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Hajer Kammoun,
Sameh Achoura,
Mohamed Dehmani Yedeas,
Khaled Radhouane,
Ridha Chkili

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Impact of notification protocol on time to response in postoperative neurological deterioration among brain tumour patients

Thara Tunthanathip, Natthanee Pisitthaworakul

Division of Neurosurgery, Department of Surgery, Faculty of Medicine, Prince of Songkla University, Hat Yai, Songkhla, THAILAND

ABSTRACT

Background: Postoperative neurological deterioration (PND) is a serious complication in brain tumour surgery, often leading to functional decline or death. Timely detection and response are critical, yet delays are common in routine practice.
Objective: The present study aimed to (1) describe the prevalence, causes, and outcomes of PND among brain tumour patients and (2) to assess the impact of a structured notification system developed using root cause analysis on clinician response time.
Methods: We retrospectively reviewed brain tumour patients undergoing surgery between 2022 and 2025. Data from 2022–2023 were used to describe PND prevalence and conduct root cause analysis. A structured notification protocol was implemented in February 2024, replacing the previous bottom-up model with a top-down approach, where bedside nurses directly notified the chief resident. Post-protocol data from February 2024 to June 2025 were analysed. The primary outcome was PND prevalence and etiology. The secondary outcome was time to physician response, compared pre- and post-protocol using t-tests and ANOVA. The primary outcome was PND prevalence and etiology. The secondary outcome was the comparison of time to physician response before and after protocol implementation, analysed using t-test and ANOVA.
Results: PND occurred in 181 of 282 patients (39.8%) during the 2022–2023 period. The most common causes were brain oedema (37.6%), hypovolemic shock (11.6%), and intracerebral haemorrhage (11.6%). After implementing the protocol, the time to response was significantly reduced ($p = 0.004$).
Conclusion: PND remains a serious complication in brain tumour surgery. The introduction of a structured notification protocol significantly improved the timeliness of medical response. This approach may be adaptable to other high-acuity settings, such as trauma or critical care, where rapid decision-making is essential.

Keywords
postoperative neurological deterioration,
brain tumour,
time to response,
Karnofsky Performance Status,
protocol,
clinical deterioration

Corresponding author:
Thara Tunthanathip

Faculty of Medicine Prince of Songkla University, Hat Yai, Songkhla, Thailand

tsus4@hotmail.com

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INTRODUCTION AND IMPORTANCE

Postoperative neurological deterioration (PND) is a critical and relatively common complication following neurosurgical procedures, particularly in patients undergoing brain tumor resection. [1,2] Clinical manifestations of PND may include changes in consciousness, new focal deficits, seizures, or signs of raised intracranial pressure. [3-5] Early recognition and prompt intervention are crucial to prevent permanent neurological damage and reduce mortality. [6]

Despite advances in neurosurgical techniques and perioperative care, the incidence of PND remains significant. Previous studies have reported deterioration rates ranging from 16% to 41%, depending on the preoperative neurological deficits, eloquent area of tumor, posterior fossa location, and patient comorbidities. [1,7,8] Delayed recognition of clinical warning signs is a major contributing factor to poor outcomes. [9] In busy clinical settings, fragmented communication between nursing staff and neurosurgical teams can result in missed opportunities for timely intervention, particularly in the critical hours after surgery. [10]

To address this issue, structured clinical protocols and early warning systems have been increasingly adopted in various medical specialties. [11] These systems aim to standardize the identification and escalation of patient deterioration, ensuring rapid evaluation by appropriate medical personnel.[4] However, evidence regarding the impact of such notification protocols in neurosurgical units, especially among postoperative brain tumor patients, is limited. Most present research focuses on general surgical, medical wards, or intensive care units. [4,11,12] There is a lack of research on brain tumor patients who had surgery in a specific context.

The present study was therefore conducted to address two main objectives: first, to describe the prevalence, clinical features, and outcomes of PND in brain tumor patients; and second, to evaluate the effect of implementing a structured PND notification protocol on the timeliness of physician response.

Methods

Study Design and Setting

This was a retrospective, two-phase cohort study conducted at a tertiary neurosurgical center in southern Thailand. According to the objective study. The study comprised a pre-protocol development phase (2022–2023) and a post-protocol implementation phase (February 2024 to June 2025).

Patient Population

All adult patients (aged ≥15 years) with histologically confirmed brain tumors who underwent craniotomy between January 2022 and June 2025 were eligible for inclusion. The primary analysis of PND prevalence, clinical features, and causes was based on data from 2022 to 2023. Patients who experienced any PND during hospitalization were included for detailed event-level analysis. Excluded patients were those with incomplete medical records or who died intraoperatively and therefore could not be assessed for postoperative deterioration.

Data Collection

Data were collected from medical records, including demographics, tumor pathology, Karnofsky Performance Status (KPS), definite cause of PND, treatment of PND, and discharge outcomes. The first-noted clinical signs or symptoms were important in triggering the notification cascade that was collected. In addition, the time from the initial symptom (as documented by nursing staff) to physician response was recorded.

The operational definition was created before the review of the medical records. PND was defined as any new or worsening neurological sign or symptom occurring after surgery that required urgent clinical evaluation. This included: alteration in the Glasgow Coma Scale (GCS), new-onset delirium or confusion, development of new focal neurological deficits [3,4,13], onset of seizure activity [5], signs of increased intracranial pressure. [14]

Time to clinical response was defined as time from the first documentation of neurological deterioration (by nursing note or vital signs chart) to the first physician response (clinical note, order entry, or intervention) recorded in the electronic medical record. Time was measured in minutes and was compared between the pre- and post-protocol periods.

Development of Notification Protocol

Following the initial analysis and high observed prevalence of PND in the 2022–2023 cohort, a structured root cause analysis (RCA) was conducted by a multidisciplinary team in early 2024. The RCA utilized incident reviews, nurse and physician interviews, and process mapping to identify critical delays in the notification and response process. Based on these findings, a structured PND Notification Protocol was developed. The protocol included: a standardized neurological early warning checklist for nurses, a clear escalation pathway. Therefore, the protocol was implemented in February 2024, and its effect was evaluated using data from patients admitted from February 2024 to June 2025.

Statistical Analysis

Descriptive statistics were utilized to determine clinical characteristics and outcomes. For continuous variables, the mean and standard deviation (SD) were utilized, whereas percentages were used for categorical variables. A Sankey diagram was constructed to visualize the multidimensional flow of patients experiencing PND, including the sequence from presenting symptom, definitive cause, treatment approach (surgical vs. conservative), and final functional outcome (as measured by KPS). Furthermore, Chi-square tests, t-tests, and one-way ANOVA were used to compare data before and after protocol implementation. To assess the effect of the notification protocol, time-to-response was compared between cohorts using violin plots and corresponding hypothesis tests. A p-value <0.05 was considered statistically significant. A p-value <0.05 was considered statistically significant. All statistical analyses and data visualizations were performed using R version 4.3.0.

Ethical Considerations

This study was approved by the Institutional Review Board of the Faculty of Medicine, Prince of Songkla University (REC 68-322-10-1). Because the present study was a retrospective review, the patient's informed consent was not required. However, patient identification numbers were encoded before analysis.

Results

Clinical characteristics and prevalence of PND

Among 282 patients, 181 (39.8%) experienced PND. The mean age was 51.85 years; 67.7% were female. Most common tumor types included meningioma (29.5%), pituitary adenoma (21.5%), and glioma (19.6%), as shown in Table 1. The most frequent definite causes of PND were brain edema (37.6%), intracerebral hemorrhage (11.6%), hypovolemic shock (11.6%), hypoxemia or pulmonary embolism (9.9%), and septic shock (9.4%). The initial clinical signs that prompted physician notification were classified into four major domains: neurological problems (60.8%), cardiovascular or hemodynamic problems (18.8%), respiratory problems (9.4%), and additional categories (13.8%) for infection-related or other systemic issues. These represent the first observable signs that triggered clinical concern at the bedside. Therefore, a Sankey diagram was established to illustrate the multimodal flow of patients with PND, including the sequence from definite etiology, treatment modality (surgical treatment versus conservative treatment), and ultimate functional outcome by KPS before hospital discharge. Moreover, Figure 1 illustrates the pathways of PND among brain tumor patients. In detail, the diagram visualizes the relationship between (1) the PND patients, (2) the definitive causes of deterioration, (3) the treatment approaches (surgical vs conservative), and (4) outcomes at hospital discharge measured by KPS. The thickness of each flow represents the number of patients in each category, allowing for visual estimation of the most common deterioration trajectories.

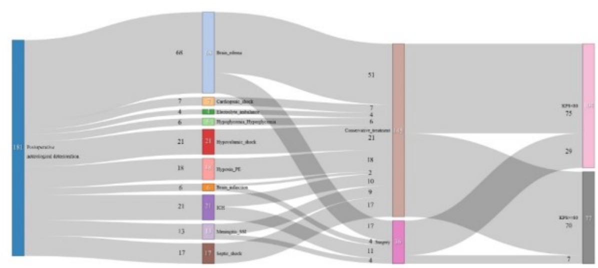

Figure 1. Sankey diagram illustrating the pathways of postoperative neurological deterioration among brain tumor patients.

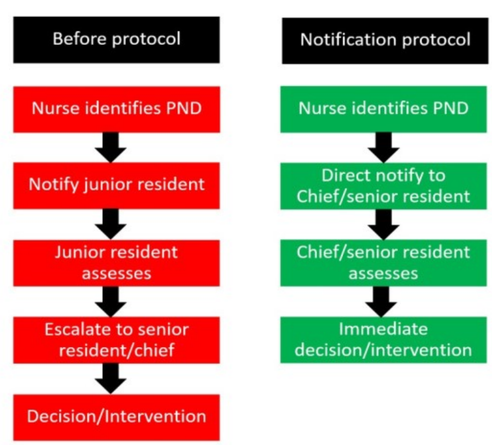

Figure 2. Comparison of notification pathways before and after protocol implementation for postoperative neurological deterioration. Pre-protocol system (left panel). Post-protocol system (right panel).

Development of Notification Protocol

From the RCA, a key finding was the inefficiency of the existing bottom-up communication model, in which bedside nurses initially notified the most junior on-call physician. This approach often resulted in delayed decision-making, communication gaps, and redundant escalation steps, particularly during night shifts or in high-acuity cases. In response, the team restructured the protocol to implement a top-down notification method, as shown in Table 2. Under this revised system, nurses were instructed to directly notify the chief or senior neurosurgical residents at the first sign or symptom of clinical deterioration, bypassing junior-level intermediaries, as shown in Figure 2. The new protocol also included a standardized neurological early warning checklist and training seminars for nursing and resident staff.

Time to Clinical Response Before vs After Protocol Implementation

Changes in the GCS were the most frequent reason for initiating physician notification in both cohorts, before and after the notification strategy was put into the real-world setting. The overall distribution of clinical characteristics, tumor type, PND treatment, and clinical outcome showed no statistically significant difference between groups, as shown in Table 3.

Figure 3 shows that the mean time to clinical response was significantly decreased after protocol implementation (t-test, p=0.004). Moreover, Figure 4 presents a violin plot illustrating the distribution of time to clinical response among patients with PND, stratified by year. (ANOVA, p=0.001). The plot shows that the median response time decreased progressively following protocol implementation.

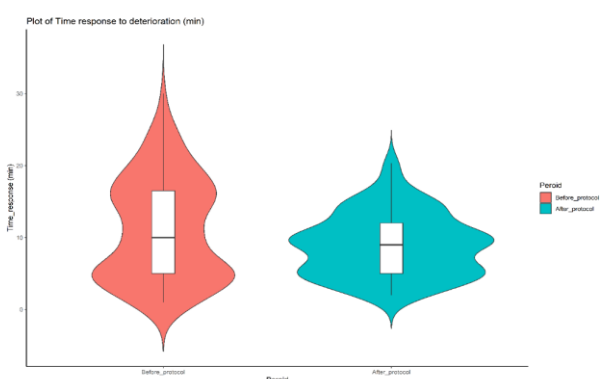

Figure 3. Violin plot of time to response before vs. after protocol.

Discussion

The present study demonstrated that PND occurred in approximately 40% of brain tumor patients, highlighting the clinical burden of this complication. This is consistent with previous studies, which revealed that PND occurred in 16-41% of brain tumor cases. [1,8] PND has been associated with a variety of intracranial and extracranial etiologies. [4, 15,16] In the present study, the most common causes of PND were brain edema, hypovolemic shock, and intracerebral hemorrhage, all of which are known to require early detection and treatment to avoid subsequent brain injury. [4,15] These findings are consistent with existing neurosurgical literature and emphasize the importance of targeted monitoring in the early postoperative period. Law et al. studied neurological deterioration in patients with intracerebral hemorrhage and observed a significantly higher rate of hematoma expansion in patients with neurological deterioration. [13,17]

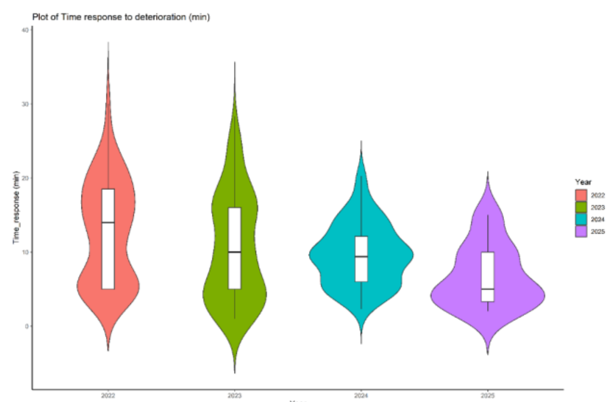

Figure 4. Comparison of time-to-response stratified by year.

A key finding of this study was the significant reduction in time to clinical response following the implementation of a structured notification protocol. The protocol formalized the process by which bedside nurses notified physicians of concerning neurological signs, leading to faster medical evaluations.[18,19] The present study also emphasizes the potential benefits of switching from a bottom-up to a top-down communication approach in controlling acute clinical deterioration. The protocol bypassed delays commonly associated with stepwise hierarchical escalation, which is a basic principle of LEAN methodology. [20,21] In the pre-protocol system, sequential escalation through junior physicians introduced delays and variability, representing a form of "waste" in communication flow. By changing the workflow to allow direct nurse-to-senior resident communication, the new protocol removed unnecessary processes and decreased response time, a significant form of process waste called in LEAN as "waiting." [21] This streamlined approach is consistent with LEAN's emphasis on providing value to patients by facilitating more rapid decision-making and decreasing damage from delayed intervention. [22] Crucially, the idea can be applied to other time-sensitive fields like critical care, emergency medicine, or cardiology, where prompt clinical judgment is crucial and hierarchical barriers may prevent immediate intervention. [23-25]

Table 1. Clinical characteristics of brain tumor patients between 2022-2023 (N=282)

Factor	N (%)
Age group-year	
<60	301 (66.2)
≥60	154 (33.8)
Mean age-year (SD)	51.85 (14.36)
Gender	
Male	147 (32.3)
Female	308 (67.7)
KPS on the date of admission	
<80	313 (68.8)
≥80	142 (31.2)
Pathological result of brain tumor	
Meningioma	134 (29.5)
Pituitary adenoma	98 (21.5)
Glioma	89 (19.6)
Primary central nervous system lymphoma	54 (11.9)
Metastasis	28 (6.2)
Schwannoma	22 (4.8)
Craniopharyngioma	11 (2.4)
Other	
Postoperative neurological deterioration	181 (39.8)
The first-noted clinical signs to notify the physician (N=181)	
Neurological problem	110 (60.8)
Glasgow Coma scale alteration	63 (34.8)
Seizure	18 (9.9)
New neurological deficit	11 (6.1)
Persistent headache	9 (5.0)
Decreased urine output	5 (2.8)
Delirium or agitation	4 (2.2)
Cariogenic problem	34 (18.8)
Hypotension	24 (13.3)
Chest pain	5 (2.8)
Blood pressure over normal range	4 (2.2)
Bradycardia	1 (0.6)
Respiratory problem	17 (9.4)
Other	20 (13.8)
Fever	14 (7.7)
Severe vomiting	6 (3.3)
Definite cause of neurological deterioration	
Brain edema	68 (37.6)
Intracerebral hemorrhage	21 (11.6)
Cerebral infarction	6 (3.3)
Meningitis/surgical site infection	13 (7.2)
Hypovolemic shock	21 (11.6)
Septic shock	17 (9.4)
Cardiogenic shock	7 (3.9)

Hypoglycemia/hyperglycemia	6 (3.3)
Electrolyte imbalance	4 (2.2)
Hypoxemia/pulmonary embolism	18 (9.9)
Management	
Conservative treatment	145 (80.1)
Surgical treatment	36 (19.9)
KPS before hospital discharge	
<80	302 (66.4)
≥80	153 (33.6)
Mortality before hospital discharge	73 (16.0)
Abbreviation: KPS= Karnofsky Performance Status, IQR= Interquartile range, SD= Standard deviation	

Table 2. Summary table of root cause analysis

Problem	Root cause	Action taken
Delayed physician response to postoperative neurological deterioration	Junior physicians as first contact lacked authority to act	Changed notification to chief resident (top-down)
Redundant notification steps	Bottom-up communication model caused delays	Eliminated redundant steps by bypassing junior staff
Lack of clarity on escalation pathway	No standard protocol for symptom-based notification	Implemented neurological early warning checklist
Inconsistent response urgency	Nursing staff unsure whom to notify first	Conducted training and posted visual escalation guide

Table 3. Clinical characteristics of patients with postoperative neurological deterioration between before and after protocol implication

Factor	Period of protocol implication		
	Before (N=181)	**After (N=101)**	
	N (%)	**N (%)**	**p-value**
Age group-year			0.73
<60	120 (66.3)	69 (68.3)	
≥60	61 (33.7)	32 (31.7)	
Mean age-year (SD)	51.69 (14.21)	51.08 (13.94)	0.72
Gender			0.47
Male	50 (27.6)	32 (31.7)	
Female	131 (72.4)	69 (68.3)	
KPS on the date of admission			0.62
<80	104 (57.5)	55 (54.5)	
≥80	77 (42.5)	46 (45.5)	
Pathological result of brain tumor			
Meningioma	52 (28.7)	28 (27.7)	0.85
Pituitary adenoma	48 (26.5)	24 (23.8)	0.61
Glioma	34 (18.8)	17 (16.8)	0.68
Primary central nervous system lymphoma	19 (10.5)	17 (16.8)	0.12
Metastasis	6 (3.3)	0 (0)	0.06
Schwannoma	13 (7.2)	9 (8.9)	0.60
Craniopharyngioma	9 (5.0)	6 (5.9)	0.72
Other			
The first-noted clinical signs to notify the physician			0.97
Neurological problem	110 (60.8)	61 (60.4)	
Glasgow Coma scale alteration	63 (34.8)	35 (34.7)	
Seizure	18 (9.9)	10 (9.9)	
New neurological deficit	11 (6.1)	9 (8.9)	

Persistent headache	9 (5.0)	5 (5.0)	
Decreased urine output	5 (2.8)	1 (1.0)	
Delirium or agitation	4 (2.2)	1 (1.0)	
Cariogenic problem	34 (18.8)	23 (22.8)	
Hypotension	24 (13.3)	17 (16.8)	
Chest pain	5 (2.8)	2 (2.0)	
Blood pressure over normal range	4 (2.2)	3 (3.0)	
Bradycardia	1 (0.6)	1 (1.0)	
Respiratory problem	17 (9.4)	10 (9.9)	
Other	20 (13.8)	7 (6.9)	
Fever	14 (7.7)	6 (5.9)	
Severe vomiting	6 (3.3)	1 (1.0)	
Definite cause of neurological deterioration			0.99
Brain edema	68 (37.6)	41 (40.6)	
Intracerebral hemorrhage	21 (11.6)	12 (11.9)	
Cerebral infarction	6 (3.3)	3 (3.0)	
Meningitis/surgical site infection	13 (7.2)	6 (5.9)	
Hypovolemic shock	21 (11.6)	12 (11.9)	
Septic shock	17 (9.4)	7 (6.9)	
Cardiogenic shock	7 (3.9)	5 (5.0)	
Hypoglycemia/hyperglycemia	6 (3.3)	3 (3.0)	
Electrolyte imbalance	4 (2.2)	2 (2.0)	
Hypoxemia/pulmonary embolism	18 (9.9)	10 (9.9)	
Management			0.98
Conservative treatment	145 (80.1)	81 (80.2)	
Surgical treatment	36 (19.9)	20 (19.8)	
KPS before hospital discharge			0.82
<80	101 (55.8)	55 (54.5)	
$\geq$80	80 (44.2)	46 (45.5)	
Mortality before hospital discharge	48 (26.5)	27 (26.7)	0.96
Abbreviation: KPS= Karnofsky Performance Status, IQR= Interquartile range, SD= Standard deviation			

From statistical analysis, patients who received faster responses after the notification protocol implementation. However, mortality rates and functional outcome did not differ significantly between the pre- and post-protocol groups in the present study. From a prior study, neurological deterioration in both the early and late phases was significantly associated with mortality in hemorrhagic stroke. [13] Furthermore, Liu et al. studied stroke registry data and reported that patients with neurological impairment in both the early and late stages had a significantly lower functional outcome. [14] Therefore, a multicenter study should be conducted in the future to explore the association of PND and clinical outcomes. Although this association has been inconclusive, the notification protocol led to a shorter duration of clinical response that is consistent with the concepts of high-quality healthcare systems for patient safety. [26] Moreover, Correia et al. evaluated an early warning score in critical disease patients and discovered that the score system increased early medical treatment by 40%. [9] In order to verify these findings and assess the clinical outcome of early detection of PND, a prospective study with standardized data collection is required in the future. [27,28]

The present study has several limitations. First, its single-center, retrospective nature would restrict its applicability to other neurosurgical populations with different notification processes. [29] Additionally, while the protocol improved response times, we did not assess long-term outcomes beyond discharge. [29,30] Future prospective studies should incorporate follow-up data and examine whether similar benefits can be observed across diverse neurosurgical populations. Furthermore, integration of automated alerts or digital monitoring systems may further enhance early detection and warrant exploration. [31,32]

Conclusion

PND remains a common and serious complication in brain tumor surgery. The introduction of a structured notification protocol significantly improved the timeliness of medical response. The protocol reflects LEAN principles by eliminating unnecessary steps and minimizing delay, thereby increasing workflow efficiency in neurosurgical care. This approach may be adaptable to other high-acuity settings, such as trauma or critical care, where rapid decision-making is essential.

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