Neurologic intensive care resource use after brain tumor surgery: An analysis of indications and alternative strategies

Wendy C. Ziai, MD; Panayiotis N. Varelas, MD, PhD; Scott L. Zeger, PhD; Marek A. Mirski, MD, PhD; John A. Ulatowski, MD, PhD, MBA

Objective: **Greater demand and limited resources for intensive care monitoring for patients with neurologic disease may change patterns of intensive care unit utilization. The necessity and duration of intensive care unit management for all neurosurgical patients after brain tumor resection are not clear. This study evaluates a) the preoperative and perioperative variables predictive of extended need for intensive care unit monitoring (>1 day); and b) the type and timing of intensive care unit resources in patients for whom less intensive postoperative monitoring may be feasible.**

Design: **Retrospective chart review.**

Setting: **A neurocritical care unit of a university teaching hospital.**

Patients: **Patients were 158 consecutive postoperative brain tumor resection patients admitted to a neurocritical care unit within a 1-yr period (1998–1999).**

Interventions: **None.**

Measurements and Main Results: **Twenty-three patients (15%) admitted to the neurocritical care unit for >24 hrs were compared with 135 (85%) patients admitted for <24 hrs. Predictors of >1-day stay in the neurocritical care unit in a logistic regression model were a tumor severity index comprising radiologic characteristics of tumor location, mass effect, and midline shift on the preoperative magnetic resonance imaging scan (odds ratio, 12.5; 95% confidence interval, 3.1–50.5); an intraoperative fluid score comprising estimated blood loss, total volume of crystalloid, and other colloid/hypertonic solutions administered (odds ratio, 1.8; 95% confidence interval, 1.2–2.6); and postoperative intubation (odds ratio, 67.5; 95% confidence interval, 6.5–702.0). Area under the receiver operating characteristic curve for the model of independent predictors for staying >1 day in the neurocritical care unit was 0.91. Neurocritical care unit resource use was reviewed in detail for 134 of 135 patients who stayed in the neurocritical care unit for <1 day. Sixty-five (49%) patients required no interventions beyond postanesthetic care and frequent neurologic exams. A total of 226 intensive care unit interventions were performed (mean ± SD, 1.7 ± 2.6) in 69 (51%) patients. Ninety (67%) patients had no further interventions after the first 4 hrs. Neurocritical care unit resource use beyond 4 hrs, largely consisting of intravenous analgesic use (72% of orders), was significantly associated with female gender, benign tumor on frozen section biopsy, and postoperative intubation (chi-square, $p < .05$).**

Conclusions: **A small fraction of patients require prolonged intensive care unit stay after craniotomy for tumor resection. A patient's risk of prolonged stay can be well predicted by certain radiologic findings, large intraoperative blood loss, fluid requirements, and the decision to keep the patient intubated at the end of surgery. Of those patients requiring intensive care unit resources beyond the first 4 hrs, the interventions may not be critical in nature. A prospective outcome study is required to determine feasibility, cost, and outcome of patients cared for in extended recovery and then transferred to a skilled nursing ward. (Crit Care Med 2003; 31:2782–2787)**

KEY WORDS: **outcome; intensive care unit; length of stay; utilization review; critical care; resource allocation**

Following craniotomy for brain tumor resection, it is recommended that all patients be observed closely in an intensive care setting for ≥12–24 hrs (1). This degree of care is justified by the need to detect serious postoperative complications early, facilitate rapid intervention, and optimize the reestablishment of systemic and neurologic homeostasis allowing overall faster recovery (1). Complication rates following brain tumor surgery are relatively low but not inconsequential. In Wilson's (2) review of 1,771 supratentorial tumors treated from 1984 through 1990, perioperative mortality rate was 2.1%, with a morbidity rate of 10%. The influence of the postoperative critical care environment on these statistics has received little attention despite institutional initiatives to ensure quality care while controlling the cost and use of scarce resources.

Optimal intensive care unit (ICU) practice has been investigated for cardiac surgery and carotid endarterectomy (3–8). Traditional protocols specifying considerable postoperative ICU length of stay (LOS) following cardiac surgery have been modified with more rapid extubation and discharge from the ICU and reduction of resource use (6). Success of these programs appears to be influenced mainly by intraoperative anesthetic management and has not had a negative impact on quality of care or patient satisfaction. Similar strategies may apply to generally healthier neurosurgical patients, namely those requiring craniotomy for brain tumor resection. The existing literature on clinical factors contributing to ICU LOS in craniotomy patients with brain tumor is scarce. Sarkissian and Wallace (9) reported that

From the Division of Neurosciences Critical Care and the Departments of Anesthesia/Critical Care Medicine and Neurology (WCZ, PNV, MAM, JAL) and Biostatistics (SLZ), The Johns Hopkins University School of Medicine, and The Johns Hopkins University Bloomberg School of Public Health, Baltimore, MD.

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31% of patients undergoing elective supratentorial craniotomy for brain tumor stayed beyond the expected 1-day ICU LOS. Factors associated with ICU LOS were tumor type, intubation on ICU admission, and postoperative complications. A comprehensive and predictive model of factors contributing to ICU LOS after craniotomy for brain tumor resection has not been performed. Such an analysis may have an impact on ICU resource allocation, evaluation of cost-effective patient outcomes, and potential reduction in LOS and cost savings.

We evaluated brain tumor patients following craniotomy for perioperative characteristics, LOS, and resource use in a neurocritical care unit (NCCU) with low nurse/physician-to-patient ratios of coverage and subspecialty trained nurses/physicians in neurocritical care. This study identified patient interventions during the ICU course and determinants of extended ICU care beyond the first 24 hrs.

PATIENTS AND METHODS

Clinical perioperative course and radiologic findings of 158 patients admitted to an NCCU following craniotomy for brain tumor resection between July 1998 and June 1999 were reviewed. Clinical data were collected from medical records including operative, pathology, and radiology reports and NCCU nursing records.

Patients were divided into two groups on the basis of length of stay in the NCCU (group 1, ≤1 day; group 2, >1 day). Group 1 included all patients who left the NCCU on the day following surgery. Longer stay in the NCCU typically was justified by an unexpected postoperative event and/or continued need for resources provided only in the NCCU. Patients designated and managed as "floor patients" in the NCCU (off monitors, vital signs per ward protocol; n < 5) were included in group 1. The charts of 134 of 135 group 1 patients were subjected to an in-depth analysis of the hourly nursing records to determine the timing and type of interventions required for each 4-hr time block during the postoperative stay. Patients who required NCCU resources after the first 4 hrs postoperatively (group 1A) were compared with those patients who had no further ICU interventions other than cardiorespiratory and neurologic monitoring (group 1B). Four hours was chosen as the maximum time period that a patient typically would be monitored in a postanesthesia care unit. An ICU intervention was defined as any therapy or increased frequency of monitoring that could not be administered on a regular neurosurgical ward (such as intravenous medications for acute hypertension, or dysrhythmia) or any complication that required transfer to the NCCU for monitoring such as a postoperative hematoma or edema, even if no specific ICU treatment resulted. A postoperative complication was defined as a secondary disease or condition arising in the postoperative course of the patient, either as a result of the surgery or independently, which caused a change in the patient's management.

Nine variables (three preoperative and six perioperative) were compared between groups 1 and 2 and between groups 1A and 1B. Preoperative characteristics included patient age, supratentorial vs. infratentorial tumor location, and a tumor severity score. The tumor severity score was developed as a global score from zero to three to represent radiologic aspects of the tumor. One point (equal weight) was given for each of the following: a) midline tumor location (vs. lateralized); b) positive mass effect; and c) >3 mm of midline shift of either the septum pellucidum or pineal gland. These factors were considered potential contributors to altered mental status by impairing anatomical regions that maintain consciousness, which may prolong LOS. Midline shift on computed tomography scan of 3–4 mm has been associated with drowsiness, whereas greater lateral displacement of the brain predicts deeper levels of unconsciousness (10).

Perioperative factors were a) duration of surgery; b) a fluid score (FS) comprising estimated blood loss (EBL), intraoperative crystalloid fluid administration (F_1; mL/kg), and volume of either colloid, blood, or hypertonic saline as volume replacement (F_2; mL/kg in equivalent units of crystalloid); c) intraoperative use of vasopressor agents for treatment of hypotension; c) tumor pathology defined by the intraoperative frozen section biopsy or neurosurgeon's expert opinion at the time of operation as found in the perioperative clinic or chart notes; e) decision not to extubate the patient at the end of surgery; and f) new postoperative hemiparesis or lower cranial nerve deficit. We were particularly interested in new postoperative deficits present within the first 4 hrs postoperatively in order to potentially alter triage decisions.

Fluid score was calculated as the sum of the z-scores for the three fluid measurements (EBL, F_1, F_2), where a z-score is the distance of an observation from its mean in SD units. The equation is as follows:

$$FS = \Sigma\frac{EBL - EBL}{SD_{EBL}} + \Sigma\frac{F_1 - F_1}{SD_{F1}} + \Sigma\frac{F_2 - F_2}{SD_{F2}} \qquad [1]$$

Statistical Analysis. Univariate association of pre/perioperative risk factors with length of NCCU stay and number of interventions beyond 4 hrs postoperatively were evaluated using the chi-square or Fisher's exact test for categorical data and the Student's t-test for continuous data. Variables with $p < .05$ and variables that had potential clinical interest were included in a multivariate logistic regression analysis. Akacki's information criteria were used to identify the best set of predictors from among all available (11). Statistical analysis was performed with SPSS software, version 10.0 (SPSS, Chicago, IL). We compared the ability of the multivariate logistic regression model to predict a longer ICU stay by calculating the area under the receiver operating characteristic curve using STATA 7.0 software (Stata, College Station, TX). Statistical significance was assigned for $p < .05$.

RESULTS

A total of 184 patients were admitted to the NCCU following brain tumor surgery from July 1998 through June 1999, representing 21% of the total number (n = 856) of admissions to the NCCU over this time period. One hundred and fifty-eight patients had available chart data, of which 135 patients (85%) were admitted to the NCCU for ≤1 day (group 1). Twenty-three patients (15%) remained in the unit for >1 day (group 2; mean, 6 ± 2 days).

There were no significant differences in patient age, gender, weight, history of smoking, alcohol use, preoperative seizures, extent of tumor resection, or neurosurgeon between groups (Table 1). Histologic diagnoses included 30 schwannomas (19%), 29 meningiomas (18%), 24 glioblastomas (15%), 20 malignant gliomas (13%), 16 metastatic tumors (10%), 15 pituitary adenomas (10%), five pilocytic astrocytomas (3%), three craniopharyngiomas (2%), two each of chordomas, hemangiomas, hemangiopericytomas, and epidermoid tumors (totaling 5%), and eight other histologic types (5%). Final histology was malignant in 69 patients (44%). There were significant differences between short and long ICU stay groups in percentage of patients with postoperative complications, total length of hospital stay, and disposition. Nearly all patients who stayed <1 day in the NCCU were discharged to home, whereas 43% of patients with longer NCCU stay were discharged to either a rehabilitation facility or a nursing home.

Among nine variables tested in the univariate analysis, one of three preoperative and five of six perioperative factors demonstrated a statistically significant correlation with >24 hrs stay in the NCCU (Table 2). Eight of ten patients with midline tumors in group 2 experienced early complications directly related to the surgery, specifically postoperative edema, cerebrospinal fluid leak, diabetes insipidus, lower cranial nerve palsies, pneumocephalus, and intrasellar hemorrhage. We looked for an association between EBL and both crystalloid volume (per kilogram, $p = .08$) and remaining intubated postoperatively ($p = .10$) but found none significant.

More than 90% of patients were successfully extubated in the operating room. Of these, one patient was reintubated for progressive cerebral edema on postoperative day 4 and another on postoperative day 2 after developing a hematoma in the surgical bed. The decision for immediate postoperative ventilation in ten patients was based on need for airway protection due to decreased mental status in five patients, presence of new lower cranial nerve palsies in four, and presumed airway edema in two. Length of postoperative mechanical ventilation ranged from 4 hrs to 36 days. The impact of specific surgeons and anesthesiologists on immediate extubation and LOS was assessed, and results demonstrated similar distributions of patients staying <1 day and >1 day in the NCCU.

The finding of a new postoperative hemiparesis requiring >24 hrs of ICU care was secondary to cerebral edema or intracerebral hemorrhage in three of the six cases. In most cases, new hemiparesis was not unexpected due to extent of resection or tumor location. Other causes of >1 day LOS were seizures and moderate hyponatremia.

Multivariate logistic regression analysis using Akacki's information criteria to determine the best set of predictors identified three variables as independent predictors of extended stay (Table 3). These were unsuccessful postoperative extubation ($p < .001$), tumor severity score ($p < .001$), and FS ($p = .006$). Figure 1 presents the receiver operating characteristic curve of the model for discrimination between patients in group 1 and patients in group 2. The area under the receiver operating characteristic curve was 0.91.

Complication rate for the first 24 hrs postoperatively (Table 4) was significantly different between groups 1 and 2 ($p < .001$), occurring in 10% (13 of 135) of group 1 vs. 74% (17 of 23) of group 2 patients ($p < .001$), but it resulted in prolonged stay only for group 2 patients. Specific ICU interventions consisted of intravenous anticonvulsants, osmotic therapy, cerebrospinal fluid drainage, frequent laboratory monitoring, sodium therapy, and treatment for cardiorespiratory complications.

Five patients required readmission to the NCCU after having been discharged to the neurosurgical ward. Three patients from group 1 were readmitted on postoperative days 2, 4, and 14; one had a hematoma in the surgical bed with pneumocephalus requiring reintubation; another developed obstructive hydrocephalus; and the third developed steroid psychosis. Two group 2 patients were readmitted on postoperative days 7 and 17, one for hydrocephalus and the other for repair of cerebrospinal fluid leak and pseudomeningocele.

Table 1. Characteristics of 158 patients based on length of stay in the neurocritical care unit (NCCU)

Characteristic	Group 1 (≤1 Day)	Group 2 (>1 Day)	*p* Value
No. of patients	135	23	
Patient age, yrs	49 ± 14	52 ± 21	.41
Gender, %			
Male	47	48	
Female	53	52	
Mean patient weight, kg	83 ± 2	78 ± 4	.29
Smoking history, %	16	17	.49
Alcohol history, %	24	17	.58
Seizure history, %	11	4	.59
Extent of tumor resection, %			.81
Gross total resection	65	62	
Subtotal resection	35	38	
Postoperative complication, %	22	87	<.001
No. of days in NCCU	1 ± 0	6 ± 2	.005
No. of days in hospital	7 ± 1	15 ± 2	.003
Disposition, %			
Home	93	52	<.001
Rehabilitation facility	6	33	<.001
Nursing home	1	10	.01
Died	0	4	.01

Table 2. Determinants of neurocritical care unit stay >1 day (n = 158)

Variable	Group 1 (≤1 Day Stay) (n = 135)	Group 2 (>1 Day Stay) (n = 23)	*p* Value
Preoperative			
Age, yrs	49 ± 14	52 ± 21	.41
Tumor severity score, %	0.96 ± 0.06	1.57 ± 0.11	<.001
Midline tumor	15	44	<.01
Mass effect	72	91	.05
Midline shift	12	26	.11
Tumor location, %			.59
Supratentorial	67	61	
Infratentorial	33	39	
Perioperative			
Fluid score, mL	3724 ± 134	6596 ± 826	.002
Estimated blood loss, mL	353 ± 20	905 ± 165	<.01
Volume intraoperative colloid/hypertonic saline, mL	41 ± 15	232 ± 109	.1
Volume crystalloid, mL	3273 ± 114	4818 ± 484	.01
Benign tumor on frozen section, %	53	74	.07
Vasopressor use in operating room, %	21	41	.04
Duration of surgery >7 hrs, %	20	52	<.01
Not extubated postoperatively, %	2	39	<.001
New hemiparesis or lower cranial nerve deficit, %	16	39	.01

Table 3. Logistic regression analysis

Factor	Odds Ratio	95% CI
TSS	12.5	3.1–50.5
Fluid score	1.8	1.2–2.6
Not extubated postoperatively	67.5	6.5–702.0

CI, confidence interval; TSS, tumor severity score.

Of 134 patients who stayed ≤1 day in the NCCU, 90 (67%) patients had no further requirements after the first 4 hrs (group 1B). Of the nine variables subjected to univariate analysis, only two

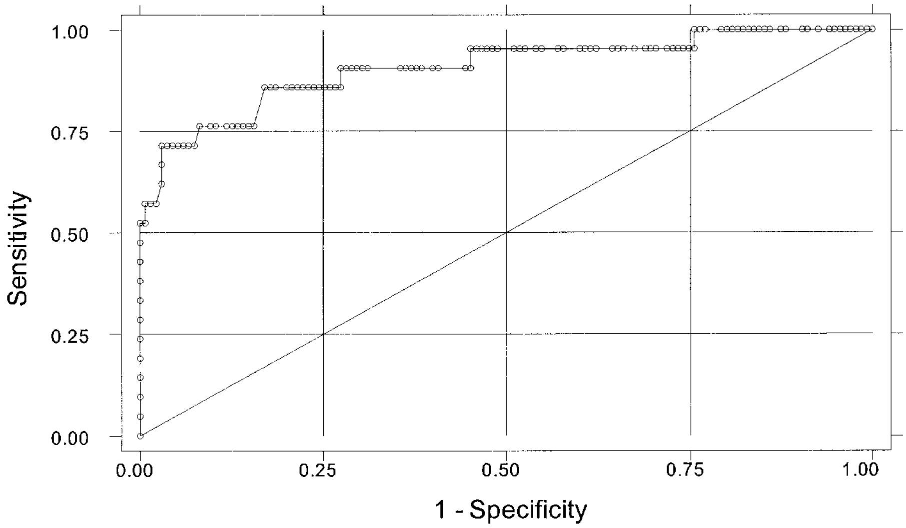

Figure 1. Receiving operating characteristic (ROC) curve, demonstrating the tradeoff between the true-positive rate (sensitivity) and the false-positive rate (1-specificity) for the logistic regression model of independent predictors for staying >1 day in the neurocritical care unit following brain tumor surgery. Area under the ROC curve, 0.91.

Table 4. Postoperative complications within first 24 hrs

Complication	Group 1 No. (%)	Group 2 No. (%)	Total No. (%)
Death	0	0	0 (0)
Hematoma	0	2 (9)	2 (1)
Cerebral edema	0	5 (22)	5 (3)
Pneumocephalus	0	3 (9)	3 (2)
Reoperation for complication	0	1 (4)	1 (1)
Stroke	0	0	0 (0)
Hydrocephalus	0	0	0
CSF leak	0	1 (4)	1 (1)
Seizures	2 (1)	3 (13)	5 (3)
Dysphagia/vocal cord paresis[a]	4 (3)	3 (13)	7 (5)
Corneal abrasion/exposure risk[b]	2 (1)	2 (9)	4 (3)
Cardiac arrhythmia	1 (1)	2 (1)	3 (2)
Hyponatremia[c]	0	2 (9)	2 (1)
Pulmonary complication	1 (1)	4 (17)	5 (3)
Hemodynamic instability	0	1 (1)	1 (1)
Cardiac ischemia	0	1 (1)	1 (1)
Wound complication	0	0	0
Diabetes insipidus[d]	3 (2)	0	3 (2)
Deep venous thrombus	0	0	0
Coagulopathy	0	1 (4)	1 (1)

CSF, cerebrospinal fluid.

[a]Requiring change in diet or gastrostomy tube; [b]requiring eye patch/drop/ophthalmologist; [c]treated with hypertonic saline; [d]treated with vasopressin infusion and volume therapy.

demonstrated statistical correlation with requirement for NCCU resources beyond 4 hrs (Table 5). There were a greater number of females (66% [1A] vs. 47% [1B], $p = .04$) and a greater percentage of benign tumors in the group receiving ICU interventions beyond 4 hrs (66% [1A] vs. 47% [1B], $p = .04$). This group also had a nonsignificantly higher number of postoperative complications (30% [1A] vs. 18% [1B], $p = .12$) and longer hospital stay (8.6 ± 2.8 vs. 5.6 ± 0.4 days, $p = .15$) compared with group 1B patients, suggesting that this population may be different from patients who required <4 hrs of ICU resources. No differences were found with respect to any medical comorbidities, intraoperative use of mannitol or vasopressors, extent of tumor resection, or final disposition.

A total of 226 ICU interventions were performed (1.7 ± 0.2 per patient) in 69 (51%) patients from group 1 (Table 6). These comprised intravenous antihypertensive therapy in nine patients, vasopressin infusion for diabetes insipidus (n = 4), intravenous glycopyrrolate for bradycardia (n = 3), hyperosmolar therapy for cerebral edema (n = 3), postoperative extubation (n = 2), intravenous bolus analgesics (n = 41), intravenous prophylactic anticonvulsants (n = 13), and intravenous sedatives for anxiety (n = 5). Beyond 4 hrs, administration of intravenous analgesics accounted for 72% (101 of 140) of all ICU intervention orders.

DISCUSSION

Our results show that only 15% of patients required prolonged (>1 day) ICU stay after craniotomy for brain tumor resection. Predictors of >1-day stay in the NCCU in the logistic regression model were a higher tumor severity score, a higher intraoperative FS, FS, and postoperative intubation. Other variables statistically correlated with >24-hr stay in the univariate analysis were duration of surgery >7 hrs, a new postsurgical hemiparesis or lower cranial nerve deficit, and intraoperative use of vasopressor therapy for hypotension. Patients who stayed ≤1 day were more likely to be discharged to home compared with those with longer ICU stays who had significantly higher discharge rates to either a rehabilitation facility or nursing home.

In patients who required <24 hrs of postoperative ICU care, few required ICU resources beyond the first 4 hrs after surgery. Significant factors identifying these patients were higher volume of intraoperative colloid or hypertonic saline, benign tumor, and postoperative intubation. The major intervention accounting for 72% of the orders was for intravenous analgesics.

The low percentage of patients requiring >24 hrs of ICU care in this study may reflect factors specific to our ICU environment. A study of intensive care unit length of stay in the United States (1993–1996) reported an observed mean ICU LOS of 3.4 ± 1.3 days following craniotomy or transphenoidal procedure for neoplasm (12). One recent study showed that a neuroscience specialty ICU staffed by specialty trained intensivists and nurses is beneficial in reducing ICU and hospital length of stay in addition to total costs of care compared with a general ICU setting (13). Our predictive model potentially could be used to compare the use of ICU resources between institutions and specifically identify whether different pa-

Table 5. Determinants of neurocritical care unit resource use >4 hrs (n = 134)

Variable	Group 1A (>4 Hrs) (n = 44)	Group 1B (<4 Hrs) (n = 90)	*p* Value
Preoperative			
Age, yrs	47 ± 2	49 ± 2	.48
Tumor severity score, %	0.91 ± 0.11	0.99 ± 0.07	.54
Midline tumor	23	11	.07
Mass effect	64	76	.15
Midline shift	7	15	.18
Tumor location, %			.08
Supratentorial	57	72	
Infratentorial	43	28	
Perioperative			
Fluid score, mL	3757 ± 210	3694 ± 173	.83
Estimated blood loss, mL	393 ± 38	332 ± 24	.16
Intraoperative crystalloid, mL	3359 ± 202	3218 ± 140	.57
Intraoperative colloid/hypertonic saline, mL	5 ± 5	59 ± 22	.02
Benign tumor on frozen section, %	66	47	.04
Intraoperative vasopressor use, %	23.0	20.0	.72
Duration of surgery >7 hrs, %	25	17	.25
Not extubated postoperatively, %	0.4	0	.04
New hemiparesis or lower cranial nerve deficit, %	21.0	13.0	.29

Table 6. Neurocritical care unit interventions by type and time interval

	No. of Patients Requiring Intervention During Time Interval, Hrs Postoperation							
Intervention	0–2	2–4	4–8	8–12	12–16	16–20	20–24	Total
IV analgesic	37	14	20	36	35	6	4	152
IV anxiolytic	4	0	3	1	3	0	0	11
IV antihypertensive	10	4	8	4	3	0	0	29
HS/colloid	1	1	1	0	1	0	0	4
IV antiepileptic	3	7	1	2	2	0	0	15
Extubation	0	1	1	0	0	0	0	2
Tx for bradycardia	2	1	1	0	0	0	0	4
Vasopressin infusion	0	0	0	1	3	4	0	8
IV magnesium	1	0	0	0	0	0	0	1
Total	58	28	35	44	47	10	4	226

IV, intravenous; HS, hypertonic saline; Tx, treatment.

Neurocritical care unit intervention refers to therapy or increased frequency of monitoring not permitted on standard neurosurgical ward.

tient case mix or other factors account for the variation in ICU length of stay. Although we are not aware of other predictive models for craniotomy patients, the area under the receiver operating characteristic curve, which is a measure of the predictive ability of the logistic regression model, compares favorably with that of predictive models for length of stay and mortality rate in the ICU following cardiac surgery (7, 14).

Most of the significant predictive variables in this study were determined perioperatively (five of six perioperative vs. two of three preoperative factors). The lack of significant preoperative factors is likely due to the semielective nature of most craniotomies for tumor resection in patients who are usually outpatients without significant coexisting medical morbidities. Higher age usually is considered an important factor predicting surgical outcomes (15). However, at least one study has found that patients >65 yrs of age undergoing craniotomy for brain tumor did not differ from younger patients in terms of length of ICU or hospital stay, final outcome at discharge from hospital, quality of life, or hospital/ICU costs, despite having a greater number of procedures and complications (16). We did not find an effect of age on ICU LOS; older patients had a similar percentage of postoperative complications compared with younger patients (29.4% vs. 30.6%).

Our results suggest that intraoperative hemodynamic factors play an important role in determining the need for longer ICU stay, although the exact cause of this association was not obvious. Blood loss leading to increased fluid administration, use of vasopressors, and hypothermia may result in postoperative intubation and ventilation. There were, however, no statistically significant associations between EBL or crystalloid, vasopressor, or mannitol use with remaining intubated in the ICU postoperatively.

Postoperative ventilation in ten patients was related to expected lower cranial nerve palsies, prolonged prone positioning with risk of upper airway edema, and delayed postoperative awakening. It is unlikely that anesthetic agents played a role in this decision because it is expected practice of all anesthesiologists at our institution to wake up craniotomy patients at the end of surgery to validate a neurologic exam. We found no pattern in anesthesiologists or surgeons favoring intubation. Mechanical ventilation clearly is associated with a greater number of interventions including blood gas analysis, weaning, and extubation. The high rate of successful extubation in the operating room cannot be understated as a determinant for reducing ICU resource need and utilization.

Presence of a new hemiparesis was associated with postoperative cerebral edema or hemorrhage in three of six patients staying >24 hrs and had no effect on length of stay in 11 other patients. Potential seriousness of this complication, however, favors a longer observation period in an ICU under certain circumstances. Presence of a new lower cranial nerve palsy (cranial nerves 9–12) was not a significant variable on its own, although this finding invokes a cautious approach to extubation, especially for posterior fossa tumor resections.

Benign tumor histology demonstrated a trend for a longer ICU stay and significantly more ICU resources beyond the first 4 hrs. This was also the finding of a pilot study which found that 30% of meningiomas, 80% of acoustic neuromas, and 0% of metastatic carcinomas had ICU LOS >24 hrs (9). Benign tumors may be more aggressively resected than malignant tumors, although the extent of resection (from the operative report) was not significantly different between groups. Alternatively, there were more meningiomas (26% vs. 17%) and pituitary tumors (17% vs. 10%) in the longer vs. shorter stay group. These two benign tumors may require longer ICU stay and resource intensity, due to size and aggressive resection or edema in the former and postoperative diabetes insipidus in the latter. Acoustic neuromas at our center had <1 day ICU LOS in 93% of cases.

A closed model neurologic intensive care unit with continuous supervision by a critical care team specializing in neurocritical care or neuroanesthesia may anticipate different outcomes and length of stay compared with a general ICU.

The second objective of this study was to identify the types of ICU resources used in postcraniotomy patients and attempt to identify a patient profile that did not require the specific interventions provided by an ICU. Several types of interventions potentially could be instituted in a postanesthesia care unit setting or by alternative modes of delivery, obviating the need for ICU admission. These include oral analgesics or intraoperative nerve blocks, oral anticonvulsants, and antihypertensive medication. Beyond the substitution of less intensive interventions, however, is the question of how long a postcraniotomy patient requires frequent neurologic monitoring to avoid a critical complication that may be undiagnosed or delayed by observation on a general neurosurgical ward. The capacity for close observation and acute intervention by itself often supports the role of ICU management. In many centers, this level of monitoring can only occur in an ICU environment.

A strategy that sends patients from the postanesthesia recovery room directly to a neurosurgical ward bed could offer potential cost savings. Based on 1998–99 patient charges, NCCU charges of $1,960 per day (admission charge, bed charge, physician consultation fee) compared with a combined postanesthesia care unit 4-hr stay/neurosurgical ward bed charge of $1,365 (admission charge, bed charge), the direct patient charges (exclusive of nursing care costs and supply charges) could be reduced by $595 per patient or $53,550 for 90 patients. Although a significant hospital cost savings could be realized, the potential cost of missing even a single neurologic catastrophe may far outweigh the potential annual savings.

Our results are subject to several limitations. The relatively small patient population and small number of patients who stayed >24 hrs in the NCCU may have influenced statistical significance of some variables. We did not directly evaluate practices of individual anesthesiologists and neurosurgeons with respect to volume and type of intraoperative fluids given, vasopressors, extubation criteria, or duration of surgery that may have influenced intra- and postoperative decision making for many of the factors assessed in this study (12).

The results of this study may not be applicable to other ICU models. A closed model neurologic ICU with continuous supervision by a critical care team specializing in neurocritical care or neuroanesthesia may anticipate different outcomes and length of stay compared with a general ICU (17, 18). A prospective study evaluating this predictive model under different ICU conditions would be needed to answer this question. The accepted paradigm of postoperative critical care for craniotomy patients following brain tumor resection has not been fully established and is likely to come under further scrutiny as diminished ICU resources are needed for other surgical patients with multiple-system disease. Patient profiles derived in this study may be useful as a screening tool but should not supplant a case-by-case decision-making process for admission to a nonintensive care area, given the heterogeneity of brain tumor surgery and potential for serious complications beyond the immediate postoperative period. If sufficient quality of neurologic monitoring found in an ICU can be provided in a sophisticated, well-managed, cost-effective location, then it will be worthwhile to study these alternative practice patterns.

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