

Original Research

Evaluating Patient Outcomes of Postoperative Admission to the Neurosurgery Floor compared to the Intensive Care Unit Following Supratentorial Craniotomy for Brain Tumor Resection

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Introduction

For years patients who underwent craniotomy for tumor would be routinely admitted to the ICU after surgery. Recently, enhanced recovery after surgery (ERAS) protocols have been developed to help with sending patients to a lower level of care after surgery. At our institution, during the COVID-19 epidemic, many patients who underwent craniotomy for tumor resection were admitted to a regular med-surg floor allowing ICU beds to be reserved for critically ill patients. These patients were not treated under a specific ERAS protocol. The objective of this study was to evaluate the safety of neurosurgical floor admission following supratentorial craniotomy for tumor resection without a formal ERAS protocol.

Methods

A retrospective chart review was conducted on adult patients undergoing supratentorial craniotomy for glioma, meningioma, or metastatic lesions between January 2017 and October 2023 by a single surgeon. Patients were grouped into pre-COVID-19 (2017–2019) and post-COVID-19 (2021–2023) cohorts, with 2020 excluded as a washout period. Postoperative admission location and outcomes, including length of stay (LOS), complications, and 30-day readmission, were compared using Fisher's exact test, Wilcoxon rank-sum test, and multivariable logistic regression.

Results

Pre-COVID-19, 6% of patients (n = 8) were admitted to the neurosurgery floor whereas 48% of patients (n = 69) were admitted to the floor postop post-COVID-19. Patient demographics, tumor type, tumor location, and Charlson Comorbidity Index (CCI) were similar across both time periods. In the pre-COVID-19 cohort, patients admitted to the floor demonstrated a non-significant trend toward reduced LOS (mean (SD): 3.8 (3.2) vs. 5.0 (3.9), p = 0.3) and fewer postoperative complications (12.5% vs. 58.9%, p > 0.9) compared to ICU patients; however, interpretation is limited by the small number of floor admissions (n = 8). In the post-COVID-19 cohort, similar differences were observed, and these reached statistical significance, likely reflecting the larger number of patients admitted to the floor. Patients admitted to the floor in the post-COVID-19 era had significantly reduced LOS (3.4 (SD 3.5) vs. 7.1 (SD 9.1), p < 0.001) compared to ICU patients. Thirty-day readmission rates were lower among floor patients in the post-COVID-19 cohort (14.5%) compared to the pre-COVID-19 cohort (37.5%), although this difference should be interpreted cautiously given the small sample size in the pre-COVID-19 group.

Conclusion

Admission of appropriately selected patients to the neurosurgical floor following supratentorial craniotomy is feasible and appears safe, with shorter LOS and no observed increase in readmissions. However, these findings are likely influenced by patient selection and system-level factors, and causal conclusions cannot be drawn. ICU

resources may be reserved for higher-acuity patients while maintaining safe postoperative care.

INTRODUCTION

Patients admitted to the intensive care unit (ICU) have access to a highly specialized team equipped to manage complex neurological conditions in a timely manner. Continuous neurological assessments, advanced imaging, low patient-to-provider ratios, and immediate availability of life-saving care are known to help optimize patient recovery in the ICU.^{1,2} While admission to the ICU may be necessary for some patients, recent literature demonstrates safety of sending post-surgical patients to the floor with an enhanced recovery after surgery (ERAS) protocol in place.³⁻⁸

ERAS protocols involve pre-operative, intra-operative and post-operative quality improvement measures for a more standardized approach to patient care. This involves pre-operative rehabilitation (“prehab”), pre and post-operative nutrition, evidence based fluid and pain management, and many other methodologies.^{5,9-13} Creation of ERAS protocols is often inter-disciplinary, institution specific and time intensive. Moreover, like most quality projects, requires continuous evaluation and re-design based on outcomes.

At our institution, ERAS protocols have been adopted for patients undergoing spine surgery¹⁴⁻¹⁷ and this has resulted in significant quality improvements for patients and providers. However, no such protocol was developed for patients undergoing craniotomy for tumor. During the COVID-19 pandemic, out of a shortage of ICU beds, many patients who underwent craniotomy for tumor were admitted to a med-surg floor level instead of the ICU. These admission trends have been published by other groups.^{18,19} However, our patients were not treated with an ERAS protocol.

Herein we evaluate and report variables including LOS, mortality, and readmissions from a large, unselected cohort managed without a formalized ERAS protocol during an acute global healthcare crisis to evaluate the safety and potential benefits of this practice.

METHODS

STUDY POPULATION

A retrospective chart review was conducted on patients over the age of 18 who underwent craniotomy for resection of supratentorial glioma, metastatic lesion(s), or meningioma between January 2017 and October 2023 by a single surgeon at our institution. A single surgeon was chosen for this study to minimize variability in postoperative management. Tumor surgeons have variable practice patterns regarding ICU versus floor admission, and there was no significant change in other surgeons’ practices before and after COVID-19. However, one surgeon uniquely altered their practice due to the pandemic, providing an opportunity to assess the safety of this change. By focusing on

a single surgeon’s patient population, we aimed to reduce confounding factors and better isolate the impact of this practice shift on patient outcomes. IRB approval (IRB202301733) was obtained to conduct this review of adult medical records during the study period. This study was conducted in accordance with institutional guidelines and the Declaration of Helsinki. The requirement for informed consent was waived by the institutional review board. Patients were identified through a search of diagnosis (ICD-9) and procedure (CPT) codes. Patients were excluded from this cohort if they were (a) under the age of 18, (b) underwent craniotomy for an indication other than tumor resection, (c) had an infratentorial tumor resection, or (d) had resection of a skull base meningioma as these patients may have other ICU indications (i.e. ventriculostomy).

DATA COLLECTION

Clinical data in the post-operative setting during patients’ admission and after discharge were collected. Individual patient medical records were assessed for Charlson Comorbidity Index (CCI), intraoperative blood loss, and length of surgery as a means for controlling for complexity of surgery.²⁰ Postoperative admission location to either the ICU or neurosurgery floor was recorded for all patients. Prior to the COVID-19 pandemic, the default postoperative admission location for the majority of patients was to the ICU. After COVID-19, the default for patients was admission to the floor which was an important change compared to prior to the pandemic. The decision for ICU admission became more focused on a combination of patient comorbidities and case complexity. After COVID, criteria for ICU admission were similar to published literature.²¹⁻²⁵ Patients were admitted to the ICU after discussion with the surgeon and anesthesia attending for increased comorbidities, advanced age, larger tumors with significant cerebral edema, and more rarely for intraoperative hemodynamic instability, new postoperative neurologic impairment, need for vasopressive medication or antihypertensive drips, airway failure requiring a need for mechanical ventilation or presence of external ventricular drain (EVD).^{21,23} Patients not meeting these criteria were admitted to the floor.

Discharge, disposition, hospital length of stay, 30-day readmission rates, and 30-day mortality rates were extracted and compared. Postoperative complications experienced during the hospital stay were collected and included acute respiratory failure, deep vein thrombosis (DVT), hematoma, surgical site infection, new neurologic deficits, seizure, and stroke. Each complication was defined using clinically standardized criteria where possible. Acute respiratory failure was defined as the need for reintubation and mechanical ventilation following initial extubation in the operating room. Surgical site infection was defined based on clinical diagnosis documented in the medical record requiring antibiotic treatment or procedural intervention. Stroke was defined as new radiographic evidence of is-

chemic or hemorrhagic infarction on postoperative imaging with corresponding clinical findings when available. New neurologic deficits were defined as any new focal neurologic impairment documented on postoperative examination compared to the preoperative baseline. At our institution, laboratory studies including basic metabolic panel, complete blood count, and blood cultures are not routinely ordered for post-craniotomy. We compared the frequency of these labs when collected within 24 hours after surgery between cohorts to evaluate differences in resource utilization and overall hospitalization costs.

Complications were analyzed at both the event level and patient level. Individual complication types were recorded as distinct events; therefore, patients with multiple complications contributed multiple events to the overall complication count. Additionally, a composite patient-level outcome was created to indicate whether a patient experienced one or more complications during hospitalization. These data were gathered to facilitate the early identification of postoperative complications, which can serve as indicators of increased medical complexity.^{26,27} This list of complications was developed based on a review of the literature detailing complications implicated in admitting patients to the ICU or general floor following unexpected complications during or after surgery as well as craniotomy-specific complications that are reported quality metrics tied to physician reimbursement.²⁸⁻³⁰

HYPOTHESIS AND MEASUREMENTS

We hypothesized that direct admission to the neurosurgical floor following supratentorial craniotomy for tumor would result in fewer postoperative complications and a shorter hospital LOS compared to routine ICU admission, without compromising patient safety. Potential risks of a floor-first approach include delayed detection of neurological deterioration, slower escalation to airway or hemodynamic support, insufficient monitoring for sodium or osmolar abnormalities, and potential staffing limitations during nights or weekends. We specifically analyzed indicators of these risks, including ICU upgrade status, indication for ICU upgrade, 30-day readmission, return to the operating room within 30 days, 30-day mortality, total number of postoperative complications, and radiographic evidence of postoperative cerebral edema. Key outcome variables for this study included postoperative admission location and complications. For the analyses that compared outcomes across our two time periods, 2017 – 2019 and 2021 – 2023, patient data from the year 2020 was excluded to serve as a washout period that accounted for the change in admission practice during the COVID-19 pandemic.

STATISTICAL ANALYSES

Statistical analyses were conducted using R version 4.4.1. Descriptive statistics including means (Standard Deviation, SD) for continuous variables and frequencies (percentages) for categorical variables, were used to describe the study population. Fisher's exact test and the Wilcoxon rank sum test were employed to assess associations between admis-

sion locations and study patients' characteristics for categorical variables and continuous variables, respectively, by time-period (Pre-COVID vs. Post-COVID). A multivariable logistic regression model was used to evaluate the association between postoperative admission location (ICU vs. Neurosurgery Floor) and postoperative complication status (Yes vs. No), while adjusting for selected patient demographic and clinical characteristics including sex, CCI, surgery recurrence, diagnosis, and length of surgery. These variables were selected based on their clinical relevance and availability within the retrospective dataset as markers of baseline comorbidity and operative complexity. However, we recognize that other potentially important confounders, including tumor size, intraoperative blood loss, functional status, and additional intraoperative variables, were not fully captured in the model.

RESULTS

A total of 327 patients who underwent supratentorial craniotomy for glioma, meningioma, metastatic lesion(s), or other were included in this study. 249 patients were admitted to the ICU (62.2% men) and 78 patients (55.1% men) were admitted to the neurosurgery floor during the entire study period ([Table 1](#)). Evaluation of ICU versus floor patients during the entire study period found no difference in CCI between the groups, type of tumor, length of surgery, readmission rate, return to the OR, complications or postoperative edema. As expected, the LOS was 5.9 days (SD 6.6) for ICU patients compared to 3.4 days (SD 3.5) ($p < 0.001$) for patients admitted to the floor. The ICU patients were less likely to be discharged home and had increased likelihood of having lab values collected within 24 hours of surgery. Other complications including death were statistically similar between ICU and floor patients overall ([Table 2](#)). Of patients admitted to the neurosurgery floor, 5 (5.4%) were upgraded to the ICU during their hospital stay ([Table 3](#)). All ICU upgrades occurred in the post-COVID-19 time-frame. Indications for upgrade included neurologic deterioration (e.g., seizures, worsening cerebral edema), cardiovascular instability (e.g., atrial fibrillation with rapid ventricular response), and need for higher-level monitoring or intervention.

Next these data were stratified with respect to pre- and post- COVID-19 time periods. Pre-COVID, only 6% of patients were sent to the floor post-operatively and this increased to 48% post-COVID-19 ([Table 4](#)). Post-COVID 19, the patients in the ICU had a trend for higher CCI (4.5) compared to the floor patients (3.9) and this difference was not seen pre-pandemic. The major differences between the pre-COVID and post-COVID cohorts were in length of surgery, LOS, disposition, difference in complication rates and lab values collected within 24 hours. The length of surgery was significantly different between ICU and floor patients pre-COVID (average 2.6 hrs vs. 1.4 hrs, $p < 0.001$) and became insignificant post-COVID (average 3.9 hrs vs. 3.7 hrs, $p = 0.02$). Pre-COVID the difference in LOS between the ICU cohort floor cohort was not statistically significant ($p = 0.3$) and it became significantly different post-COVID (LOS for ICU 7.1

Table 1. Demographic and Clinical Characteristics for All Patients by Admission Location (ICU vs. Neurosurgery Floor).

	Overall (N = 327)	ICU (N = 249)	Neurosurgery Floor (N = 78)	p-value ⁺
Gender				0.3
Male	198 (60.6%)	155 (62.2%)	43 (55.1%)	
Female	129 (39.4%)	94 (37.8%)	35 (44.9%)	
CCI				0.2
Mean (SD)	4.2 (2.1)	4.2 (2.1)	4.0 (2.2)	
Median	4.0	4.0	3.5	
Range	0.0 to 14.0	0.0 to 14.0	0.0 to 11.0	
Diagnosis				0.6
Glioma	278 (85.0%)	209 (83.9%)	69 (88.5%)	
Meningioma	6 (1.8%)	6 (2.4%)	0 (0.0%)	
Metastatic lesion	13 (4.0%)	11 (4.4%)	2 (2.6%)	
Other*	30 (9.2%)	23 (9.2%)	7 (9.0%)	
Length of surgery (hours)				0.2
Mean (SD)	3.1 (1.8)	3.0 (1.5)	3.4 (2.5)	
Median	2.8	2.8	3.1	
Range	0.1 to 21.2	0.1 to 10.5	1.0 to 21.2	
LOS				< 0.001
Mean (SD)	5.3 (6.1)	5.9 (6.6)	3.4 (3.5)	
Median	3.0	4.0	2.0	
Range	0.0 to 68.0	1.0 to 68.0	0.0 to 22.0	
Disposition				< 0.001
Home	226 (69.1%)	157 (63.1%)	69 (88.5%)	
Skilled nursing home	2 (0.6%)	2 (0.8%)	0 (0.0%)	
In-patient rehabilitation	83 (25.4%)	75 (30.1%)	8 (10.3%)	
Patient died	3 (0.9%)	3 (1.2%)	0 (0.0%)	
Other*	13 (4.0%)	12 (4.8%)	1 (1.3%)	
Readmission within 30 days of surgery	55 (16.8%)	42 (16.9%)	13 (16.7%)	> 0.9
Return to the operating room within 30 days of surgery	45 (13.8%)	39 (15.7%)	6 (7.7%)	0.090
Mortality within 30 days of surgery	9 (2.8%)	9 (3.6%)	0 (0.0%)	0.12
Total number of patients with complications during hospital stay	49 (15.4%)	44 (18.3%)	5 (6.4%)	0.011
Laboratory values collected within 24 hours of surgery	171 (53.6%)	146 (60.6%)	25 (32.1%)	< 0.001
Postoperative edema	167 (51.2%)	121 (51.9%)	46 (49.5%)	0.7

This table summarizes baseline patient characteristics and postoperative outcomes for the entire study cohort, stratified by admission location. Key comparisons of interest include LOS, discharge disposition, complication rates, and resource utilization (laboratory testing). P-values reflect comparisons between ICU and floor cohorts.

*Diagnosis of "other" refers to patients who had a supratentorial tumor outside of the aforementioned defined diagnoses. Disposition of "other" refers to disposition outside of the aforementioned defined locations.

+P-values were calculated with a Fisher's exact test or Wilcoxon rank sum test

CCI – Charlson Comorbidity Index, ICU – Intensive Care Unit, LOS – Length of Hospital Stay, SD – Standard Deviation,

Table 2. Complications During Hospital Stay by Admission Location (ICU vs. Neurosurgery Floor) for All Patients (2017-2019 and 2021-2023)

	Overall (N = 327)	ICU (N = 249)	Neurosurgery Floor (N = 78)	p-value
Acute respiratory failure	4	4 (1.6%)	0 (0.0%)	0.6
Death	3	3 (1.2%)	0 (0.0%)	> 0.9
Hematoma	7	6 (2.4%)	1 (1.3%)	>0.9
Infection	9	7 (2.8%)	2 (2.6%)	>0.9
New neurologic deficits	3	2 (0.8%)	1 (1.3%)	0.6
Seizure	19	16 (6.4%)	3 (3.8%)	0.6
Stroke	7	6 (2.4%)	1 (1.3%)	>0.9
DVT	2	2 (0.8%)	0 (0.0%)	>0.9

The total number of complications for all patients in this study was extracted and analyzed. For patients with multiple complications, each complication was coded and analyzed as a separate event (event-level analysis), while overall complication rates were also assessed at the patient level. Values are reported as frequency (percent). P-values were calculated with a Fisher's exact test.

DVT = Deep Vein Thrombosis; ICU = Intensive Care Unit

Table 3. Indications for ICU Upgrade from the Neurosurgery Floor Post-COVID-19 (2021-2023).

Age/ Gender	CCI	Diagnosis	Postoperative Admission Location	Indication for ICU Upgrade
74-year-old male	7	GBM	Neurosurgery floor	Intractable seizures
57-year-old male	3	GBM	ICU	On postoperative day 9 and 10, the patient became progressively more confused and repeat MRI demonstrated significantly worsened edema, midline shift
63-year-old male	9	Astrocytoma	Neurosurgery floor	Patient spontaneously went into atrial fibrillation with rapid ventricular response while on the neurosurgery floor and was upgraded to the ICU the same night.
74-year-old male	6	Meningioma	ICU	Intractable seizures
60-year-old male	7	Metastatic melanoma	ICU	On postoperative day 2 he experienced venous infarct requiring take back to the OR

This table details individual cases of ICU escalation among patients initially admitted to the neurosurgery floor, including patient characteristics, diagnosis, and clinical indications for upgrade. Of the patients admitted to the neurosurgery floor for the entire study timeframe, 5 patients (5.4%) were upgraded from the neurosurgery floor to the ICU. Individual CCI, diagnosis, and indication for ICU upgrade from the neurosurgery floor is reported here. These events provide insight into the safety and failure modes of a floor-first admission strategy.

CCI – Charleson Comorbidity Index; GBM – Glioblastoma; ICU – Intensive Care Unit; MRI – Magnetic Resonance Imaging

days (SD 9.1) vs. 3.4 days (SD 3.5) for the floor patients, $p < 0.001$). Similarly, disposition status was not different between ICU and floor patients pre-COVID ($p = 0.3$) and after the pandemic the floor patients were much more likely to be discharged home (89.9%) compared to the ICU patients (64%) $p = 0.001$. Approximately 58% of patients who were admitted to the ICU underwent routine laboratory studies within 24 hours of surgery both in the Pre-COVID and Post-COVID cohorts. Because a much larger portion of patients were admitted to the floor in the post-COVID period, much fewer patients had routine lab studies ordered after surgery ($p = 0.004$). Lastly, prior to the pandemic risk of complications was similar between ICU and floor patients. After the pandemic, patients admitted to the floor had less complications $p = 0.012$.

Multivariable logistic regression analysis demonstrated no significant independent association between postoperative admission location and the odds of developing postoperative complications (Table 5). Likewise, CCI, surgery recurrence, diagnosis, and surgery length were not significantly associated with complication risk in the adjusted model.

DISCUSSION

The ICU is an invaluable resource that is necessary to provide patients with highly specialized life-saving care. While admission to the ICU may be warranted for critical patients after surgery, the change in admission practices necessitated by the COVID-19 pandemic required surgeons at our institution to be more thoughtful about which patients should be admitted to the ICU following craniotomy for supratentorial tumor. Our results suggest that admission of appropriately selected patients who undergo supratentorial craniotomy for resection of tumor to a med-surg floor level is feasible and appears safe, even without a formal ERAS protocol. In the post-pandemic analysis, patients were discharged home sooner, were less likely to have routine lab work and did not have increased risk of being upgraded to

the ICU or readmitted. An additional consideration when interpreting these findings is the potential impact of broader system-level changes between the pre-COVID-19 and post-COVID-19 time periods. The COVID-19 pandemic introduced substantial shifts in hospital operations, including changes in discharge practices, increased pressure on hospital throughput, alterations in staffing models, and evolving resource utilization strategies such as more selective laboratory testing. These factors may have independently influenced outcomes such as length of stay and discharge disposition, irrespective of postoperative admission location. As such, the observed reductions in LOS and differences in resource utilization in the post-COVID-19 cohort may reflect, in part, these systemic adaptations rather than solely the effects of changes in ICU triage practices.

The observed ICU upgrade rate of 5.4% among patients initially admitted to the neurosurgery floor represents an important safety metric. These escalation events were relatively infrequent and were driven by clinically identifiable changes, including neurologic deterioration and cardiopulmonary instability. Importantly, all upgrades occurred in the post-COVID-19 period, when a larger proportion of patients were triaged to the floor, reflecting real-world implementation of this practice pattern. While the sample size is limited, these findings suggest that a floor-first approach with appropriate patient selection can be safely implemented, provided that systems are in place for early recognition and timely escalation of care. The low rate of ICU transfer supports the feasibility of this model, though continued vigilance and clearly defined escalation pathways remain essential.

These data confirm prior descriptions of patients after craniotomy being admitted to the floor. Young et al.²⁵ developed a “Safe Transitions Pathway” model in which select patients were admitted to an ICU step-down unit rather than the ICU after craniotomy. Patients were included in the Safe Transitions Pathway model if they were under the age of 65, had a supratentorial tumor size < 3 cm, case length < 6 hours, and estimated blood loss < 500 mL.²⁵ Pa-

Table 4. Demographic and Clinical Characteristics by Time Period (2017-2019: Pre-COVID vs. 2021-2023: Post-COVID) and Admission Location (ICU vs. Neurosurgery Floor)

	2017 – 2019			2021 – 2023		
	ICU (N=127)	Neurosurgery Floor (N=8)	p-value	ICU (N=75)	Neurosurgery Floor (N=69)	p-value
Gender			0.5			0.7
Male	80 (63.0%)	4 (50.0%)		45 (60.0%)	39 (56.5%)	
Female	47 (37.0%)	4 (50.0%)		30 (40.0%)	30 (43.5%)	
CCI			0.5			0.052
Mean (SD)	4.1 (2.1)	4.1 (1.7)		4.5 (2.3)	3.9 (2.2)	
Median	4.0	3.5		4.0	3.0	
Range	0.0 to 13.0	2.0 to 7.0		2.0 to 14.0	0.0 to 11.0	
Diagnosis			0.4			0.091
Glioma	111 (87.4%)	7 (87.5%)		60 (80.0%)	61 (88.4%)	
Meningioma	2 (1.6%)	0 (0.0%)		3 (4.0%)	0 (0.0%)	
Metastatic lesion	3 (2.4%)	1 (12.5%)		6 (8.0%)	1 (1.4%)	
Other*	11 (8.7%)	0 (0.0%)		6 (6.8%)	7 (10.1%)	
Length of surgery (hours)			< 0.001			0.2
Mean (SD)	2.6 (1.0)	1.4 (0.3)		3.9 (1.5)	3.7 (2.5)	
Median	2.4	1.3		3.6	3.3	
Range	0.5 to 5.7	1.2 to 2.0		1.4 to 8.6	1.0 to 21.2	
LOS			0.3			< 0.001
Mean (SD)	5.0 (3.9)	3.8 (3.2)		7.1 (9.1)	3.4 (3.5)	
Median	4.0	3.0		4.0	2.0	
Range	1.0 to 19.0	0.0 to 8.0		1.0 to 68.0	0.0 to 22.0	
Disposition			0.3			0.001
Home	79 (62.2%)	6 (75%)		48 (64.0%)	62 (89.9%)	
Skilled nursing home	1 (0.8%)	0 (0.0%)		1 (1.3%)	0 (0.0%)	
In-patient rehabilitation	41 (32.3%)	1 (12.5%)		21 (28.0%)	7 (10.1%)	
Patient died	1 (0.8%)	0 (0.0%)		2 (2.7%)	0 (0.0%)	
Other	5 (3.9%)	1 (12.5%)		3 (4.0%)	0 (0.0%)	
Readmission within 30 days of surgery	16 (12.6%)	3 (37.5%)	0.084	15 (20.0%)	10 (14.5%)	0.5
Return to operating room within 30 days of surgery	12 (9.4%)	0 (0.0%)	> 0.9	13 (17.3%)	6 (8.7%)	0.15
Mortality within 30 days of surgery	3 (2.4%)	0 (0.0%)	> 0.9	5 (6.7%)	0 (0.0%)	0.059
Total number of patients with complications during hospital stay	20 (16.1%)	1 (12.5%)	> 0.9	15 (20.8%)	4 (5.8%)	0.012
Laboratory values collected within 24 hours of surgery	73 (58.9%)	2 (25.0%)	0.076	42 (58.3%)	23 (33.3%)	0.004
Postoperative edema	59 (50.4%)	9 (47.4%)	> 0.9	34 (45.3%)	34 (49.3%)	0.7

This table compares patient characteristics and outcomes across pre-COVID-19 (2017–2019) and post-COVID-19 (2021–2023) cohorts, stratified by admission location. Interpretation of pre-COVID-19 floor comparisons should be approached with caution due to the small sample size (n=8). Key comparisons include LOS, disposition, complication rates, and resource utilization. Patients treated in the year 2020 were excluded from this analysis because 2020 served as a washout period. Diagnosis of “other” refers to patients who had a supratentorial tumor outside of the aforementioned defined diagnoses. Disposition of “other” refers to disposition outside of the aforementioned defined locations. P-values were calculated with a Fisher’s exact test or Wilcoxon rank sum test

CCI – Charlson Comorbidity Index, ICU – Intensive Care Unit, LOS – Length of Hospital Stay, SD – Standard Deviation

Table 5. Multivariable Logistic Regression Model of Complications (Yes vs. No) for All Patients (2017-2019 and 2021-2023)

	Odds Ratio (OR)	95% Confidence Interval	p-value
Neurosurgery floor admission location (ref: ICU)	0.69	0.39, 1.23	0.2
Sex (ref: Male)	0.66	0.40, 1.06	0.090
CCI	1.06	0.93, 1.20	0.4
Recurrent surgery	1.02	0.53, 1.91	>0.9
Diagnosis (ref: Glioma)			
Meningioma	2.69	0.50, 20.0	0.3
Metastatic lesion	0.45	0.09, 1.81	0.3
Other	1.00	0.43, 2.22	>0.9
Surgery length (hours)	1.04	0.90, 1.19	0.6
Laboratory values collected within 24 hours of surgery	1.35	0.83, 2.21	0.2

This model evaluates the association between postoperative admission location and the odds of developing complications, adjusting for selected patient demographic and clinical variables. Admission location was not independently associated with complication risk.

CCI – Charlson Comorbidity Index

tients in the Safe Transitions Pathway group were found to have significantly decreased LOS and direct cost per case by approximately \$422,000.²⁵ No patients were upgraded to the ICU, returned to the operating room, or died within the study time frame.²⁵ A later study by Laan et al.¹⁸ implemented a “no ICU, unless” policy to compare outcomes following supratentorial craniotomy when admitted to the ICU or ICU step-down unit. The implementation of this policy was found to provide a 13.3% reduction in cost for patients and significantly reduced postoperative complications without increasing LOS.¹⁸ Patients included in this protocol were interviewed after discharge and reported feeling safe and at ease while admitted to the ICU step-down unit.¹⁸ Perez-Varga et al.²³ developed an ICU step-down unit specifically for craniotomy for tumor patients during the COVID-19 pandemic. Patients were admitted to this intermediate unit if they were found to have no immediate postoperative complications, no signs and symptoms of clinical deterioration, no intracranial pressure monitors, no external ventricular drain, and no use of vasopressors.²³ Patients in this cohort experienced no adverse outcomes with significant financial savings.²³

The safety of ICU step-down admission led several investigators to compare outcomes following admission to the general floor as compared to the ICU. Florman et al.²¹ admitted supratentorial craniotomy for tumor patients to the neurosurgery floor rather than the ICU if they were hemodynamically stable with no new postoperative neurologic impairment. The floor admission protocol was created in a multidisciplinary manner based on historical patient outcomes with oversight by all practicing neurosurgeons, neurointensivists, nursing, and the neuro-surgical physical extender group.²¹ The results of this study found that patients sent to the floor had significantly shorter LOS and length of surgery with significantly more patients being discharged home.²¹ A postoperative post-anesthesia care unit pathway developed by Hoffman et al.²² was found to significantly reduce LOS in craniotomy for tumor patients treated from January 2021 to January 2022 with no in-

creased risk of early hospital readmission. Patients with case lengths of < 5 hours and estimated blood loss < 500mL were admitted to the floor using this protocol.²² However, reduced ICU utilization should be interpreted cautiously. Azad et al. reported that 2.1% of patients initially managed outside the ICU required escalation of care, while other studies have reported similar rates of unplanned ICU transfer (approximately 2–2.5%), typically due to neurologic deterioration, seizures, or hemodynamic instability.^{21,31,32} These findings highlight that even with appropriate patient selection, a subset of patients will require higher-level monitoring.

Ultimately, the level of postoperative care provided is individualized to the patient’s needs. Previous studies have indicated that craniotomy patients should be admitted to the ICU if they experience hemodynamic instability, severe neurologic complications, significant blood loss, low blood oxygen after extubation, a need for postoperative insulin drip, or duration of surgery longer than six hours.^{18,33,34} Franko et al.³⁵ observed that less than 10% of supratentorial craniotomy for tumor patients required ICU-level care and developed a 4-point score to guide ICU admission decisions. This score included a Karnofsky Performance Status less than 70 (1 point), need for general endotracheal anesthesia (1 point), and development of postoperative complications (2 points). The authors of this study found that a greater 4-point prediction score increased the likelihood of requiring ICU-specific care, indicating the use of this 4-point score may aid clinicians in stratifying the need for ICU admission in resource-limited settings. Based on our analysis, patients admitted to the ICU from 2021 to 2023 were more likely to have a higher CCI as compared to patients admitted to the general floor. Importantly, neurologic complications after craniotomy remain relatively common, particularly in the early postoperative period. Lonjaret et al. reported that 31% of patients experienced at least one complication and 16% developed neurologic complications within 24 hours, supporting the role of ICU monitoring for early detection in higher-risk patients.²⁹ Al-

though rare, postoperative hemorrhage (1.3%) and early postoperative seizures (~5%) can also result in significant morbidity and may require ICU-level resources.^{36,37} Additionally, subclinical seizures detectable only by continuous EEG monitoring, which is more readily available in ICU settings, have been described in this population.³⁸

Implementing a more personalized ICU admission protocol based on specific postoperative criteria and individual patient comorbidities ensures that ICU resources are allocated to the most critical patients, allowing for improved patient outcomes. This approach could additionally lead to a more efficient system that significantly reduces patient costs and unnecessary use of ICU resources. However, current risk stratification tools remain limited, with studies demonstrating only modest predictive performance and limited ability to reliably identify patients who can safely bypass ICU-level care.³⁹ Furthermore, heterogeneity in study design and significant selection bias across the literature limit the generalizability of existing findings.^{31,40} Finally, readmission rates after craniotomy remain substantial (approximately 10–13%), often due to neurologic or infectious complications, underscoring the importance of careful postoperative monitoring and follow-up regardless of initial admission location.^{41,42}

The present study is unique in the sense that our change in practice of admitting patients to the neurosurgery floor rather than the ICU was sudden and in absence of a formal ERAS protocol or standard operating procedure (SOP). Patients admitted to the ICU and neurosurgical floor prior to the pandemic were similar with respect to CCI, LOS, and postoperative complications, although these comparisons are limited by the small number of floor admissions in the pre-COVID-19 cohort. Following the change in practices brought about by the COVID-19 pandemic, our population of patients admitted to the ICU following craniotomy for tumor were more complicated, as indicated by the higher CCI than those admitted to the floor. In addition to differences in patient selection, these findings must also be interpreted in the context of concurrent system-level changes during the pandemic, which may have influenced clinical decision-making, discharge efficiency, and overall hospital resource utilization. The increased number of unique postoperative complications following this change in practice for ICU patients may be a direct reflection of this higher complexity of patients, as more critical patients are at a greater risk of developing postoperative complications by nature. Similarly, the observed reduction in LOS for patients admitted to the neurosurgery floor likely reflects differences in clinical complexity, as lower-acuity patients were more likely to be triaged to floor care. The downward trend in 30-day readmission rates for patients admitted to the floor pre-COVID-19 as compared to post-COVID-19 suggests that lower-risk patients were appropriately triaged to the floor rather than the ICU, further supporting this idea. We found this shift in practice patterns to be associated with safe outcomes, suggesting that our decision-making algorithm of sending more critical patients to the ICU and less critical patients to the neurosurgery floor following supratentorial craniotomy for tumor resection may be

effective when applied to appropriately selected patients. These observations have strengthened discussions regarding defining a SOP for ICU vs. floor admission for patients that have undergone a craniotomy for tumor at our institution; this is feasible and would support patient safety and appropriate allocation of resources.

The novelty of our study lies in demonstrating that selective admission to the neurosurgical floor following supratentorial craniotomy can be both feasible and safe. This approach was implemented under unanticipated, high-pressure conditions in the absence of a formalized protocol and may offer meaningful benefits to patients. Previous studies investigating the shift in ICU triage as a result of the COVID-19 pandemic have been conducted in controlled settings with narrowly defined criteria. Our study demonstrates pragmatic validation of previously proposed concepts and generalizable insights for institutions aiming to refine ICU triage practices. While not all COVID-era adaptations represent ideal practice, this particular change may represent a sustainable model for the future, especially in settings with constrained ICU availability.

The primary limitation of this study is the non-randomized allocation of patients to postoperative admission location, which introduces confounding by indication. In the post-COVID-19 period, patients were triaged to the ICU or neurosurgery floor based on clinical judgment, comorbidities, and surgical complexity, such that higher-risk patients were more likely to be admitted to the ICU. As a result, the observed differences in postoperative complications and length of stay between ICU and floor cohorts may reflect appropriate patient selection rather than a direct effect of admission location. This limitation is inherent to the retrospective, observational design and precludes causal inference regarding the impact of admission location on outcomes. Furthermore, all patient data were collected from a single surgeon at a single institution, which may have influenced the case distribution and surgical decision-making. The exclusion of other tumors outside of the supratentorial region may introduce selection bias and fail to represent the broader population of all craniotomy patients, although this was done intentionally to limit the confounders that may come with tumors in other locations (i.e. ventriculostomy). Patients were not randomly assigned to ICU or floor admission; rather, disposition was determined based on clinical judgment, including patient comorbidities, operative complexity, and perceived risk of postoperative complications. As a result, patients admitted to the neurosurgery floor were likely lower risk compared to those admitted to the ICU. This selection bias may partially explain the observed differences in outcomes, including reduced length of stay and complication rates among floor patients, and limits the ability to attribute these findings solely to admission location.

The small number of patients admitted to the neurosurgery floor in the pre-COVID-19 cohort (n=8) reflects historical practice patterns at our institution, but limits statistical power, increases susceptibility to type II error, and reduces the reliability of comparisons between ICU and floor patients in the pre-COVID-19 period. The small num-

ber of ICU upgrade events (n=5) further limits the ability to identify predictors of escalation or draw definitive conclusions regarding risk factors for ICU transfer. As such, findings from pre-COVID-19 subgroup analyses should be interpreted with caution and not overemphasized. An additional limitation is that the multivariable logistic regression model could not account for all clinically relevant confounders. Although the model included available markers of comorbidity and operative complexity, important factors such as tumor size, intraoperative blood loss, preoperative functional status, and other intraoperative variables were not comprehensively incorporated. As postoperative admission location was itself determined by clinical judgment based on many of these same factors, residual confounding may be present, and the adjusted model should not be interpreted as establishing a causal effect of admission location. Future studies using propensity score-based methods or prospective protocols would help better account for treatment-selection bias and more rigorously evaluate the independent relationship between admission location and postoperative outcomes. The comparison of cohorts across two distinct time periods introduces potential confounding from broader system-level changes associated with the COVID-19 pandemic. Differences in discharge practices, hospital throughput pressures, staffing models, and resource utilization may have independently impacted outcomes such as length of stay and laboratory utilization. As a result, temporal changes unrelated to admission location may partially explain the observed differences between pre- and post-COVID-19 cohorts. Future research efforts should be conducted to analyze data across a variety of neurosurgical pathologies, surgeons, and procedures to improve the validity of this study.

CONCLUSION

ERAS protocol development is not a pre-requisite to sending patients to the floor after craniotomy for tumor resection. Postoperative admission to the neurosurgery floor for supratentorial craniotomy is not surprisingly associated with reduced LOS without increased readmissions. Use of ICU beds can be reserved for critically ill patients while reducing LOS of post-craniotomy patients by sending them to the floor after surgery.

ABBREVIATIONS

CCI - Charlson Comorbidity Index
DVT – Deep vein thrombosis
ERAS – Enhanced Recovery After Surgery
ICU - Intensive Care Unit
LOS – Length of Stay
OR – Odds Ratio
SD - Standard Deviation

AUTHOR CONTRIBUTIONS

GH: Drafting of original manuscript, revision of manuscript, data collection
RM: Drafting of original manuscript, revision of manuscript
GL: Drafting of original manuscript, data analysis
GE: Data collection
KM: Data collection
AM: Data collection
GP: Data collection
JL: Revision of manuscript
AD: Revision of manuscript, data collection
MR: Project oversight, revision of manuscript, primary surgeon

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