Reexamining the Role of Postoperative ICU Admission for Patients Undergoing Elective Craniotomy: A Systematic Review*

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OBJECTIVES: The standard-of-care for postoperative care following elective craniotomy has historically been ICU admission. However, recent literature interrogating complications and interventions during this postoperative ICU stay suggests that all patients may not require this level of care. Thus, hospitals began implementing non-ICU postoperative care pathways for elective craniotomy. This systematic review aims to summarize and evaluate the existing literature regarding outcomes and costs for patients receiving non-ICU care after elective craniotomy.

DATA SOURCES: A systematic review of the PubMed database was performed following PRISMA guidelines from database inception to August 2021.

STUDY SELECTION: Included studies were published in peer-reviewed journals, in English, and described outcomes for patients undergoing elective craniotomies without postoperative ICU care.

DATA EXTRACTION: Data regarding study design, patient characteristics, and postoperative care pathways were extracted independently by two authors. Quality and risk of bias were evaluated using the Oxford Centre for Evidence-Based Medicine Levels of Evidence tool and Risk Of Bias In Non-Randomized Studies–of Interventions tool, respectively.

DATA SYNTHESIS: In total, 1,131 unique articles were identified through the database search, with 27 meeting inclusion criteria. Included articles were published from 2001 to 2021 and included non-ICU inpatient care and same-day discharge pathways. Overall, the studies demonstrated that postoperative non-ICU care for elective craniotomies led to length of stay reduction ranging from 6 hours to 4 days and notable cost reductions. Across 13 studies, 53 of the 2,469 patients (2.1%) intended for postoperative management in a non-ICU setting required subsequent care escalation.

CONCLUSIONS: Overall, these studies suggest that non-ICU care pathways for appropriately selected postcraniotomy patients may represent a meaningful opportunity to improve care value. However, included studies varied greatly in patient selection, postoperative care protocol, and outcomes reporting. Standardization and multi-institutional collaboration are needed to draw definitive conclusions regarding non-ICU postoperative care for elective craniotomy.

KEY WORDS: care de-intensification; elective craniotomy; intensive care unit; value-based care

As healthcare costs rise, there has been a growing focus on improving care value. Within this larger initiative, there has been a specific focus on analyzing and reducing costs in resource-intensive specialties (1–4). Prior studies have demonstrated that a key driver of the total cost related to surgical procedures is postoperative care (5, 6). As a result, several surgical fields, including colorectal surgery and gynecology, have implemented and optimized various early

*See also p. 1408.

DOI: 10.1097/CCM.0000000000005588

discharge and enhanced recovery after surgery protocols to improve patient recovery and care value (7–9).

Within neurosurgery, efforts to optimize postoperative care costs have largely been in the domain of spine surgery (10). In contrast, the application of these principles to craniotomies has been limited by the long-standing belief that cranial neurosurgery requires intensive monitoring postoperatively to detect and mitigate potentially catastrophic complications. While the standard-of-care after elective craniotomy is still postoperative ICU admission at most institutions, a number of studies have begun investigating whether patients benefit from this higher level of care (11–13).

Given the significant resource utilization associated with ICU level, neurosurgical teams have begun investigating alternative postoperative care pathways that bypass the ICU for select patients. However, the transition away from routine ICU postoperative care is not codified, and efforts to transition to non-ICU care are heterogeneous and institution-specific. Thus, this study aims to consolidate current evidence by systematically reviewing the available literature regarding non-ICU care pathways for elective craniotomy patients.

METHODS

Search Strategy

A systematic review of the literature was performed in accordance with the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to identify studies characterizing non-ICU care pathways (**Supplemental Digital Content 1**, http://links.lww.com/CCM/H134) (14). The search query consisted of a comprehensive string related to the terms "non-ICU disposition" and "elective craniotomy" (**Supplemental Digital Content 2**, http://links.lww.com/CCM/H135). The PubMed database was searched and all studies from database inception to database query (August 9, 2021) were included. This study was registered in advance with the International Prospective Register of Systematic Reviews (CRD42021252465). The initial protocol was amended once to reflect an updated search date and a narrower scope of focus that excluded patient and care team satisfaction from formal analysis.

Screening Strategy

The study screening was performed using the Covidence.org (Covidence, Melbourne, VIC, Australia) systematic review tool. The screening was conducted in two stages: 1) abstract and title screening and 2) full-text review for final inclusion.

Both screening steps were independently performed by two investigators (P.P.S., N.V.K.), with oversight involving a clinician who regularly cares for this patient population (T.D.A). Conflicts between the two authors were resolved by consensus involving a clinician (T.D.A).

Inclusion and Exclusion Criteria

To be included, studies must have: 1) been published in full article form in a peer-reviewed journal; 2) been published in English; 3) included patients undergoing elective craniotomies that did not have routine postoperative ICU care; and 4) specifically described outcomes for the non-ICU postoperative care cohort. All age groups and study designs were considered.

After eliminating duplicate articles, studies were excluded for the following reasons: 1) included nonelective surgical indications; 2) did not include patients undergoing cranial neurosurgery (stereotactic biopsy was not considered to be cranial neurosurgery); 3) did not specify postoperative care pathway; 4) did not report outcomes specifically for non-ICU postoperative care pathways; 5) only included qualitative outcomes; 6) only included patients undergoing stereotactic biopsy; 7) was a literature review or meta-analysis; and 8) was a case report or included fewer than five patients.

Data Extraction and Analysis

Data extraction was performed independently by two investigators (P.P.S., N.V.K.), with oversight involving a clinician (T.D.A.). Factors considered for each study included study design, number and age of patients, overall patient status (Karnofsky Performance Status and ASA Physical Status Classification System Score), indications for craniotomy, inclusion criteria for non-ICU care pathway, postoperative care pathway details, and indications for transfer of patients from non-ICU to ICU level of care. Units that provided a level of care between the neurosurgical floor and the ICU were considered intermediate care units (IMCs). Data were compiled into summative tables, and pooled analyses were performed for cost savings from non-ICU care pathways and the number of patients requiring transfer to a higher level of care. To avoid over-representation, if multiple studies analyzed the same patient population (e.g., a study cohort had significant overlap with a later updated study), only the most comprehensive study was included in summative analyses (pooled analyses, risk of bias analysis, and level of evidence determination). This study did not attempt a more comprehensive meta-analysis due to the heterogeneity in craniotomy indications, postoperative care pathways, and outcomes reported.

Study quality was evaluated using the 2011 Oxford Centre for Evidence-Based Medicine (OCEBM) Levels of Evidence tool (15), which assigns an evidence level based on study design and quality. Risk of bias for included studies was assessed using the Risk Of Bias In Non-Randomized Studies—of Interventions tool (16). This tool evaluates studies in seven domains and assigns an overall risk of bias of Low, Moderate, Serious, or Critical. Quality and bias assessments were performed by one investigator (P.P.S.) with oversight and review by a clinician (T.D.A.).

RESULTS

Of the 1,135 total articles initially identified in this study, 55 studies met eligibility criteria for full-text screening (**Fig. 1**). Inter-rater agreement was 95.5% at the title and abstract screening stage and 92.6% at the full-text review stage. One-thousand eighty studies were excluded during initial screening as studies that met search criteria but were deemed not relevant upon manual title and abstract review. Leading reasons for study exclusion at the full-text stage were "Outcomes not specifically reported for non-ICU patients" ($n = 10$), "Intervention other than elective craniotomy" ($n = 9$), and "no non-ICU patients" ($n = 6$). Twenty-seven records published between 2001 and 2021 met the final inclusion criteria. Studies were conducted in the United States ($n = 10$), Canada ($n = 9$), the United Kingdom ($n = 2$) (17, 18), the Netherlands ($n = 2$) (19, 20), Italy ($n = 2$) (21, 22), Japan ($n = 1$) (23), and Australia ($n = 1$) (24). Five included studies were published earlier this year (2021) (20, 21, 25–27). Publications by Bernstein and Mannien's groups from the University of Toronto (28–36) and Ter Laan et al (19, 20) contained significant overlap of included patients, so only the most comprehensive study from each center was included in figures and summative analyses. Thus, 18 studies in total were included in summative analyses (17, 18, 20–28, 37–43).

After excluding studies with overlapping patient populations, 16 studies describing inpatient non-ICU postoperative care and two studies describing outpatient craniotomy were included in the level of evidence analyses. Notably, no studies met OCEBM criteria for level 1 (systematic review of randomized trials or n-of-1 trials) or level 2 (randomized trial or observational study with dramatic effect evidence). Six studies presented level 3 evidence (cohort study or control arm of randomized trial), and 12 studies presented level 4 evidence (case-series or case-control studies, or poor quality prognostic cohort study). The risk of bias for nine studies was not evaluated as these studies either did not have a control group or did not make any statistical comparisons between groups. For the remaining nine studies, the risk of bias was moderate in five studies (20, 23, 25, 27, 43) and serious in four studies (24, 37, 40, 41) generally due to inherent differences in baseline patient status used to assign patients to ICU versus non-ICU care pathways. For example, patients who received non-ICU postoperative care had to meet specific predetermined criteria for eligibility, inherently adding bias to the comparison between these patients and those ineligible for stepdown care.

Patient Selection

The 17 studies that investigated outcomes for non-ICU inpatient care after craniotomy included 4,647 unique patients in total, 3,006 (64.7%) of whom received non-ICU care (**Table 1**). There was significant heterogeneity in patient selection for non-ICU care in the included studies. For example, while five studies included multiple indications for elective craniotomy, 12 focused on a single indication (e.g., only supratentorial tumor resection or only microvascular decompression for trigeminal neuralgia). Inclusion criteria for non-ICU care also varied greatly between studies and institutions. While two studies stated that neurosurgeon and anesthesiologist judgment was primarily used to determine inclusion (21, 27), others used a variety of preoperative, intraoperative, and postoperative factors (**Table 2**).

Postoperative Care Pathways

Non-ICU care pathways for 13 studies placed patients in neurosurgical floor beds, three studies placed patients in IMC beds, and one study placed patients

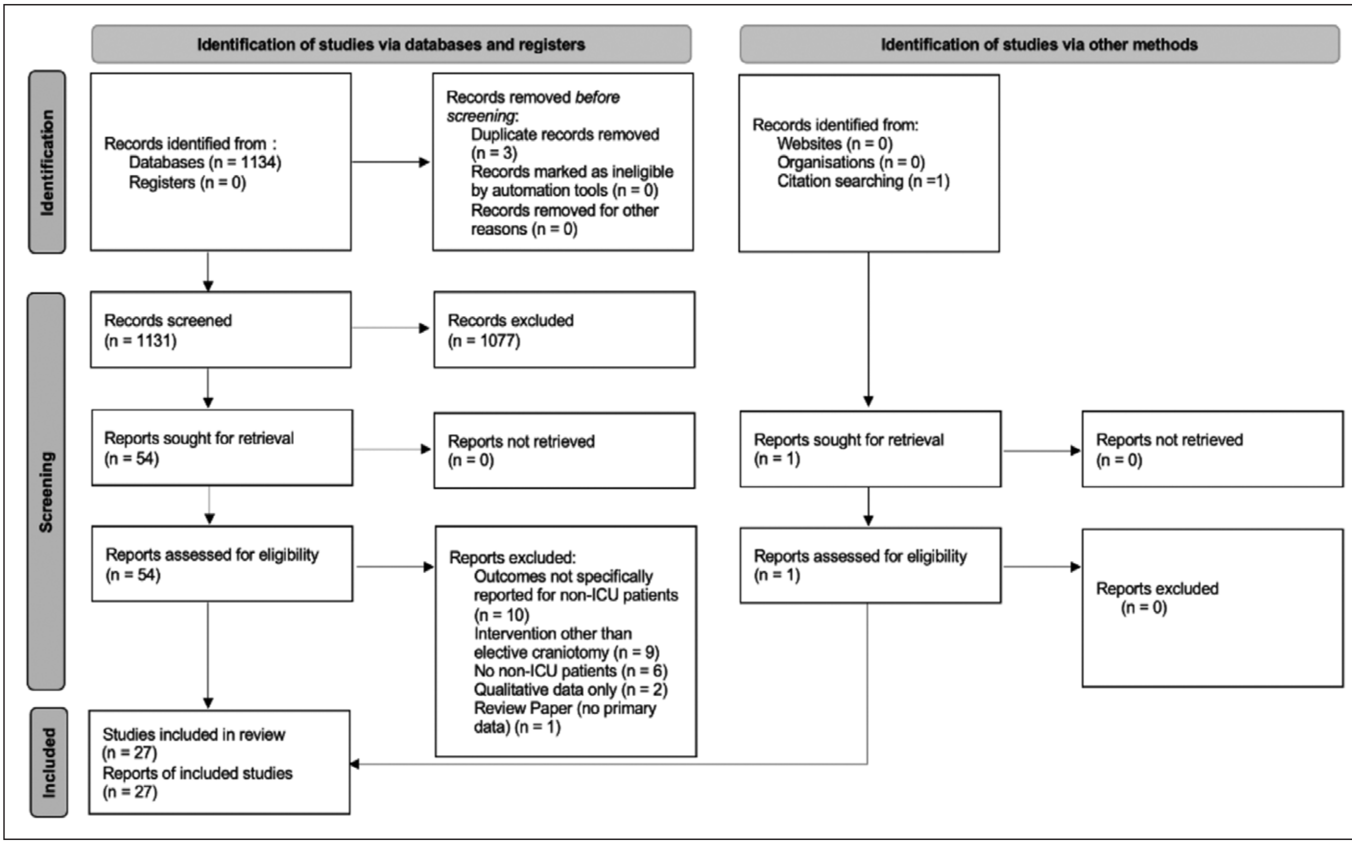

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram outlining study screening.

in both floor and IMC beds. Notably, Florman et al (40) and Ter Laan et al (19, 20) included both ICU and IMC patients in their control cohort and compared them with patients admitted to the neurosurgical floor. Patients generally were transitioned to the postanesthesia care unit (PACU) postoperatively and then often were required to meet certain selection criteria (including timeline of extubation, cognitive status, vitals, and need for additional monitoring) for subsequent transfer to the IMC or neurosurgical floor (Table 2). Several studies also described outcomes for craniotomy patients who were discharged on the same day as surgery (**Supplemental Digital Content 3**, http://links.lww.com/CCM/H136; and **Supplemental Digital Content 4**, http://links.lww.com/CCM/H137) (18, 28–36).

The specifics of care pathways varied greatly by institution, even for studies placing patients at the same postoperative level of care (e.g., IMC or floor). For example, Altieri et al (22) and Lawrence et al (41) both transferred patients to the neurosurgical floor. However, the former required hourly neurologic exams for the first 16 hours after craniotomy for supratentorial tumor resection, while the latter only required neurologic checks every 6 hours after microvascular decompression for trigeminal neuralgia. Importantly, while 14 studies in total transferred patients to the neurosurgical floor, five of them also included status checks every hour (20, 22, 24) or every 2 hours (39, 40), which is often considered outside of the scope of standard floor-level care (42).

Complications Requiring Transfer to a Higher Level of Care

After excluding studies with overlapping patient populations, 13 studies reported data regarding complications that required care escalation. Of these 13 studies, 10 reported rates of transfer to a higher level of care from the neurosurgical floor or IMC, one study reported rates of transfer from the operating room or PACU directly to the ICU, and two studies reported rates of transfer from both. Thirty-one out of 1,126 patients (2.8%) were transferred to higher acuity care directly from the operating room or PACU, while 22 out of 2,040 patients (1.1%) were transferred to

TABLE 1.
Summary of Studies Assessing Outcomes for Inpatient Non-ICU Hospitalization After Elective Craniotomy

Study	Study Design	Age Group	Number of Patients by Care Pathway	Age, yr, Mean (SD)	Status, Mean (SD)	Level of Evidence	Risk of Bias
			ICU, Non-ICU	ICU, Non-ICU	ICU, Non-ICU		
Beauregard and Friedman (43) United States	Retrospective cohort	≥ 18 yr	233, 193	53.6 (NA)[b]	NA, NA	3	Moderate
Terada et al (23)[a] Japan	Case-control	Adult	166, 130	58.1 (11.8), 58.8 (15.2)	ASA 1.7 (0.4), 1.7 (0.5)	4	Moderate
Bui et al (24) Australia	Retrospective cohort	≥ 16 yr	43, 351	53.8 (NA), 54.4 (NA)	NA, NA	4	Serious
Gabel et al (42) United States	Retrospective cohort	< 18 yr	NA, 61	8.3 (4.7)	NA, NA	4	NA
Ma et al (17)[d] United Kingdom	Retrospective/ prospective cohort	Adult	NA, 75	52(NA)	NA, NA	4	NA
Lawrence et al (41) United States	Case-control	≥ 18 yr	90, 190	56.7 (13.1), 57.8 (13.5)	ASA 2.3 (0.6), 2.5 (0.6)	4	Serious
Florman et al (40)[c] United States	Prospective cohort	> 17 yr	114, 200	58 (NA), 57 (NA)	NA, NA	3	Serious
Altieri et al (22) Italy	Retrospective cohort	> 18 yr	21, 243	66 (NA)	Admission Karnofsky Performance Status 69.4 (NA), 77.3 (NA)	4	NA
Mirza et al (39) United States	Retrospective cohort	All ages	66, 355	NA	NA, NA	4	NA
Osorio et al (38) United States	Prospective cohort	Adult	NA, 10	NA, 49 (NA)	NA, NA	4	NA
Ter Laan et al (19)[e] The Netherlands	Retrospective/ prospective cohort	Adult	68, 39 25, 84	55.5 (NA) 54.6 (NA)	ASA 2.1 (0.6) ASA 2.2 (0.6)	NA	NA
Young et al (37)[a] United States	Retrospective cohort	≥ 15 yr	220, 94	46.8 (NA), 49.1 (NA)	NA, NA	3	Serious
Munari et al (21) Italy	Retrospective cohort	≥ 18 yr	NA, 420	56.2 (14.3)	ASA 2 (2–3), median (interquartile range)	4	NA
Sun et al (27) United States	Retrospective cohort	≥ 18 yr	340, 209	51.2 (NA), 52.7 (NA)	NA, NA	3	Moderate

(Continued)

TABLE 1. *(Continued).*

Study	Study Design	Age Group	Number of Patients by Care Pathway	Age, yr, Mean (SD)	Status, Mean (SD)	Level of Evidence	Risk of Bias
			ICU, Non-ICU	ICU, Non-ICU	ICU, Non-ICU		
Ter Laan et al (20)[c] The Netherlands	Retrospective/prospective cohort	Adult	94, 13 59, 199	55.5 (NA) 56 (NA)	NA, NA NA, NA	3	Moderate
Pendharkar et al (26) United States	Prospective cohort	≥ 18 yr	NA, 63	45.4 (NA)	ASA 2.2 (0.6)	3	NA
Mallari et al (25)[f] United States	Case-control	Adult	73, 18 29, 59	49.1 (15.7) 48.1 (16.9)	2.5 (0.5) 2.6 (0.5)	4	Moderate

NA = not available.
[a]Numbers provided for full, unmatched cohort.
[b]Unspecified as mean or median.
[c]Control group included ICU and intermediate care unit patients.
[d]Study also included endoscopic minicraniotomy.
[e]Excluded from risk of bias and level of evidence analyses due to overlapping patient population with Ter Laan et al (20).
[f]Numbers reported for craniotomy subgroup of overall study.

TABLE 2.
Patient Selection and Postoperative Destination for Studies Assessing Non-ICU Hospitalization After Elective Craniotomy

Study Details	Indication For Elective Craniotomy	Inclusion Criteria for Non-ICU Care Pathway	Postoperative Unit (Frequency of Status Checks)
Beauregard and Friedman (43)	Brain tumor, pituitary adenoma, trigeminal neuralgia, hemifacial spasm, or Chiari malformation	Uneventful intraoperative course and wake-up in the PACU	Neurosurgical floor and IMC
Terada et al (23)	Vascular disease or tumor	ASA class < III, second 1.5 yr of study duration	Neurosurgical floor (3–4 hr)
Bui et al (24)	Supratentorial tumor, vascular, endoscopic ventriculostomy, skull base, infratentorial tumor, developmental	Nonprolonged operation, low anesthetic risk, no history of arteriovenous malformation, and no sleep apnea requiring positive pressure ventilation	Neurosurgical floor (every hour for the first 6 hr, then every 4 hr)
Gabel et al (42)[a]	Tumor resection	Did not present to the emergency department and/or were not transferred from another facility, did not require an external ventricular or lumbar drain postprocedure, no known intraoperative complications or postoperative neurologic deficits, extubated postoperatively	Neurosurgical floor

(Continued)

TABLE 2. (Continued).

Study Details	Indication For Elective Craniotomy	Inclusion Criteria for Non-ICU Care Pathway	Postoperative Unit (Frequency of Status Checks)
Ma et al (17)	Tumor resection	Elective endoscopic and awake craniotomies by a single surgeon	Neurosurgical floor
Lawrence et al (41)	MVD for trigeminal neuralgia	Patients at institution A	Neurosurgical floor (every 6 hr)
Florman et al (40)	Supratentorial tumor resection	Extubated within 1 hr of arrival in PACU, cognitive status adequate for clear communication and cooperation, stable neurologic status in PACU, only mild focal deficit concordant with presurgical examination findings, stable on nasal cannula oxygen, no new cardiac symptoms, systolic blood pressure < 150 mm Hg, no intraoperative status epilepticus or seizure in PACU, no intracranial drains, no coagulopathy or need for transfusion, no diabetes insipidus monitoring, no need for IV medication drips at the time of transfer	Neurosurgical floor (every 2 hr for the first 8 hr, then every 4 hr)
Altieri et al (22)	Supratentorial high-grade glioma	Karnofsky Performance Status > 70, ASA class < III, and Charlson Comorbidity Index ≤ 5	Neurosurgical floor (every hour for the first 16 hr)
Mirza et al (39)	Intra-axial brain tumor resection	No absolute indication for ICU intervention (ventilator requirement, external ventricular drain, medically unstable)	Neurosurgical floor (every 2–4 hr)
Osorio et al (38)	Supratentorial tumor resection	Routine craniotomy, tumor size < 3 cm, age < 65 yr	Neurotransitional care unit (IMC)
Ter Laan et al (19)	Supratentorial tumor resection	Age < 65 yr, no indication specified for intensive monitoring, length of surgery < 6 hr, supratentorial location	Neurosurgical floor (every hour)
Young et al (37)	Tumor, MVD, or Chiari decompression	Routine craniotomy, tumor size < 3 cm, operative time < 5 hr, blood loss < 500 mL, routine extubation, no intraoperative events or cardiopulmonary comorbidities requiring ICU	Neurotransitional care unit (IMC)
Munari et al (21)	Supratentorial tumor resection	Anesthesiologist/surgeon recommendation	Neurosurgical floor
Sun et al (27)	Supratentorial tumor resection	Anesthesiologist/surgeon recommendation	Neurosurgical floor
Ter Laan et al (20)	Supratentorial tumor resection	Supratentorial location, tumor size < 3 cm	Neurosurgical floor
Pendharkar et al (26)	MVD, tumor resection, cavernous malformation resection, Chiari decompression	Elective craniotomy for extra-axial tumors, neurosurgeon selection of low-risk patient, age < 65, ASA ≤ 3, not requiring > 2 doses of IV hypertensives in PACU within 1 hr prior to transfer	Neurosurgical floor
Mallari et al (25)	Tumor resection	No concerns during postoperative vital and neurologic monitoring, negative postoperative CT	Stepdown unit (IMC)

IMC = intermediate care unit, MVD = microvascular decompression, PACU = postanesthesia care unit.
[a]Study only included pediatric patients.

higher acuity care after initial admission to a step-down unit or the neurosurgical floor. After adjusting for double counting, 53 out of 2,469 patients (2.1%) overall required escalation to higher level postoperative care from their original non-ICU care pathway (**Table 3**). All reported complications by postoperative care pathway are described in **Supplemental Digital Content 5** (http://links.lww.com/CCM/H138). The median overall transfer rate to higher acuity care from the floor and IMC was 0.7%, ranging from 0% to 9.8% (**Fig. 2**). The highest rate of transfer (9.8%) was presented in Gabel et al (42), which was the only exclusively pediatric study that met inclusion criteria. Notably, three sizable studies based at quaternary care institutions in the United States (*n* = 63, *n* = 94, and *n* = 190) including a total of 347 patients did not require any transfers to higher level care (26, 37, 41). Additional outcomes for patients receiving non-ICU postoperative care are described in **Supplemental Digital Content 6** (http://links.lww.com/CCM/H139).

TABLE 3.
Rate of Transfer to Higher Acuity Care From Non-ICU Pathway After Elective Craniotomy

Study	Transfers to ICU/IMC From Intervention Group, *n* (%)	Comments Regarding Clinical Course for Patients Who Had Complications
Beauregard and Friedman (43)	Transfer from floor/IMC: 2/193 (1.0)	ICU observation and discharge 1 (0.5)
	Venous infarction 1 (0.5); cerebrospinal fluid leak 1 (0.5)	"Multiple active interventions, … ultimately made an excellent recovery." 1 (0.5)
Bui et al (24)	Transfer from floor: 2/343 (0.6)	"No patient suffered permanent sequelae as a result of the acute condition leading to the MET call."
	Severe hyponatremia 1 (0.3); deliberate drug overdose 1 (0.3)	
	Transfer from OR/PACU: 8/351 (2.3)	NA
	Slow neurologic recovery 3 (0.9); intraoperative blood loss 2 (0.6); unanticipated prolonged operation 1 (0.3); arterial hypertension 1 (0.3); refractory seizures 1 (0.3)	
Gabel et al (42)[a]	Transfer from floor: 6/61 (9.8)	Neurologically intact at follow-up 3 (4.8)
	Mild respiratory distress 1 (1.6); status epilepticus and intracranial hemorrhage 1 (1.6); intracranial hemorrhage 1 (1.6); increased seizure frequency 1 (1.6); cerebral salt wasting 1 (1.6); bradycardia 1 (1.6)	Death 1 (1.6) Lost to long-term follow-up 1 (1.6) Panhypopituitarism, bitemporal hemianopsia (present before surgery) 1 (1.6)
Lawrence et al (41)	Transfer from floor: 0/190	NA
Florman et al 2017 (40)	Transfer from floor: 5/200 (2.5)	"None of the 5 patients suffered any morbidity as a result of delayed diagnoses."
	Agitation 3 (1.5); Seizure 1 (0.5); Neurologic change 1 (0.5)	
Altieri et al (22)	Transfer from floor: 2/243 (0.8)	"The mean KPS of these patients at discharge was 76.4. No vascular complications were described."
	Hematoma requiring surgery 2 (0.8)	
Mirza et al (39)	Transfer from floor: 3/354 (0.8)	NA
	Unstable supraventricular tachycardia 1 (0.3); respiratory distress 1 (0.3); acute hydrocephalus 1 (0.3)	
	Transfer from OR/PACU: 1/355 (0.3)	NA
	Operative bed hemorrhage requiring reoperation 1 (0.3)	

(Continued)

TABLE 3. *(Continued).*

Study	Transfers to ICU/IMC From Intervention Group, *n* (%)	Comments Regarding Clinical Course for Patients Who Had Complications
Osorio et al (38)	Transfer from neurotransitional care unit (IMC): 0/10	NA
Ter Laan et al (19)[b]	Transfer from floor: 2/84 (2.4) Perforated diverticulitis 1 (1.2); bradycardia 1 (1.2)	NA
Young et al (37)	Transfer from neurotransitional care unit (IMC): 0/94	NA
Munari et al (21)	Transfer from PACU: 22/420 (5.2) Bleeding 7 (1.7); delayed emergence from anesthesia 12 (2.9); seizures 1 (0.2); postsurgical cerebral edema 1 (0.2); diabetes insipidus 1 (0.2)	NA
Ter Laan et al (20)	Transfer from floor: 2/212 (1.0) Opioid-induced respiratory insufficiency 1 (0.5); venous infarction requiring surgical decompression 1 (0.5)	NA
Pendharkar et al (26)	Transfer from floor: 0/63	NA
Mallari et al (25)	Transfer from stepdown unit (IMC): 0/77	NA

IMC = intermediate care unit, NA = not available, OR = operating room, PACU = postanesthesia care unit.
[a]Study only included pediatric patients.
[b]Study not included in summative analyses due to overlapping patient population with Ter Laan et al (21).

DISCUSSION

The standard-of-care for postoperative management of elective craniotomy has traditionally involved ICU admission for close monitoring of neurologic status and hemodynamic parameters. However, an emphasis on value-based care in neurosurgery (1, 2, 4) and findings that postoperative care is a significant driver of cost for neurosurgical procedures (6) have motivated critical examination of the clinical utility and expense of routine ICU care after elective craniotomy.

Several studies investigating the rates of serious postoperative complications and ICU-level interventions in this population suggested that ICU admission may be not be necessary for a number of patients. For example, one study analyzing outcomes for craniotomy patients at a quaternary care center in the United States determined that only 33 (8.3%) of the 400 patients admitted to the ICU postoperatively actually required an ICU-level intervention other than IV blood pressure medication or had a significant postoperative complication (11). One of the feared complications of craniotomies that is often used to justify ICU-level postoperative care is postoperative hematoma, but the rate of this complication may be as low as 1–2% (44–47). Additionally, studies examining the time course of postoperative complications have determined that they often present within the first few hours after surgery. For example, postoperative hematomas tend to occur within 2 to 6 hours following surgery, and thus early head imaging may be used to risk stratify patients (33, 47, 48). Overall, these findings that acute complications following elective craniotomy may be infrequent and mostly occur soon after surgery suggest that close postoperative monitoring for a limited time followed by non-ICU placement may not compromise the quality or safety of postoperative care for appropriate craniotomy patients.

While the benefits of routine ICU admission after craniotomy are not uniform, cost analyses demonstrated that this practice added substantial cost to care. For example, one center in the Netherlands reported that 1 day of ICU care at their center costs €2,154 (approximately \$2,376), while 1 day at the neurosurgical ward only costs €395 (approximately \$436) (19). Direct cost data for neurologic ICU care in the United States is limited, but the cost of ICU-level care may range from approximately \$1,700 to upwards of \$5,000 per day. One single-institution

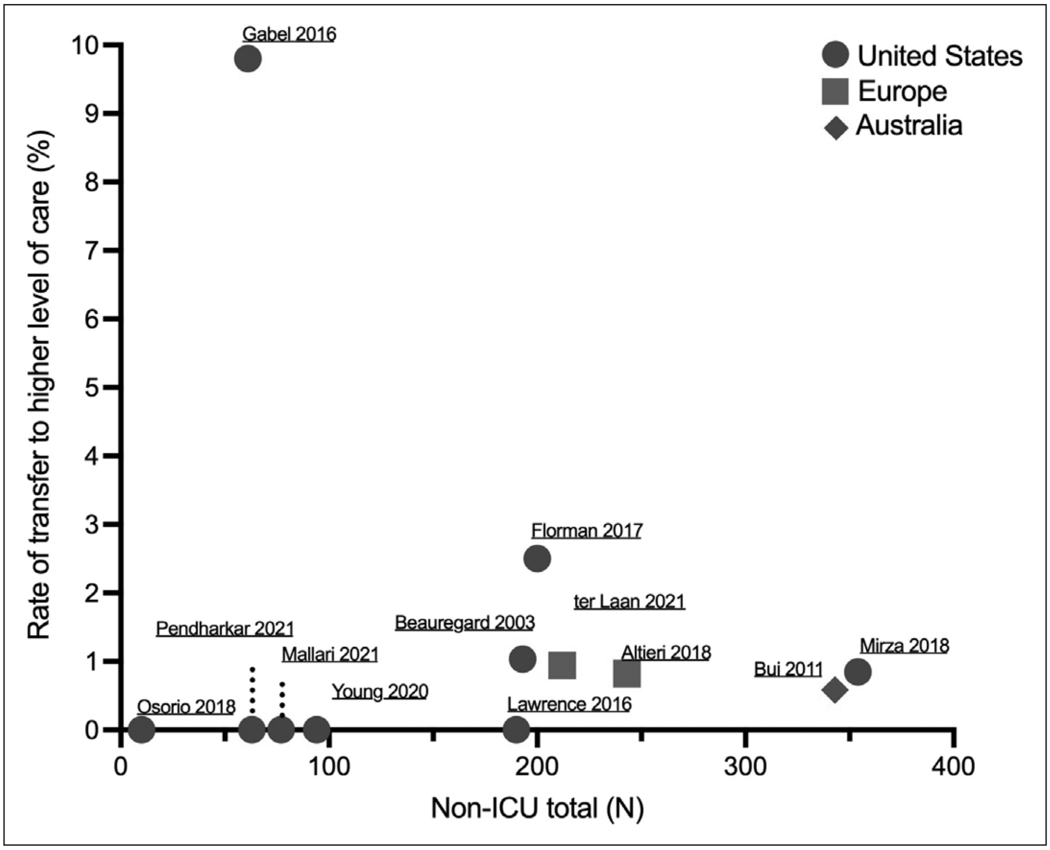

Figure 2. Rate of patients requiring transfer from non-ICU postoperative bed to a higher level of care versus total number of patients with non-ICU disposition after elective craniotomy.

study at a quaternary care center found that the neurologic ICU was their most expensive ICU (38). This study also found that the cost difference between the neurologic ICU and the neuro transitional care unit, which is their next highest level of care, was $1,504 per day (38).

Given the high costs of standard ICU admission following elective craniotomy, neurosurgeons have begun investigating alternative postoperative pathways utilizing lower acuity care. In this review, we have observed that appropriate utilization of non-ICU care after craniotomy has the potential to reduce costs while maintaining quality of care. Cost savings were estimated to be about $2,916 per patient, and only 1.1% of patients admitted to non-ICU care pathway destinations required subsequent transfer to higher acuity care during their postoperative course. However, savings were inconsistently reported among included studies and may not necessarily reflect hidden costs such as additional resources and staffing required for nontraditional care in the floor or stepdown units related to care pathways. Additionally, though the rate of complications requiring transfer were low, the complications that did require transfer were often significant, including repeat cranial surgery, status epilepticus, hemorrhage, and cerebral edema. While multiple included studies stated that clinical outcomes for the patients that did require eventual transfer to the ICU were not negatively impacted by their initial lower acuity care and delay in transfer, additional data from larger prospective studies is needed to confirm this (24, 39, 40, 43). Statistical comparisons were limited between patients who were initially admitted to the ICU postoperatively and those who required transfer to the ICU from lower acuity care, likely due to the limited number of patients who required transfer to higher acuity care in the included studies. Additionally, there was a considerable risk of bias present in the included studies, and all studies presented either data that was level 3 or 4 evidence. While initial studies are encouraging, higher-quality prospective studies are greatly needed to further characterize the performance of non-ICU postoperative care pathways.

The studies included in this review highlight multiple potential models for de-intensification of postoperative care. Studies performed at the University of California, San Francisco, incorporated a broad number of indications, including select posterior fossa tumors and retrosigmoid craniectomies, but made a relatively smaller change in postoperative care acuity, transitioning patients from the ICU to the IMC rather than directly to the floor (37, 38). In contrast, another study performed at the University of Pittsburgh Medical Center identified a relatively lower-risk procedure, microvascular decompression for trigeminal neuralgia, and directly transitioned the default postoperative care for these patients from the ICU to the lowest acuity of care—the neurosurgical floor (41). While risk stratification and postoperative care strategies differed between the two studies, they collectively achieved a transfer rate of 0% for a total of 294 patients. Furthermore, the University of Toronto care team reports relatively safe same-day discharge for a number of appropriately selected patients (28). Importantly, two qualitative studies assessing patient sentiment toward care de-intensification pathways demonstrated high overall satisfaction, suggesting that patients may also be amenable to newer, lower acuity care pathways (49, 50). Although this review focused on a variety of non-ICU care pathways, it is also important to note that care centers are also exploring cost reduction pathways that aim to reduce ICU length of stay rather than bypass ICU care entirely. While some of these protocols may be more feasible to implement, they would not provide the additional resource allocation benefit of ICU bed sparing, and potential savings may be reduced.

It is also notable that the studies identified in this review were produced by authors in seven different countries utilizing five different payer systems. While included studies had disparate inclusion criteria and significant bias, their individual and collective results suggest that care de-intensification after elective craniotomy may be broadly applicable. Although most of the publications identified in this review were produced by major academic institutions, implementation of care de-intensification was also described in the community hospital setting (25). Although the vast majority of studies were produced after 2016, it is notable that Beauregard and Friedman (43) investigated non-ICU care pathways nearly 2 decades ago with a transfer rate of 1.0%. While there have been a number of advances in the operating room and postoperative care, it is interesting to note that the transfer rate from this 2003 study is similar to the overall transfer rate noted across all studies in this review.

Although initial results regarding the efficacy of non-ICU care pathways for craniotomy patients have been promising, additional studies are needed prior to adoption into wider clinical practice (51). Given the potential severity of comorbidities and complications in this patient population, it is important to rigorously develop non-ICU care protocols in larger prospective studies. Importantly, these studies should include detailed criteria informing appropriate patient selection, capture objective data regarding the impact of delayed care on patients who require escalation, and characterize the transfer of burden from ICU to floor resources. These protocols would then need to be evaluated in clinical trials and compiled into detailed guidelines. Additionally, multiple articles have mentioned sentiments of "going to the neurologic ICU is the way it has always been done" and gut instinct as rationale for continuing the current practice (37, 52, 53). Specifically, some neurosurgeons continue to believe that ICU-level care maintains patient safety by allowing timely response to serious complications, and thus lower cost of care is not a justifiable rationale for lower acuity care (52, 53). However, standardized protocols for rapid response teams and communications strategies for expeditious level of care upgrade when complications do occur may help mitigate this concern. Another limitation of current studies is that the protocols described in the literature may not be compatible with existing workflows at many institutions. While 14 studies stated that they provided "floor-level" postoperative care, five of them involved status checks every 1 to 2 hours for their initial management on the floor, which is not available with standard floor care at many treatment centers.

Nevertheless, the data presented here have generated discussion within the neurosurgery community (52–54) and demonstrated that multiple institutions have begun to successfully allocate appropriate patients to non-ICU care following elective craniotomy.

While a comprehensive search string was used to identify studies of interest, additional relevant studies may have been excluded. Furthermore, the high degree of heterogeneity, particularly in inclusion criteria and reported outcomes, in the identified studies greatly limited the ability to perform meta-analyses. Inclusion criteria such as "surgeon's practice preference" will be difficult to generalize, and future studies should aim to develop stringent, objective criteria for non-ICU care. Overall complication data are difficult to compare across studies given the discrepancies in reporting (e.g., only complications with Clavien-Dindo grade 2 or higher [20], only complications requiring head CT earlier than 24 hr postoperatively [22], only complications leading to death [39]). Additionally, some studies did not delineate between complications that occurred in ICU versus non-ICU care pathways. Clinical outcomes for patients who suffered complications were not characterized in a number of studies. While cost data from the reviewed studies supported the claim that non-ICU care pathways produce significant savings, these studies may not capture the full extent of indirect costs involved in implementing alternate care pathways, and cost data were not provided in a number of studies. Finally, most of the studies analyzed in the present systematic review were retrospective in nature.

CONCLUSIONS

While the standard for postoperative craniotomy management remains ICU-level care, a growing body of literature demonstrates the potential feasibility of postoperative patient care in dedicated stepdown units and neurosurgical floor units. Although these studies show significant promise for non-ICU postoperative care, published articles contain a high level of heterogeneity in patient selection, postoperative care, and outcome reporting. Moving forward, more rigorous studies and clinical trials, followed by standardized development pathways and reporting of outcomes across care centers would allow for stronger validation of protocols, greater generalizability of results, and more nuanced statistical analyses to optimize complication prediction and patient selection. While further studies are needed, patient-specific allocation of postoperative care for elective craniotomy patients may provide an important opportunity to improve value in neurosurgical care.

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (http://journals.lww.com/ccmjournal).

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Dr. Rincon-Torroella's institution received funding from the National Institute of Neurological Disorders and Stroke (R25 grant holder [5R25NS065729]); she received support for article research from the National Institutes of Health (NIH). Dr. Jackson received funding from Boehringer Laboratories and Egret Therapeutics. Dr. Brem received funding from the NIH, Johns Hopkins University, Arbor Pharmaceuticals, and Bristol-Myers Squibb; he disclosed that he is a consultant for AcuityBio Corp., InSightec, Accelerating Combination Therapies, Catalio Nexus Fund II, CraniUS, Candel Therapeutics, LikeMinds, Galen Robotics, Nurami Medical, AsclepiX Therapeutics, and StemGen. Dr. Bettegowda disclosed that he is a consultant for Depuy-Synthes, Bionaut Labs, and Galectin Therapeutics. The remaining authors have disclosed that they do not have any potential conflicts of interest.

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