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POSTOPERATIVE NEUROLOGICAL MONITORING AND CARE STRATIFICATION IN ADULT PATIENTS AFTER CRANIOTOMY: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT
The postoperative period following craniotomy is a critical phase because patients are at risk for early neurological deterioration, the need for escalation of care, delirium, delayed awakening, and other complications that can impact safety and clinical outcomes. An appropriate approach to neurological monitoring, including the selection of the care unit and stratification of observation intensity, is a crucial issue in modern neurosurgical practice. Synthesizes current scientific evidence regarding postoperative neurological monitoring and care stratification in adult patients after craniotomy, specifically regarding the safety of non-intensive care unit (non-ICU) care, the use of prediction scores, and postoperative clinical outcomes. This review used a systematic literature review design following the PRISMA 2020 principles and has been registered with PROSPERO (CRD420261350040). Searches were conducted in PubMed, Scopus, Web of Science, SAGE, and Springer Nature for articles published between 2020 and 2026. Methodological quality was assessed using the Joanna Briggs Institute Critical Appraisal Tools according to study design. Due to the heterogeneity of designs, interventions, and outcomes, the synthesis was conducted narratively and thematically. Of the initial 534 articles, 18 studies met the inclusion criteria. Four studies were of high quality and fourteen studies were of moderate quality. Three main themes were identified: (1) non-ICU monitoring pathways in selected patients can be safe when supported by structured neurological observation; (2) prediction scores and risk stratification help adjust monitoring intensity; and (3) structured postoperative pathways, including same-day discharge in selected patients, have the potential to reduce length of stay, costs, and ICU use without showing significant safety signals. Available evidence suggests that structured, risk-based postoperative neurological monitoring supported by strong nursing competencies has the potential to improve resource efficiency without compromising patient safety. However, the evidence remains largely based on observational studies.

Keywords: ICU; kraniotomi; monitoring neurologis; PACU; pathway pascaoperasi; risk stratification; same-day discharge

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INTRODUCTION

Craniotomy is a major surgical procedure on the central nervous system that carries a risk of postoperative neurological complications, such as intracranial hemorrhage, cerebral edema, seizures, and decreased consciousness (Fan et al., 2024; Qasem et al., 2022). The first 24 hours postoperatively are critical because most serious complications occur during this time, requiring intensive and continuous neurological monitoring. Traditionally, post-craniotomy patients were routinely admitted to the intensive care unit (ICU) for early detection of complications. However, in recent years, this practice has shifted toward a risk-stratification-based approach. Several studies have shown that selective ICU admission, monitoring in the post-anesthesia care unit (PACU), care in a dedicated neurology ward, and same-day discharge in selected patients can be performed safely without increasing adverse outcomes (Munari et al., 2025; Nothofer et al., 2025). This approach aims to improve resource efficiency without compromising patient safety.

Delays in detecting post-craniotomy neurologic deterioration can have fatal consequences, including brain herniation and death, making early detection crucial in clinical practice (Yang, 2024). Serial neurologic monitoring is a key component of patient care, which relies heavily on the competence and vigilance of nurses, the healthcare professionals who interact most frequently with patients (Figueiredo et al., 2024). Nurses play a central role in observing changes in level of consciousness, focal neurologic deficits, pain, and behavior, as well as monitoring vital signs and signs of increased intracranial pressure (ICP). Furthermore, nurses' ability to recognize subtle changes and promptly escalate to the medical team has been shown to contribute significantly to improved patient outcomes and the prevention of secondary complications (Chen et al., 2025).

Evolving evidence in recent years suggests a shift toward a risk-stratification-based approach in post-craniotomy patients. Various prediction scores and predictive models have been developed to identify patients at high risk for complications, including delayed recovery and the need for intensive care (Qian et al., 2025). Furthermore, the concept of “no ICU unless” and fast-track neurosurgery pathways are increasingly being implemented to optimize ICU utilization without compromising patient safety (Murugaiyan et al., 2025). This approach is supported by increasing research on complications such as postoperative delirium, delayed awakening, and early detection of neurological complications that impact clinical outcomes (Russo et al., 2025; Yuan et al., 2023; Zeng et al., 2024). Overall, these trends underscore the importance of individualized, risk-based care in modern neurosurgery practice.

Although numerous primary studies have been published in the past five years on post-craniotomy care, comprehensive syntheses specifically examining post-surgical neurological monitoring and stratification of location and intensity of care are limited. Some studies have focused on the safety aspects of ICU bypass or the “no ICU unless” approach, while others have focused on developing prediction scores to determine the need for intensive care care (Qian et al., 2025). Furthermore, several studies have explored the implementation of clinical pathways, such as fast-track neurosurgery, to improve service efficiency (Murugaiyan et al., 2025). However, to date, few studies have integrated all these approaches into a comprehensive framework, particularly from a nursing perspective. Nurses play a key role in continuous neurological monitoring and clinical decision-making based on changes in the patient's condition.

The conceptual framework in this study can be explained through the failure to rescue and early detection of deterioration approaches, which emphasize the importance of early detection of deteriorating patient conditions to prevent fatal outcomes. In the post-craniotomy context, failure to recognize early signs of neurological deterioration can increase the risk of serious complications and mortality (Guo et al., 2025; Thornton et al., 2025). Therefore, continuous and systematic neurological monitoring is at the heart of surveillance nursing practice, with nurses acting as the vanguard in identifying early clinical changes (Chen et al., 2025). Integrating this concept with a risk-stratified postoperative care approach allows for the appropriate location and intensity of care, thereby improving patient safety while optimizing resource utilization (Jiwa et al., 2025; Wagner et al., 2025).

This study aims to synthesize current scientific evidence regarding postoperative neurological monitoring practices and the stratification of location and intensity of care in adult patients after craniotomy. The primary focus includes evaluating the effectiveness of neurological monitoring across various care settings, the safety of implementing non-ICU pathways in selected patients, and the use of prediction scores in determining the need for intensive care. Furthermore, this review aims to identify the clinical and nursing implications of a risk-based approach on patient outcomes, including early detection of complications and optimization of patient safety.

The objective of this review is to synthesize and critically analyze the existing evidence regarding postoperative neurological monitoring after craniotomy. Specifically, this review aims to (1) evaluate the effectiveness of neurological monitoring across different postoperative care settings, including the ICU, PACU, and general wards; (2) assess the safety and effectiveness of non-ICU care pathways, such as ICU bypass and selective ICU admission, in selected adult patients; (3) examine the contribution of prediction scores and risk stratification tools in guiding decisions on the location and intensity of postoperative monitoring; and (4) analyze the implications of these monitoring strategies for clinical outcomes and nursing practice, particularly in the early identification of postoperative complications.

METHOD
Design
This study employed a Systematic Literature Review (SLR) design with a reporting approach that adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. This design was chosen to systematically search, assess, and synthesize empirical evidence regarding postsurgical neurological monitoring and treatment stratification in adult patients after craniotomy.

Review Protocol
This review protocol has been registered with PROSPERO under registration number CRD420261350040. Registration was conducted prior to the final synthesis to prioritize the review questions, eligibility criteria, search strategy, primary outcomes, data extraction process, methodological quality assessment, and synthesis approach. This step is essential to reduce the risk of selective reporting and increase the methodological transparency of the review.

Literature search strategy
A systematic literature search was conducted in five major electronic databases: PubMed, Scopus, Web of Science, SAGE Journals, and Springer Nature. The search was limited to articles published between 2020 and 2026 to ensure that the synthesized evidence reflects the latest developments in postoperative neurological monitoring, stratification of care intensity, use of prediction scores, and selective care pathways in adult patients after craniotomy. The search strategy was developed using a combination of controlled and free-text terms. In some databases, the search was also expanded to include clinical outcome terms, such as early detection, neurological deterioration, postoperative complication, neurological complication, and clinical outcome. Details of the search strategy for each database are presented in Table 1. Based on the search, 39 articles were retrieved from PubMed, 87 from Scopus, 96 from Web of Science, 98 from SAGE Journals, and 214 from Springer Nature, resulting in a total of 534 articles identified.

Table 1.
Literature search strategy

Database	Search strategy	Year	Number of articles
PubMed	Craniotomy AND neurological monitoring AND postoperative care	2020-2026	39
Scopus	Craniotomy OR neurosurgery AND neurological assessment OR monitoring	2020-2026	87
Web of Science	Craniotomy AND neurological monitoring	2020-2026	96
SAGE	Craniotomy AND neurological assessment	2020-2026	98
Springer Nature	Craniotomy AND postoperative neurological complication AND monitoring	2020-2026	214
Total artikel			534

RESULT
Inclusion and Exclusion Criteria Based on PICOS
The inclusion and exclusion criteria in this review were developed using the PICOS framework, which includes Population, Intervention/Exposure, Comparator, Outcome, and Study Design. Full details of these criteria are shown in Table 2. In the population component, included studies were studies in adult patients aged 18 years or older undergoing craniotomy or elective intracranial surgical procedures and in the acute postoperative phase. Studies were excluded if they involved pediatric patients, patients not undergoing intracranial surgery,

focused only on the intraoperative phase, or did not address the acute postoperative phase. In the intervention/exposure component, this review included studies that assessed postoperative monitoring and surveillance, such as postoperative neurological assessment, patient placement based on care intensity in the PACU, ward, neuroscience ward, or ICU, selective care pathways without routine ICU admission, risk stratification, prediction scores, and postoperative pathways for early detection of neurological complications and determining the need for intensive monitoring. Studies that addressed only intraoperative monitoring or non-neurological monitoring without relevance to the postoperative phase were excluded. For the comparator component, studies could use routine ICU, standard care, PACU, neuroscience ward, routine monitoring, conventional pathways, or other surveillance strategies. Observational studies without a formal comparator were considered as long as they reported relevant clinical outcomes and provided a contextual overview of postoperative care. For the outcome component, included studies were those that reported early detection of neurological complications, changes in neurological status, ICU requirements, unplanned transfers, length of stay, mortality, need for reoperation, costs of care, postoperative delirium, delayed awakening, or other relevant postoperative clinical outcomes. Studies that did not report relevant clinical or neurological outcomes were excluded. For the study design component, this review included randomized controlled trials, where available, quasi-experimental, cohort, case-control, prospective and retrospective observational studies, and studies developing or validating predictive models based on observational designs. Review articles, systematic reviews, meta-analyses, scoping reviews, editorials, commentaries, letters, case reports, case series, protocols, and conference abstracts without complete data were excluded. Only articles published in English or Indonesian published between 2020 and 2026 were included.

Study Selection Process

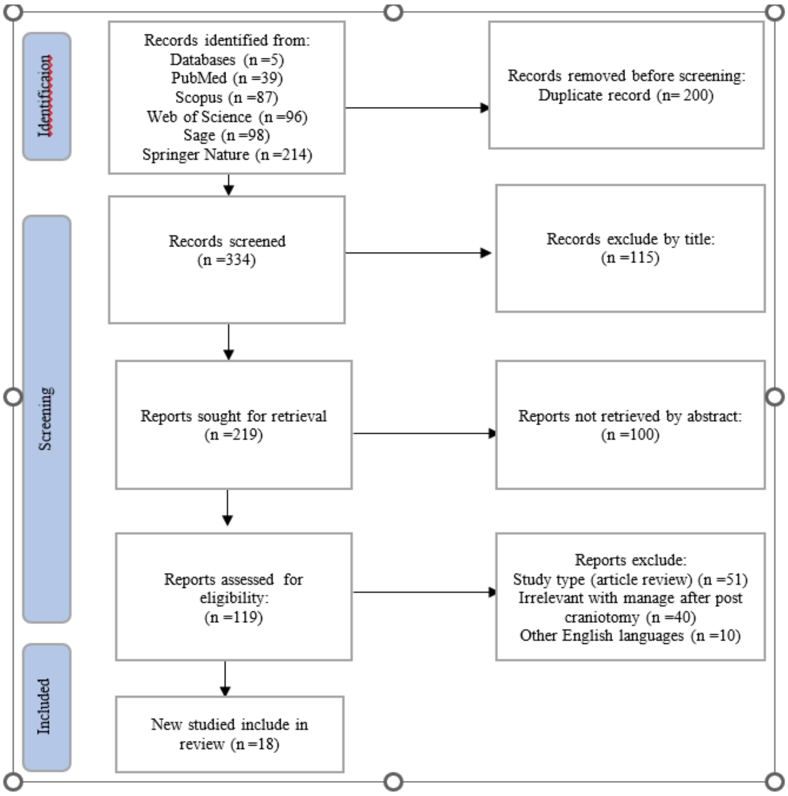

Figure 1. Flowchart of the 2020 PRISMA study selection process

The study selection process was conducted according to the PRISMA 2020 framework and is summarized in Figure 1. A literature search of PubMed, Scopus, Web of Science, SAGE Journals, and Springer Nature yielded a total of 534 articles. Prior to screening, 200 duplicate articles were removed, leaving 334 articles to be screened based on title. At this stage, 115 articles were excluded. Next, 219 articles proceeded to the abstract review stage. Of these, 100 articles were excluded because they did not meet the inclusion and exclusion criteria. Thus, 119 articles underwent full-text review. At the full-text stage, 101 articles were excluded due to being reviews (n=51), not relevant to post-craniotomy management (n=40), and being in a language other than English or Indonesian (n=10). Ultimately, 18 studies were included in the final synthesis. Study selection was conducted by two independent reviewers, and disagreements were resolved through discussion until consensus was reached.

Data Extraction

Data extraction was conducted systematically for each study that met the inclusion criteria. Data collected included author names, year of publication, country of origin, study design, sample size and characteristics, and study setting. Additionally, information regarding the type of postoperative monitoring or pathway implemented, comparators used, outcomes assessed, and the main results of the study was recorded. To enhance relevance to nursing practice, each study was also extracted based on the nursing implications derived from the findings. A summary of the data extraction is presented in Table 2.

Table 2.
Data extraction of included studies

Title, Researcher	Country	Research Method (Design) and Sample	Intervention	Key Results	Implications for Nursing
Postoperative Monitoring After Elective Intracranial Surgery in a Postanesthesia Care Unit is Safe, Efficient, and Cost-Effective (Wagner et al., 2025).	German	Comparative retrospective cohort; 5638 adult patients undergoing elective intracranial surgery	Postoperative monitoring in the PACU compared to the ICU	Monitoring in the PACU is safe, efficient, and reduces ICU utilization without significantly increasing clinical risk.	Nurses need to strengthen neurological observation and early detection of complications in the PACU as a safe alternative to the ICU in selected patients.
Adverse Events Within 24 hours After 1070 Adult Brain Tumor Surgeries Recovered in a Neurocritical Care Unit or a Postanesthesia Care Unit. (Almansouri et al., 2025)	Canada	Comparative retrospective cohort of 1070 adult patients postoperatively with brain tumors	Postoperative recovery in PACU compared to NCCU	Adverse events within 24 hours postoperatively in selected patients in the PACU were comparable to those in the NCCU.	Nurses need to carry out close monitoring in the first 24 hours to recognize neurological changes and early complications.
No ICU Unless 2.0 – Refining ICU admission criteria after elective craniotomy. (Qasem et al., 2025)	German	Comparative retrospective cohort; 1162 patients were analyzed from 1441 elective craniotomies	Selective care pathway without routine ICU	Most patients can be safely cared for without routine ICU admission, and postoperative risk scoring can aid patient selection.	Nurses need to optimize structured neurological assessments in non-ICU patients to ensure safety.
Implementation of the "No ICU – Unless" approach in postoperative neurosurgical management in times of COVID-19. (Qasem et al.,	German	Comparative retrospective cohort; 171 patients consisting of 96 NIU group and 75 control group	The "No ICU-Unless" approach compared to routine ICU	The selective approach did not show worse clinical outcomes than routine ICU.	Nurses need to be prepared to perform high-quality neurological monitoring in non-ICU units on stable patients.

Title, Researcher	Country	Research Method (Design) and Sample	Intervention	Key Results	Implications for Nursing
2022)					
Routine ICU Surveillance after Brain Tumor Surgery: Patient Selection Using Machine Learning. (Neumann et al., 2024)	German	Retrospective cohort; 1000 adult patients with brain tumor surgery	Predictive model to determine ICU surveillance needs	Predictive models help select patients who truly need the ICU so that ICU use can be more selective.	Nurses can utilize risk stratification to determine more appropriate postoperative monitoring intensity.
Necessary Intensity of Monitoring After Elective Craniotomies: A Prediction Score for Postoperative Complications to Stratify Postoperative Monitoring. (Kurz et al., 2025)	German	Retrospective cohort: 1,000 adult patients undergoing brain tumor surgery This single-center retrospective cohort included 860 consecutive elective craniotomy patients, consisting of 376 men and 484 women, with a mean age of 60.6 years. The data were divided into score development and internal validation sets.	Development of a predictive score for stratification of postoperative monitoring intensity after elective craniotomy, based on age, Charlson Comorbidity Index, duration of surgery, vascular pathology, blood loss, and ASA score.	Forty-three patients experienced postoperative adverse events requiring monitoring. Independent predictors of complications were age, CCI, surgical duration, vestibular schwannoma, blood loss, and ASA score. The model demonstrated an AUC of 0.78 in validation data. The study also concluded that 12-hour monitoring was sufficient to capture 90% of complications. This score supports low-, intermediate-, and high-risk classification for more precise ICU/IMC allocation.	Nurses need to conduct neurological observation and clinical monitoring based on risk, not uniformly across all patients. High-risk patients require more intensive monitoring, while low-risk patients can be fast-tracked while maintaining safety through structured neurological assessment, respiratory and hemodynamic monitoring, and early detection of decreased consciousness.
The necessity for routine intensive care unit admission following elective craniotomy for epilepsy surgery. (Bahna et al., 2022)	German	Retrospective cohort; 266 patients	Routine ICU admission policy after epilepsy craniotomy	Routine ICU is not always necessary in all patients, especially when the risk factors for complications are low.	Nurses can play a role in early identification of risk factors to determine the need for intensive care.
Postoperative Admission of Adult Craniotomy Patients to the Neuroscience Ward Reduces Length of Stay	United States of America	Retrospective cohort, 549 patients (NICU group 340 patients and NW group 209 patients)	Admission to the neuroscience ward compared to the NICU	Care in the neuroscience ward reduces length of stay and costs in selected patients without compromising	Nurses in the neuroscience ward need to be able to perform competent neurological monitoring so that patients do not

Title, Researcher	Country	Research Method (Design) and Sample	Intervention	Key Results	Implications for Nursing
and Cost, (Sun et al., 2021)				safety.	have to be routinely treated in the NICU.
Postoperative Surveillance in the Postoperative vs. Intensive Care Unit for Patients Undergoing Elective Supratentorial Brain Tumor Removal: A Retrospective Observational Study, (Nothofer et al., 2025)	German	Retrospective cohort; 405 patients.	Surveillance in the postoperative unit compared to the ICU	Surveillance in the post-operative unit shows shorter lengths of stay and lower rates of certain complications.	Nurses need to strengthen neurological assessment and post-operative surveillance in the intensive care unit so that ICU transfers can be minimized.
External validation of the Cranioscore for prediction of early postoperative complications requiring ICU after brain tumor craniotomy. (Betbeder et al., 2023)	French	Retrospective cohort; 127 patients.	Validation of Cranioscore to predict early complications requiring ICU	Cranioscore helps identify patients at risk for postoperative complications requiring ICU admission.	Nurses can use risk score information to increase vigilance and intensity of neurologic monitoring.
Same-day discharge after craniotomy for brain tumor resection: enhancing patient selection through a prognostic scoring system. (Levy et al., 2023)	United States of America	Retrospective cohort, Sample of 90 patients	Prognostic scoring system for same-day discharge patient selection	The scoring system helps select patients who are safe to be discharged more quickly.	Nurses can use risk stratification to assess patient readiness and the need for further observation.
A Protocol for Reducing Intensive Care Utilization After Craniotomy: A 3-Year Assessment. (Ruiz Colón et al., 2023)	United States of America	Retrospective cohort before and after intervention. A sample of 4,837 craniotomies from May 2014 to December 2021, consisting of 2,302 pre-protocol and 2,535 post-protocol. Of the post-protocol group, 534 patients (21%) were included in the NICE protocol.	Implementation of the NICE protocol (Non-Intensive Care) to select low-risk craniotomy patients who can bypass the ICU, transferred to the PACU for a minimum of 3 hours, and then to the neurosurgery ward. In the PACU, vital signs and neurological checks are performed every 15 minutes for the first hour, then more frequently.	After protocol implementation, postoperative LOS decreased from 4.0 to 3.5 days; in protocol patients, the average LOS was 2.4 days. ICU utilization decreased from 57% to 42%, resulting in savings of approximately US$760,000. ICU readmissions and complications also decreased. The 30-day readmission rate in protocol	Nurses play a key role in non-ICU pathways. Nurses must be able to perform close neurological monitoring in the PACU and wards, recognize early signs of complications, maintain stable blood pressure, and ensure rapid escalation of any changes in neurological status. This study confirms that the competence of neuroscience-trained nurses is

Title, Researcher	Country	Research Method (Design) and Sample	Intervention	Key Results	Implications for Nursing
			Neurological monitoring and vital signs are then performed every 4 hours on the ward by trained nurses.	patients was 5.8%, and none were considered preventable by routine ICU care alone.	crucial for safe non-ICU patient selection.
Routine postoperative admission to the neurocritical intensive care unit after microvascular decompression: necessary or can it be abandoned. (Hatipoglu Majernik et al., 2022)	German	Comparative retrospective observational study of 236 patients.	Routine NICU admission after microvascular decompression compared to PACU/ward pathway	Routine NICU admission may not always be necessary in all microvascular decompression patients.	Nurses can support patient selection based on clinical stability and the need for postoperative neurologic monitoring.
Enhanced recovery and same-day discharge after brain tumor surgery under general anesthesia: initial experience with Hospital-at-Home-based postoperative follow-up. (Pelaez-Sanchez et al., 2023)	Europe	Retrospective comparative observational study; 18 case groups and 59 control groups	ERAS program with same-day discharge, and Hospital-at-Home follow-up	This approach is feasible in selected patients with good follow-up safety.	Nurses play a vital role in home-based postoperative follow-up, education, symptom monitoring, and early detection of complications.
Same-day discharge after craniotomy for tumor resection: a retrospective observational single-center study of 630 patients. (Nijs et al., 2023)	Canada	Single-center retrospective observational study; 630 patients	Pathway home on the same day after supratentorial tumor resection	Same-day discharge is possible for selected patients with acceptable safety outcomes.	Nurses need to comprehensively assess patient readiness before rapid discharge and ensure a clear follow-up plan.
Evaluation of post-craniotomy cerebral hemodynamic by transcranial Doppler, (Rebai et al., 2025)	Tunis	Prospective observational study, 48 patients.	Postcraniotomy cerebral hemodynamic monitoring with transcranial Doppler	TCD can help identify delayed awakening and postoperative ischemic complications.	Nurses need to understand the results of additional monitoring to support early detection of neurological disorders and cerebral perfusion.
Reduced time to imaging, length of stay, and hospital charges following implementation of	United States of America	Quasi-experimental study; 395 patients.	Implementation of a new postoperative pathway after craniotomy	Faster time to imaging, shorter length of stay, and lower costs after pathway	Nurses play a role in coordinating post-operative flow, accelerating problem detection,

Title, Researcher	Country	Research Method (Design) and Sample	Intervention	Key Results	Implications for Nursing
a novel postoperative pathway for craniotomy. (Hoffman et al., 2023)				implementation	and accelerating diagnostic measures.
Same-day discharge after brain tumor resection: a prospective pilot study. (Vallejo et al., 2022)	United States of America	Prospective quasi-experimental study; 37 patients.	Pathway home on the same day after brain tumor resection	Same day discharge is feasible in selected patients with good safety outcomes.	Nurses need to ensure that patient education, observation, and readiness to go home are optimal before rapid discharge.

Methodological Quality Assessment

Methodological quality assessment was conducted using the Joanna Briggs Institute Critical Appraisal Tools, tailored to each study's design. Cohort studies were assessed using the JBI Checklist for Cohort Studies, quasi-experimental studies using the appropriate checklist, and observational or other analytical studies using the JBI instrument most relevant to the characteristics of their research design. Because each design has a different number of assessment items, a quality score was calculated as a percentage based on the number of "yes" responses to the total number of items assessed. The methodological quality of the studies was then classified as high quality for a score of ≥75%, moderate quality for a score of 50–74%, and low quality for a score of <50%. In predictive model development or validation studies, quality assessment was still based on the underlying observational design, not solely on the study's analytical objectives. The quality assessment process was conducted by two independent reviewers to minimize bias. If there were discrepancies in the assessment results, the final decision was made through discussion until a consensus was reached. The quality assessment results are summarized in Table 3.

Table 3.
Methodological quality assessment

No	Author, Year	Study design	Results	Category
1	(Wagner et al., 2025).	Comparative retrospective cohort	8/11 (72,7%)	Medium
2	(Almansouri et al., 2025).	Comparative retrospective cohort	8/11 (72,7%)	Medium
3	(Qasem et al., 2025)	Comparative retrospective cohort	8/11 (72,7%)	Medium
4	(Qasem et al., 2022)	Comparative retrospective cohort	8/11 (72,7%)	Medium
5	(Neumann et al., 2024)	Retrospective cohort	8/11 (72,7%)	Medium
6	(Kurz et al., 2025)	Retrospective cohort	8/11 (72,7%)	Medium
7	(Bahna et al., 2022)	Retrospective cohort	8/11 (72,7%)	Medium
8	(Sun et al., 2021)	Retrospective cohort	8/11 (72,7%)	Medium
9	(Nothofer et al., 2025)	Retrospective cohort	8/11 (72,7%)	Medium
10	(Betbeder et al., 2023)	Retrospective cohort	8/11 (72,7%)	Medium
11	(Levy et al., 2023)	Retrospective cohort	8/11 (72,7%)	Medium
12	(Ruiz Colon et al., 2023)	Comparative retrospective cohort	8/11 (72,7%)	Medium
13	(Hatipoglu Majernik et al., 2022)	Comparative retrospective observational	8/11 (72,7%)	Medium
14	(Pelaez-Sanchez et al., 2023)	Comparative retrospective observational	7/9 (77,8%)	High
15	(Nijs et al., 2023)	Comparative retrospective observational	8/11 (72,7%)	Medium
16	(Rebai et al., 2025)	Prospective observational	6/8 (75,0%)	High
17	(Hoffman et al., 2023)	Quasi-experimental	7/9 (77,8%)	High
18	(Vallejo et al., 2022)	Prospective quasi-experimental	7/9 (77,8%)	High

Data Synthesis

Meta-analysis was not performed in this review due to heterogeneity in study design, type of intervention or exposure, treatment setting, and reported outcomes across studies. Therefore, research results were synthesized using narrative synthesis to systematically describe patterns of findings and compare results across included studies. To strengthen the interpretation of the results, the synthesis was also conducted thematically by grouping studies based on the primary focus of monitoring, treatment strategies, and reported clinical outcomes. The synthesis process was conducted by examining study characteristics, the type of monitoring or pathway used, and the direction of reported results. These groups were then grouped into three main themes: (1) non-ICU monitoring pathways in selected patients, (2) prediction scores and risk stratification to determine monitoring needs, and (3) structured postoperative pathways, including same-day discharge, in selected patients.

DISCUSSION

Search Results and Study Selection

A literature search of PubMed, Scopus, Web of Science, SAGE Journals, and Springer Nature identified a total of 534 articles. Prior to the screening process, 200 duplicate articles were removed, leaving 334 articles to be screened based on title. At this stage, 115 articles were excluded. Next, 219 articles proceeded to the manuscript review stage. Of these, 100 articles were excluded at the abstract stage, leaving 119 articles for full-text eligibility assessment. At the full-text stage, 101 articles were excluded due to being reviews (n=51), not relevant to post-craniotomy management (n=40), or being in a language other than English or Indonesian (n=10). Thus, 18 studies were included in the final synthesis. Details of the study selection process are shown in Figure 1 in the PRISMA flowchart.

Characteristics of Included Studies

A total of 18 studies were included in the final synthesis. The studies came from several countries, with the largest number coming from Germany and the United States, followed by Canada, Italy, France, Tunisia, and one study from Europe. This indicates that evidence regarding postoperative neurological monitoring and post-craniotomy care stratification is still dominated by research from high-income countries. Based on study design, the included studies were predominantly observational, primarily retrospective cohort, comparative retrospective cohort, and retrospective observational studies. In addition, there were several quasi-experimental studies, one retrospective case-control study, and one prospective observational study. No randomized controlled trials were found in the included studies. Sample sizes varied widely across studies, ranging from 37 to 5,638 patients. Most studies were conducted in adult patients undergoing elective craniotomy, primarily for brain tumor resection, although some studies also included patients with other neurosurgical indications such as epilepsy and microvascular decompression. This variation in sample size reflects the differences in study scale, ranging from pilot studies to large-center retrospective studies. In terms of care settings, the studies analyzed covered a variety of postoperative monitoring locations, such as the ICU, neurocritical care unit, postanesthesia care unit (PACU), neuroscience ward, postoperative unit, neurosurgical ward, and home-based follow-up within the same-day discharge pathway. This variety of settings demonstrates that postoperative neurological monitoring is not limited to the ICU but is also shifting to non-ICU units for appropriately selected patients. The types of interventions or exposures assessed also varied, including postoperative neurological monitoring in the PACU or ward, routine ICU policies versus selective non-ICU pathways, the use of prediction scores and risk stratification models, the implementation of structured postoperative pathways, and same-day discharge programs with continued follow-up. Several studies also specifically assessed the detection of specific neurological complications, such as postoperative delirium and delayed awakening, including the use of transcranial Doppler as an additional monitoring tool.

Methodological Quality of Studies

Methodological quality assessment revealed that of the 18 synthesized studies, 7 were categorized as high quality and 11 as moderate quality. No studies were classified as low quality. These findings indicate that the available evidence is generally of sufficient methodological quality to support a narrative synthesis in this review. In general, the most frequently encountered limitation was the use of a retrospective design, which has the potential to introduce selection bias and limited control for confounding variables. Furthermore, heterogeneity of comparators and variations in care settings between studies also presented challenges in directly comparing results. Nevertheless, all studies made important contributions to elucidating postsurgical neurological monitoring and care stratification in adult patients after craniotomy.

Synthesis Approach and Theme Formation

The results were synthesized narratively and thematically because the included studies exhibited variations in study design, type of monitoring strategy, care setting, comparator, and reported clinical outcomes. All study results were thoroughly reviewed to identify recurring patterns of findings, both in terms of the monitoring strategy used and the direction of reported outcomes. Next, the studies were grouped based on the type of postoperative monitoring strategy and the primary outcomes. Key codes were generated from several aspects that emerged most frequently across the studies: care setting, risk stratification tools, neurological complications, and service efficiency. These codes were then organized into descriptive themes to illustrate the patterns of study results, and then developed into analytical themes representing a synthesis across studies. Based on this process, three main themes emerged: (1) non-ICU monitoring pathways can be safe in selected patients, (2) prediction scores and risk stratification support more appropriate monitoring intensity, and (3) structured postoperative pathways improve service efficiency. This approach was used to facilitate interpretation of the results and emphasize the relationship between monitoring strategies, clinical outcomes, and their implications for nursing practice.

Analytical themes synthesize results

Theme 1. Non-ICU monitoring pathways can be safe in selected patients

Several studies in this review demonstrate that non-ICU monitoring pathways can be safely implemented in appropriately selected post-craniotomy patients. Wagner et al. (2025) reported that postoperative monitoring in the PACU was safe, efficient, and more cost-effective than the ICU in selected elective intracranial patients. Similar findings were reported by Almansouri et al. (2025), who showed that adverse events within 24 hours postoperatively in brain tumor surgery patients recovering in the PACU were comparable to those in neurocritical care units. Nothofer et al. (2025) also found that surveillance in the postoperative unit was associated with shorter lengths of stay and lower rates of certain complications compared to the ICU in the context of supratentorial brain tumor surgery. In another setting, Sun et al. (2021) demonstrated that care in a neuroscience ward can reduce length of stay and costs without compromising clinical safety. The "No ICU Unless" approach also yielded consistent results. Qasem et al. (2022) and Qasem et al. (2025) reported that selective pathways without a routine ICU did not show worse clinical outcomes than those with a routine ICU, especially when patient selection was based on postoperative risk. Ruiz Colón et al. (2023) also demonstrated a reduction in ICU use, length of stay, and costs using the NICE protocol. Although the results tended to be positive, the magnitude of the benefits was not entirely consistent across studies. This variation is likely influenced by differences in surgical case type, patient selection criteria, intensity of observation in the PACU or ward, as well as nurse readiness and escalation systems at each hospital. Therefore, the safety of non-ICU pathways is determined not only by the location of care, but also by the quality of neurological surveillance, clear observation protocols, and the team's ability to detect early clinical changes.

Theme 2. Prediction scores and risk stratification support more appropriate monitoring intensity

Several studies in this review demonstrate that the use of prediction scores and risk stratification can help determine more appropriate postoperative monitoring intensity. Neumann et al. (2024) developed a machine learning-based model to select postoperative brain tumor patients who truly require ICU surveillance. The study's results suggest that a predictive approach can help differentiate high-risk patients from low-risk patients, thus making ICU use more selective and no longer routinely administered to all patients. Kurz et al. (2025) developed a postoperative complication score to determine the intensity of monitoring after elective craniotomy. This score is constructed from several important clinical predictors, such as age, Charlson Comorbidity Index, surgical duration, vascular pathology, blood loss, and the American Society of Anesthesiologists score. The model demonstrated good discriminatory ability with an area under the curve of 0.78 in internal validation and estimated that 12 hours of monitoring could capture most postoperative complications. External validation of the risk stratification approach was also demonstrated by Betbeder et al. (2023) through Cranioscore, which helps identify patients at risk of early complications requiring ICU. In the context of rapid discharge, Levy et al. (2023) used a prognostic scoring system to select patients who were safe for same-day discharge after brain tumor resection. Practically, these tools can be implemented during postoperative triage to help determine whether patients are suitable for PACU/ward, intermediate care, or ICU admission. However, the role of predictive tools must remain understood as decision-aid tools. Most models were developed from single-center retrospective studies, so their external validity, cross-population calibration, and feasibility of application in different settings still require further study. Therefore, prediction scores need to be combined with clinical judgment, serial neurological assessments, and hemodynamic and respiratory assessments by nurses and the medical team.

Theme 3. Structured postoperative pathways improve service efficiency

Several studies in this review have shown that structured postoperative pathways can improve service efficiency without significantly compromising patient safety. Hoffman et al. (2023) reported that implementing a novel postoperative pathway after craniotomy was associated with faster time to imaging, shorter length of stay, and lower hospital costs. (Ruiz Colón et al. (2023) also demonstrated, through implementation of the NICE protocol, that low-risk patients could bypass the routine ICU, be monitored first in the PACU, and then transferred to a neurosurgical ward with structured neurological monitoring by trained nurses. After the protocol was implemented, ICU utilization decreased, length of stay was shortened, and hospitals achieved significant cost savings. The concepts of early discharge and same-day discharge have also become important components of structured pathways after craniotomy. Vallejo et al. (2022) demonstrated that same-day discharge after brain tumor resection is feasible in carefully selected patients. These findings are supported by Levy et al. (2023), who used a prognostic scoring system to improve patient selection, and (Nijs et al. (2023), who reported acceptable safety results in a single-center observational study, and (Pelaez-Sanchez et al. (2023), who combined enhanced recovery and same-day discharge with Hospital-at-Home follow-up. Although the direction of benefit for these pathways tends to be consistent, differences in results between studies may still arise due to variations in discharge protocols, access to follow-up, patient and family educational readiness, and the types of outcomes assessed. This means that the success of a structured postoperative pathway depends heavily on appropriate patient selection, clear observation protocols, pre-discharge education, and adequate postoperative follow-up.

Summary of the direction of intervention effects

In general, the included studies demonstrated a consistent direction of benefit for more selective postoperative monitoring strategies in appropriately selected patients. Several studies demonstrated that monitoring in the PACU, neuroscience ward, or non-ICU postoperative unit did not significantly increase clinical risk compared to routine ICU care, especially in patients at low risk of complications. In some contexts, this approach was also associated with shorter lengths of stay, lower ICU utilization, and reduced service costs. However, these findings should not be interpreted as implying that all post-craniotomy patients can be immediately placed on a non-ICU pathway. Most studies emphasize that the safety of interventions relies heavily on rigorous patient selection, both through clinical considerations and the use of prediction scores. Furthermore, the certainty of the evidence is limited because the database is predominantly retrospective observational studies, so the risk of confounding and selection bias still needs to be considered. Therefore, the direction of effect of the interventions in this review can be summarized as beneficial in selected patients, equivalent to routine ICU in certain contexts, requiring rigorous selection, and highly dependent on team competence and standardized care protocols.

Key Interpretation of Review Results

The results of this review indicate that routine ICU care after craniotomy is not necessary for all patients. Several studies have shown that appropriately selected adult patients after craniotomy can be safely monitored in the PACU, neuroscience ward, or other non-ICU pathways without significantly increasing adverse clinical outcomes. These findings signal a shift from the conventional approach of placing nearly all post-craniotomy patients in the ICU toward a more selective, risk-based approach. However, caution should be exercised when interpreting the results, as most of the evidence comes from retrospective observational studies. Therefore, this review is best understood as supporting the safety and feasibility of selective pathways in selected patients, rather than as definitive causal evidence that all non-ICU pathways are superior to routine ICU care.

Significance of Findings for Neurological Monitoring

The findings of this review emphasize that non-ICU pathways should not be understood as a less restrictive form of monitoring. Rather, their success depends on disciplined, standardized, and responsive serial neurological observation to early clinical changes. Patients admitted to the PACU, ward, or same-day discharge pathway still require consistent monitoring for level of consciousness, behavioral changes, focal neurological deficits, vital signs, pain, and other signs of deterioration. Therefore, the quality of monitoring is more important than simply the location of the care unit. Non-ICU units can be safe if they have a robust observation system, appropriate assessment frequency, good documentation, and clear escalation protocols. Conversely, even if patients are admitted to the ICU, delays in recognizing neurological changes can still occur if monitoring is not structured. These findings demonstrate that the key to post-craniotomy patient safety lies in the quality of neurological surveillance, not just the care unit label.

The role of prediction scores and clinical judgment

The review results indicate that prediction scores and risk stratification models have significant value in assisting the triage process for post-craniotomy patients. The machine learning-based model, Cranioscore, and postoperative complication predictive scores can help distinguish patients requiring intensive surveillance from those who may be safely treated on a non-ICU pathway or early discharge. Practically, these scores can be used after surgery or during the early recovery phase to support decisions regarding patient placement, frequency of neurological observation, the need for rapid imaging, and readiness for transition to the ward or discharge. However, prediction scores should not replace clinical judgment. Most of the models in the included studies were developed retrospectively and in specific settings, so their external validity, ease of use, and performance in different populations still need to be considered. Therefore, the scores should be used as decision-support tools, not as the sole basis for determining monitoring intensity. The use of prediction scores should be combined with clinical assessment by nurses and the medical team, including direct observation of the patient's neurological status, hemodynamics, pain, respiration, and general condition.

Variation in Results and Sources of Inconsistency Between Studies

The differences in results between studies are likely influenced by several factors. First, the surgical populations studied were not entirely homogeneous, as some studies focused on supratentorial tumor resection, while others evaluated epilepsy surgery, microvascular decompression, or mixed elective neurosurgical pathways. Second, outcome definitions and observation horizons also differed; for example, some studies assessed 24-hour adverse events, others assessed ICU requirements, and still others assessed length of stay, costs, or readmission. Third, the dosage of monitoring interventions varied, ranging from the frequency of neurological checks in the PACU, the length of initial observation, access to imaging, to the availability of neuroscience-trained nurses. Fourth, contextual factors such as ICU capacity, escalation culture, and post-discharge follow-up systems also influenced outcomes. Therefore, inconsistencies between studies do not necessarily indicate the failure of a particular strategy, but more often reflect variations in implementation and service context.

Implications for the Role of Nurses

The implications of this review's results are significant for nursing practice, as nurses are the closest personnel to patients in the acute postoperative phase. Nurses play a central role in conducting serial neurological assessments, including assessing level of consciousness, orientation, pupillary response, motor strength, behavior, and signs of other neurological complications. Through repeated and structured observations, nurses are at the forefront of early deterioration detection. Furthermore, nurses play a crucial role in communication and clinical escalation. When changes in neurological status are detected, delays in reporting can directly impact patient outcomes. Therefore, accurate documentation, prompt communication with the medical team, and an understanding of escalation protocols are crucial. In early or same-day discharge pathways, nurses also play a role in assessing readiness for discharge, providing education to patients and families, explaining danger signs, and ensuring a clear follow-up plan. Therefore, the quality of postoperative pathway implementation is highly dependent on the competence and preparedness of nurses.

Relevance to patient safety or surveillance nursing

The results of this review are highly relevant to the concepts of patient safety and surveillance nursing. From a patient safety perspective, the primary goal of postoperative monitoring is to prevent delayed recognition of complications that can lead to clinical deterioration, the need for re-intervention, or death. The surveillance nursing approach emphasizes that nurses not only collect data but also interpret changes in the patient's condition, recognize early signs of problems, and initiate appropriate clinical actions. The findings of this review demonstrate that the success of non-ICU pathways and efficient pathways are highly dependent on robust surveillance. Safely cared for patients outside the ICU does not mean they do not require close monitoring, but rather requires a surveillance system that enables early detection and rapid response. Therefore, the results of this review support that risk-stratified postoperative care can only be safe if accompanied by high-quality, patient-safety-oriented surveillance nursing.

Hospital Implementation Context

In the context of hospitals with limited ICU capacity, the results of this review have important practical implications. Selective monitoring pathways can be a rational strategy to reduce ICU burden and optimize resource utilization, especially in low-risk patients. However, implementing this approach requires clear, standardized protocols, including patient selection criteria, neurological observation schedules, escalation indicators, and inter-team communication channels. Without robust protocols, efficiency efforts can actually increase the risk of delayed complication detection. Nurse training is also a key factor. Hospitals wishing to implement non-ICU or same-day discharge pathways must ensure that nurses are competent in neurological assessment, delirium detection, delayed awakening recognition, and early deterioration. In the Indonesian context, implementation of this approach may need to be gradual, starting with large referral hospitals with adequate resources, protocols, and training. Afterward, the model can be adapted to suit the service capacity of each hospital.

Transferability to Indonesian settings and low-middle-income countries

The predominance of studies from high-income countries requires careful assessment of the transferability of findings. Non-ICU pathways and rapid discharge are likely easier to implement in hospitals with trained neurosurgical nurses, a robust handover system, 24-hour imaging access, and clear escalation criteria. In Indonesia or other low- and middle-income countries, necessary adaptations may include gradual implementation for low-risk patients, the use of a simple neurologic observation checklist, enhanced training of ward nurses, standardization of referral pathways back to the ICU, and guaranteed post-discharge follow-up. With this approach, the principle of risk-stratified care can still be applied, but its implementation must be tailored to the capacity of local human resources, infrastructure, and communication systems.

Comparison with Other Literature

In general, the findings of this review align with the development of the neurosurgical fast-track and efficiency-based care literature, which emphasizes that not all post-craniotomy patients require routine ICU care. The studies in this review support a similar approach, namely more appropriate patient selection, reduced ICU utilization, and optimized postoperative pathways without compromising safety. However, this alignment does not eliminate the need to assess the local context. Hospitals with limited human resources, delayed access to imaging, or immature protocols may face different challenges. Therefore, interpretation of the review's findings should consider the readiness of the care system before recommendations are widely implemented.

CONCLUSION

Available evidence suggests that postoperative neurological monitoring in adult patients after craniotomy is best understood as a structured, risk-based approach supported by adequate nursing competency. Non-ICU pathways appear to be safely implemented in selected patients, particularly when supported by clear neurological observation protocols and a rapid escalation system. Prediction scores and risk stratification can help determine more appropriate monitoring intensity, but their use must be combined with clinical judgment and direct assessment by the clinical team. Because the evidence base is still dominated by observational studies, these conclusions need to be applied cautiously to the local context.

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