Robinson M, Serletis D. Systematic review of Enhanced Recovery after Surgery in patients undergoing cranial surgery. *World Neurosurg*. 2021;158:279. https://doi.org/10.1016/j.wneu.2021.10.176, 89.e1.
22. Hagan KB, Bhavsar S, Raza SM, et al. Enhanced recovery after surgery for oncological craniotomies. *J Clin Neurosci*. 2016;24:10–16. https://doi.org/10.1016/j.jocn.2015.08.013.
23. Johnson A, Rice AN, Titch JF, Gupta DK. Identifying components necessary for an enhanced recovery after surgery pathway for elective intracranial surgery: an improvement project using the Quality of Recovery-15 score. *World Neurosurg*. 2019;130:e423–e430. https://doi.org/10.1016/j.wneu.2019.06.108.
24. Greisman JD, Olmsted ZT, Crorkin PJ, et al. Enhanced Recovery after Surgery (ERAS) for cranial tumor resection: a review. *World Neurosurg*. 2022;163:104. https://doi.org/10.1016/j.wneu.2022.03.118, 22.e2.
25. Gustafsson UO, Hausel J, Thorell A, et al. Adherence to the enhanced recovery after surgery protocol and outcomes after colorectal cancer surgery. *Arch Surg*. 2011;146:571–577. https://doi.org/10.1001/archsurg.2010.309.
26. Sughrue ME, Bonney PA, Choi L, Teo C. Early discharge after surgery for intra-axial brain tumors. *World Neurosurg*. 2015;84:505–510. https://doi.org/10.1016/j.wneu.2015.04.019.
27. The impact of enhanced recovery protocol compliance on elective colorectal cancer resection: results from an international registry. *Ann Surg*. 2015;261:1153–1159. https://doi.org/10.1097/SLA.0000000000001029.
28. Ma R, Livermore LJ, Plaha P. Fast track recovery program after endoscopic and awake intraparenchymal brain tumor surgery. *World Neurosurg*. 2016;93:246–252. https://doi.org/10.1016/j.wneu.2016.06.015.
29. Purzner T, Purzner J, Massicotte EM, Bernstein M. Outpatient brain tumor surgery and spinal decompression: a prospective study of 1003 patients. *Neurosurgery*. 2011;69:119–126. https://doi.org/10.1227/NEU.0b013e318215a270. ; discussion 126-7.
30. Goettel N, Chui J, Venkatraghavan L, Tymianski M, Manninen PH. Day surgery craniotomy for unruptured cerebral aneurysms: a single center experience. *J Neurosurg Anesthesiol*. 2014;26:60–64. https://doi.org/10.1097/ANA.0b013e3182991d8b.
31. Venkatraghavan L, Bharadwaj S, Au K, Bernstein M, Manninen P. Same-day discharge after craniotomy for supratentorial tumour surgery: a retrospective observational single-centre study. *Can J Anaesth*. 2016;63:1245–1257. https://doi.org/10.1007/s12630-016-0717-8.
32. Guyatt G, Oxman AD, Akl EA, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol*. 2011;64:383–394. https://doi.org/10.1016/j.jclinepi.2010.04.026.
33. Qu L, Liu B, Zhang H, et al. Management of postoperative pain after elective craniotomy: a prospective randomized controlled trial of a neurosurgical Enhanced Recovery after Surgery (ERAS) program. *Int J Med Sci*. 2020;17:1541–1549. https://doi.org/10.7150/ijms.46403.
34. Liu B, Liu S, Wang Y, et al. Neurosurgical Enhanced Recovery After Surgery (ERAS) programme for elective craniotomies: are patients satisfied with their experiences? A quantitative and qualitative analysis. *BMJ Open*. 2019;9, e028706. https://doi.org/10.1136/bmjopen-2018-028706.
35. Liu B, Liu S, Wang Y, et al. Impact of neurosurgical Enhanced Recovery after Surgery (ERAS) program on health-related quality of life in glioma patients: a secondary analysis of a randomized controlled trial. *J Neuro Oncol*. 2020;148:555–567. https://doi.org/10.1007/s11060-020-03548-y.
36. Kapoor I, Mahajan C, Prabhakar H. Enhanced Recovery after Surgery (ERAS) for patients undergoing craniotomy: a systematic review. *J Neurosurg Anesthesiol*. 2021;34:437–438. https://doi.org/10.1097/ANA.0000000000000764.
37. Choi BY, Bae JH, Lee CS, Han SR, Lee YS, Lee IK. Implementation and improvement of Enhanced Recovery after Surgery protocols for colorectal cancer surgery. *Ann Surg Treat Res*. 2022;102:223–233. https://doi.org/10.4174/astr.2022.102.4.223.
38. Ripollés-Melchor J, Sánchez-Santos R, Abad-Motos A, et al. Higher adherence to ERAS Society® recommendations is associated with shorter hospital stay without an increase in postoperative complications or readmissions in bariatric surgery: the Association between Use of Enhanced Recovery after Surgery Protocols and Postoperative Complications after Bariatric Surgery (POWER 3) multicenter observational study. *Obes Surg*. 2022;32:1289–1299. https://doi.org/10.1007/s11695-022-05949-6.
39. Feng J, Li K, Xu R, et al. Association between compliance with enhanced recovery after surgery (ERAS) protocols and postoperative outcome in patients with primary liver cancer undergoing hepatic resection. *J Cancer Res Clin Oncol*. 2022;148:3047–3059. https://doi.org/10.1007/s00432-021-03891-1.
40. Pickens RC, Cochran AR, Lyman WB, et al. Impact of multidisciplinary audit of Enhanced Recovery after Surgery (ERAS)® programs at a single institution. *World J Surg*. 2021;45:23–32. https://doi.org/10.1007/s00268-020-05765-y.