Association between in-hospital adverse events and mortality for patients with brain tumors

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OBJECT The Agency for Healthcare Research and Quality patient safety indicators (PSIs) and the Centers for Medicare and Medicaid Services hospital-acquired conditions (HACs) are administrative data-based metrics. The use of these outcomes as standard performance measures has been discussed in previous studies. With the objective of determining the applicability of these events as performance metrics among patients undergoing brain tumor surgery, this study had 2 aims: 1) to evaluate the association between PSIs, HACs, and in-hospital mortality rates; and 2) to determine a correlation between hospital volume, PSIs, and HACs.

METHODS Patients with brain tumors treated between 1998 and 2009 were captured in the Nationwide Inpatient Sample database. Hospitals were categorized into groups according to surgical volume. Associations between PSIs, HACs, and in-hospital mortality rates were studied. Factors associated with a PSI, HAC, and mortality were evaluated in a multivariate setting.

RESULTS A total of 444,751 patients with brain tumors underwent surgery in 1311 hospitals nationwide. Of these, 7.4% of patients experienced a PSI, 0.4% an HAC, and 1.9% died during their hospitalization. The occurrence of a PSI was strongly associated with mortality. Patients were 7.6 times more likely to die (adjusted odds ratio [aOR] 7.6, CI 6.7–8.7) with the occurrence of a PSI in a multivariate analysis. Moderate to strong associations were found between HACs, PSIs, and hospital volume. Patients treated at the highest-volume hospitals compared with the lowest-volume ones had reduced odds of a PSI (aOR 0.9, CI 0.8–1.0) and HAC (aOR 0.5, CI 0.5–0.08).

CONCLUSIONS Patient safety–related adverse events were strongly associated with in-hospital mortality. Moderate to strong correlations were found between PSIs, HACs, and hospital procedural volume. Patients treated at the highest-volume hospitals had consistently lower rates of mortality, PSIs, and HACs compared with those treated at the lowest-volume facilities.

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KEY WORDS patient safety indicators; hospital-acquired conditions; in-hospital mortality; hospital procedural volume; oncology

IN an effort to improve patient safety, systems and measures have been proposed by the Agency for Healthcare Research and Quality (AHRQ) since the early 1990s. The patient safety indicators (PSIs), developed by the AHRQ and revised by the University of California at San Francisco–Stanford University Evidence-based Practice Center (UCSF–Stanford EPC), are a set of administrative data-based metrics used to identify potential in-hospital patient safety events.¹ Furthermore, the Centers for

Medicare and Medicaid Services (CMS) proposed a set of hospital-acquired conditions (HACs) that are used to guide reimbursement penalties as part of a pay-for-performance program.¹⁰ Postoperative events such as pulmonary embolism (PE) or deep venous thrombosis (DVT), respiratory failure, and hemorrhage/hematoma are among some of the PSIs proposed by the AHRQ. Catheter-associated urinary tract infections (UTIs), falls, and trauma are part of the CMS list of HACs. The PSIs focus on potentially prevent-

ABBREVIATIONS AHRQ = Agency for Healthcare Research and Quality; aOR = adjusted odds ratio; CCI = Charlson Comorbidity Index; CMS = Centers for Medicare and Medicaid Services; DVT = deep venous thrombosis; HAC = hospital-acquired condition; IQR = interquartile range; NIS = Nationwide Inpatient Sample; PE = pulmonary embolism; PSI = patient safety indicator; UCSF–Stanford EPC = University of California at San Francisco–Stanford University Evidence-based Practice Center; UTI = urinary tract infection; V1–V4 = lowest- to highest-volume hospitals.

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able instances of complications, whereas the HACs represent an undesirable condition arising during a hospital stay. It is worth noting that some of these indicators do not specifically measure a patient's outcome or the standard of care provided. Rather, they measure an aspect of care that is correlated with measures of quality or patient outcomes.

Because performance outcomes continue to be important factors for patients and hospitals as well as health care providers, newly proposed metrics such as PSIs and HACs need to be evaluated in specific clinical domains. Numerous outcomes have been considered to evaluate hospital performance. Some of these metrics include in-hospital mortality, 30-day readmissions, in-hospital length of stay, and complications, to name a few.^{5,8,18,19,21,25,32,35,37} These outcomes have been evaluated in association with hospital procedural volume. An established association suggests that patients treated at higher-volume hospitals have a tendency to attain outcomes that are superior to those reported for patients treated at these hospitals' lower-volume counterparts. In this study, we evaluate the occurrence of safety-related adverse events (i.e., PSIs) and HACs for patients with brain tumor who underwent a craniotomy. Our study aims first to evaluate the association between PSIs, HACs, and in-hospital mortality rates, and second to assess any association between hospital volume, PSIs, and HACs. We anticipate that a confirmed association between PSIs, HACs, and mortality rates may motivate efforts to prevent or reduce the occurrence of these events, with the focus on improving in-hospital mortality. Similarly, establishing a correlation between hospital volume, PSIs, and HACs may support the use of these metrics as hospital performance measures in this patient population.

Methods

Data Source and Cohort Selection

We used the Nationwide Inpatient Sample (NIS) database to capture patients with brain tumor who had been surgically treated in US hospitals between 1998 and 2009. Data were obtained from the Healthcare Cost and Utilization Project of the AHRQ.² The NIS collects data for a stratified random sampling (20%) of hospitals that are representative of the American medical community. Using *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes, we identified adult patients (18 years of age or older) with a primary diagnosis of acoustic neuroma (ICD-9-CM: 225.1), meningioma (ICD-9-CM: 225.2), and malignant tumor (ICD-9-CM: 191.0–191.9, 192.0, 192.1, 194.3, 194.4, 198.3) of the brain; only patients who underwent either a biopsy (ICD-9-CM: 1.11–1.15, 1.18, 1.19) or a craniotomy (ICD-9-CM: 1.23–1.25, 1.31, 1.32, 1.39, 1.51–1.53, 1.59, 1.60) were included (Table 1). The primary diagnosis code is the principal condition requiring admission for treatment, as determined by the admitting physician.¹³

Patient and Hospital Characteristics

A patient's age, sex, preexisting medical conditions (Charlson Comorbidity Index [CCI]),¹¹ and hospital characteristics such as teaching status, hospital bed size, and hospital surgical volume were documented. Hospitals

TABLE 1. The ICD-9-CM codes for diagnoses, procedures, and HACs

Factor	ICD-9-CM Code
Primary diagnosis	
Acoustic neuroma	225.1
Meningioma	225.2
Malignant brain tumor	191.0–191.9, 192.0, 192.1, 194.3, 194.4, 198.3
Surgical procedure	
Biopsy	1.11–1.15, 1.18, 1.19
Craniotomy	1.23–1.25, 1.31, 1.32, 1.39, 1.51–1.53, 1.59, 1.60
HAC	
Foreign object retained after surgery	998.4, 998.7
Air embolism	999.1
Falls & trauma	
Fracture	800–829
Dislocation	830–839
Intracranial injury	850–854
Crushing injury	925–929
Burn	940–949
Other injuries	991–994
Catheter-associated UTI	996.64
Vascular catheter-associated infection	999.31, 999.32, 999.33
Manifestations of poor glycemic control	
Diabetic ketoacidosis	250.10–250.13
Nonketotic hyperosmolar coma	250.20–250.23
Hypoglycemic coma	251.0
Secondary diabetes w/ ketoacidosis	249.10–249.11
Secondary diabetes w/ hyperosmolarity	249.20–249.21

were classified into 1 of 4 cohorts (V1–V4) according to yearly surgical volume. The lowest-volume hospitals were designated by V1, whereas the highest-volume ones were referred to as V4 hospitals. The average number of procedures per year conducted in V1 hospitals ranged from 0 to 15, it was 16–50 among V2 hospitals, 51–100 for V3 hospitals, and 101 or more for hospitals designated by V4. Categorization of hospital cohorts according to procedural volume was reached based on volume thresholds that were deemed clinically relevant by neurosurgeons in our team (C.G.P., D.M.). It is worth noting that hospital volume was first evaluated as a continuous variable, and the findings were consistent with our results obtained using multiple categories. Data were missing for sex in 1410 (0.32%) patients, for race in 109,699 (24.7%), for income in 11,477 (2.6%), and for hospital teaching status and bed size in 1198 (0.30%).

Outcomes of Interest

Complications, as captured by PSIs, HACs, and in-hospital mortality, were the main outcomes of interest in

this study. Hospital procedural volume was a secondary outcome. The PSIs evaluated included the following: 1) decubitus ulcer; 2) iatrogenic pneumothorax; 3) central venous catheter–related bloodstream infections; 4) postoperative hip fracture; 5) postoperative hemorrhage or hematoma; 6) postoperative physiological and metabolic derangement; 7) postoperative respiratory failure; 8) postoperative PE or DVT; 9) postoperative sepsis; 10) postoperative wound dehiscence; and 11) accidental puncture or laceration during a procedure or medical care (Table 2). A variable describing the number of days from admission to secondary procedures was used to confirm that all PSIs resulting from postsurgical procedures occurred within the index hospitalization of interest. The HACs considered were as follows: 1) foreign object retained after surgery; 2) air embolism; 3) falls and trauma; 4) catheter-associated UTI; 5) vascular catheter-associated infection; 6) manifestations of poor glycemic control; 7) diabetic ketoacidosis; 8) nonketotic hyperosmolar coma; 9) hypoglycemic coma; 10) secondary diabetes with ketoacidosis; and 11) secondary diabetes with hyperosmolarity.

Statistical Analysis

Descriptive statistics were used to summarize patient and hospital characteristics. A multivariate logistic regression model that adjusted for patient and hospital factors evaluated associations with PSI, HAC, and postprocedural mortality outcomes. Separate models were used to evaluate each of these outcomes (mortality, HAC, PSI). Adjustments were made for a patient's race and income, and these factors were found to have no additional predictive value or association in these predictive models. Chi-square and Student t-tests were used to evaluate differences in mortality rates for PSI versus non-PSI and HAC versus non-HAC cohorts as a function of hospital volume. Adjusted odds ratio (aOR), 95% CI, interquartile range (IQR), and corresponding p values were reported. Nationwide estimates were derived using the SAS PROC SURVEY methodology. All analysis used SAS version 9.1 for Windows (SAS Institute, Inc.).

Results

Demographic Data

According to the NIS database, 444,751 patients underwent brain tumor surgery at 1311 US hospitals between 1998 and 2009. The median patient age was 57 years (IQR 46–68 years) with a female preponderance (52.6%), and a significant portion (47.3%) of patients who had 2 or more preexisting conditions (Table 3). Most patients were treated at teaching hospitals (76.3%). A significant fraction of patients underwent a craniotomy (87.2%) compared with biopsy (12.8%). Among the 1311 hospitals, 760 fell within the V1 cohort (lowest volume), 409 were in the V2 cohort, 86 in the V3 cohort, and the remaining 56 hospitals were placed among the highest-volume cohort (V4). In a univariate setting, the highest-volume hospitals compared with the lowest-volume ones had younger patients (54 vs 61 years, $p < 0.0001$), fewer females (51.7% vs 53.0%, $p = 0.03$), fewer comorbidities (40.9% vs 55.0%, $p < 0.0001$), and higher rates of craniotomy (89.4% vs 85.8%, $p < 0.0001$).

TABLE 2. The ICD-9-CM codes for PSIs

PSI	ICD-9-CM Code
Pressure ulcer	707.0–707.07, 707.09, 707.23, 707.24, 707.25
Iatrogenic pneumothorax	512.1
Central venous catheter–related bloodstream infections	996.62, 999.3, 999.31, 999.32
Postop hip fracture	820.00–820.03, 820.09–820.13, 820.19–820.22, 820.30–820.32, 820.8, 820.9
Postop hemorrhage or hematoma	998.11, 998.12, 287, 388.0–388.9, 394.1, 399.8, 499.5, 579.3, 609.4, 180.9, 540, 541.2, 591.9, 610, 699.8, 701.4, 710.9, 759.1, 759.2, 860.4
Postop physiological & metabolic derangement	249.10, 249.11, 249.20, 249.21, 249.30, 249.31, 250.10–250.13, 250.20–250.23, 250.30–250.33, 584.5–584.9, 586, 997.5, 399.5, 549.8
Postop respiratory failure	518.51, 518.53, 518.81, 518.84, 967.0–967.2, 960.4
Postop PE or DVT	451.11, 451.19, 451.2, 451.81, 451.9, 453.40–453.42, 453.8, 453.9, 415.1, 415.11, 415.13, 415.19
Postop sepsis	038.0, 038.1, 038.10, 038.11, 038.12, 038.19, 038.2, 038.3, 785.52, 785.59, 998.0, 998.00, 998.02, 038.40–038.44, 038.49, 038.8, 038.9, 995.91, 995.92
Postop wound dehiscence	546.1
Accidental puncture or laceration during procedure or medical care	E870.0–E870.9, 998.2

Associations Among PSIs, HACs, and Mortality Rates

Although the overall mortality rate was 1.9%, this rate increased to 11.8% (5.2-fold) with the occurrence of a PSI, and to 4.3% (1.3-fold) with an HAC. The strong association between a PSI and mortality was independent of hospital volume. Univariate analysis showed that the mortality rate of patients who experienced a PSI was 15.3% if treated at the lowest-volume (V1) hospitals compared with the 8.8% rate captured among highest-volume (V4) facilities ($p < 0.0001$, Fig. 1). While HACs were consistently associated with higher mortality rates, this finding was particularly significant ($p = 0.003$) if patients received treatment at V1 hospitals (Fig. 2).

In a multivariate model that adjusted for a patient's age, sex, preexisting comorbidities, and hospital volume, among other factors, we found that the occurrence of a PSI

TABLE 3. Patient and hospital characteristics of adult patients who underwent resection for brain tumor in US hospitals between 1998 and 2009*

Variable	All Patients	Hospitals by No. of Procedures per Yr				p Value
		V1	V2	V3	V4	
No. of patients	444,751	61,808	162,819	85,448	134,676	
No. of hospitals	1311	760	409	86	56	
Age at admission in yrs						<0.0001
Mean	57.1	59.9	58.6	56.4	54.4	
Median (IQR)	57 (46–68)	61 (49–71)	59 (48–69)	56 (46–67)	54 (43–65)	
Sex†						0.03
Male	210,089 (47.4)	28,992 (47.0)	76,307 (46.9)	40,065 (47.1)	64,725 (48.3)	
Female	233,253 (52.6)	32,728 (53.0)	86,258 (53.1)	45,016 (52.9)	69,251 (51.7)	
Race†						0.04
White	269,492 (80.4)	36,656 (74.6)	95,626 (81.1)	50,078 (81.2)	87,132 (81.9)	
Nonwhite	65,560 (19.6)	12,451 (23.4)	22,323 (18.9)	11,557 (18.8)	19,229 (18.1)	
Median income†						0.0008
\$1–\$38,999	102,444 (23.6)	16,731 (27.8)	39,183 (24.6)	19,924 (23.9)	26,606 (20.4)	
\$39,000–\$47,999	111,695 (25.8)	16,166 (26.9)	43,157 (27.1)	22,669 (27.2)	29,703 (22.7)	
\$48,000+	219,136 (50.6)	27,270 (45.3)	76,629 (48.2)	40,867 (49.0)	74,371 (56.9)	
CCI						<0.0001
0–1	234,514 (52.7)	27,827 (45.0)	81,464 (50.0)	45,656 (53.4)	79,567 (59.1)	
2+	210,237 (47.3)	33,981 (55.0)	81,355 (50.0)	39,792 (46.6)	55,109 (40.9)	
Tumor type						0.75
Benign	121,481 (27.3)	16,914 (27.4)	44,105 (27.1)	24,093 (28.2)	36,369 (27.0)	
Malignant	323,271 (72.7)	44,894 (72.6)	118,715 (72.9)	61,356 (71.8)	98,306 (73.0)	
Teaching hospital†						<0.0001
No	104,994 (23.7)	38,043 (61.8)	59,813 (36.8)	5,708 (6.7)	1,430 (1.1)	
Yes	338,559 (76.3)	23,547 (38.2)	102,704 (63.2)	79,062 (93.3)	133,246 (98.9)	
Procedure						<0.0001
Craniotomy	387,956 (87.2)	53,046 (85.8)	140,527 (86.3)	74,008 (86.6)	120,374 (89.4)	
Biopsy	56,796 (12.8)	8,762 (14.2)	22,292 (13.7)	11,440 (13.4)	14,302 (10.6)	

V1 = hospitals averaged 0–15 procedures per year; V2 = hospitals averaged 16–50 procedures per year; V3 = hospitals averaged 51–100 procedures per year; V4 = hospitals averaged 101–420 procedures per year (V1 = lowest volume; V4 = highest volume).

* Unless otherwise indicated, values are given as the number (%).

† In the categories in which data are missing, the percentages are calculated based on the number of cases reported in that category, not the overall total.

was strongly associated with death (Table 4). Patients who experienced a PSI were 7.6 times more likely to die during their hospitalization (aOR 7.6, CI 6.7–8.7). The occurrence of an HAC did not impact the odds of death in this cohort (aOR 1.0, CI 0.6–1.9).

Other factors shown to be marginally associated with increased odds of death included a patient's age (aOR 1.2, CI 1.1–1.2), more preexisting comorbidities (aOR 1.2, CI 1.1–1.2), and longer hospital stays (aOR 1.1, CI 1.1–1.1). Female sex was mildly associated with a reduction in the odds of death (aOR 0.9, CI 1.0–1.6).

Associations Among PSIs, HACs, and Hospital Volume

We found that 7.4% of patients contracted a PSI, and 0.4% experienced an HAC (Table 5). The most common adverse events in our cohort were postoperative PE or DVT (2.3%), postoperative respiratory failure (1.8%), and postoperative hemorrhage or hematoma (1.5%), statistics that are mirrored in previous studies focusing on

alternate patient cohorts.^{17,34} In the univariate analysis, the lowest-volume hospitals had significantly higher rates of PSIs (8.7% vs 7.2%, $p = 0.01$) and HACs (0.7% vs 0.3%, $p < 0.0001$) than the highest-volume hospitals. The overall mortality rate was 1.9%, with a decreasing trend that persisted as hospital volume increased ($p < 0.0001$).

After adjusting for patient and hospital confounders, we found that hospital volume was marginally associated with the occurrence of a PSI (Table 6). Patients who were treated at the highest-volume hospitals (V4) compared with the lowest-volume ones (V1) had a 10% reduction in the odds of a PSI (aOR 0.9, CI 0.8–1.0). A stronger association between hospital volume and HAC was documented (Table 7). Patients treated at the highest-volume hospitals compared with the lowest-volume ones had a 50% reduction in the odds of experiencing an HAC (aOR 0.5, CI 0.3–0.8). The decreasing odds of an HAC were consistently observed among patients treated at V2 (aOR 0.7, CI 0.5–0.9) and V3 (aOR 0.6, CI 0.4–0.9) hospitals.

FIG. 1. Graph showing mortality rate by hospital surgical volume according to whether patients experienced an adverse event (i.e., PSI) during their hospitalization.

Discussion

Patients with brain tumors undergoing a craniotomy were found to experience a safety-related adverse event (i.e., PSI) at a rate of 7.4%. Significantly fewer patients (0.4%) contracted a HAC. Postoperative PE or DVT, followed by respiratory failure and hemorrhage/hematoma accounted for the majority of the adverse events. The PSI rates documented in our cohort were significantly lower

than previously reported for patients with ruptured¹⁶ and unruptured¹⁷ brain aneurysms. In these studies, Fargen et al. aimed to establish PSIs and HACs as standard performance measures in patients with ruptured and unruptured aneurysms. They showed that the occurrence of a PSI or HAC was associated with longer hospital stays, higher charges, and greater in-hospital mortality rates in both ruptured and unruptured aneurysm cohorts. The occur-

FIG. 2. Graph showing mortality rate by hospital surgical volume according to whether patients experienced an HAC during their hospitalization.

TABLE 4. The aOR and 95% CI for factors associated with mortality*

Variable	aOR	95% CI†	p Value
Greater age in decade increments	1.2	1.1–1.2	<0.0001
Sex (ref: male)			
Female	0.9	1.0–1.6	0.03
CCI, per increment	1.2	1.1–1.2	<0.0001
Tumor type (ref: benign)			
Malignant	1.4	1.2–1.6	0.28
Teaching hospital (ref: no)			
Yes	1.0	0.9–1.2	0.89
Hospital bed size (ref: large)			
Small	0.7	0.5–0.9	0.39
Medium	1.0	0.9–1.1	0.24
Hospital vol (ref: V1 [lowest vol])			
V2	0.8	0.7–0.9	0.006
V3	0.7	0.6–0.9	<0.0001
V4 (highest vol)	0.5	0.4–0.7	<0.0001
Mean LOS in days	1.1	1.1–1.1	<0.0001
Occurrence of a PSI (ref: no)			
Yes	7.6	6.7–8.7	<0.0001

LOS = length of hospital stay; ref = reference value.

* The occurrence of a PSI, race, and income were nonsignificant predictors of mortality.

† Estimates in the CIs were rounded up and therefore may include 1.0 even when $p \leq 0.05$.

rence of a PSI was strongly associated with in-hospital mortality. Similar to these previous studies, we found that patients who experienced a PSI were 7.6 times more likely to die during their hospitalization than those who did not. This effect of a PSI on mortality is comparable to the 7- to 8-fold increase reported in patients with ruptured subarachnoid hemorrhage.¹⁶

Additionally, our multivariate model demonstrated a

significant protective effect of malignant lesions against the development of a PSI. Although this initially appears counterintuitive, given the limitations of a national database as well as the treatment and surgical factors involving these benign histological types (meningioma and vestibular schwannoma), this result is logically explicable. Meningiomas are often large tumors by the time patients undergo surgical intervention, thereby necessitating longer operating times and predisposing patients to postoperative events such as venous thromboembolisms and infectious complications.²⁸ In accordance with these considerations, 2 recent studies have reported a higher incidence of postoperative complications (namely hematoma and surgical site infection) in patients with meningioma as opposed to other intrinsic tumors, such as gliomas.^{25,33} Furthermore, postoperative meningitis is a well-known complication following skull base surgery, such as that for treatment of vestibular schwannoma.^{6,12} In a study by Darrouzet et al., tumor size was a significant predictor of the development of meningitis postoperatively.¹² Furthermore, although tumor size and location are important confounding factors, we did not have access to these variables, and thus were unable to adjust for them in our multivariate model to evaluate these hypotheses.

In our bivariate evaluation of the correlation between PSIs, HACs, and hospital procedural volume, we found a strong association between HACs and volume; PSIs had a moderate correlation with hospital volume. Patients treated at the highest-volume hospitals were 50% less likely to experience an HAC compared with those treated at the lowest-volume facilities. Similarly, patients treated at the highest-volume hospitals experienced a 10% reduction in the odds of experiencing a safety-related adverse event.

Since the early work of Luft et al. demonstrating a relationship between operative volume and surgical outcomes,²⁷ numerous studies have explored similar correlations for several patient populations. Recent research supports an association between 30-day readmissions and procedural volume.^{8,18,19,21,35,37} Tsai et al., showed that hospitals with high surgical volume and low surgical mor-

TABLE 5. Rates of mortality, PSIs, and HACs among adult patients with brain tumors who underwent resection in US hospitals between 1998 and 2009*

Variable	Overall Rate	Hospitals by No. of Procedures per Yr				p Value
		V1	V2	V3	V4	
PSIs (%)						
Any	7.4	8.7	7.1	7.1	7.2	0.01
Postop hemorrhage/hematoma	1.5	1.7	1.4	1.5	1.4	0.58
Postop physiologic/metabolic derangement	1.2	1.5	1.3	1.0	1.0	0.0002
Postop respiratory failure	1.8	2.9	2.0	1.6	1.2	<0.0001
Postop PE or DVT	2.3	1.9	1.8	2.4	3.0	<0.0001
Postop sepsis	0.7	1.0	0.7	0.6	0.5	<0.0001
Accidental puncture or laceration	0.4	0.3	0.3	0.4	0.5	0.53
HACs (%)						
Any	0.4	0.7	0.4	0.3	0.3	<0.0001
In-hospital mortality rate (%)	1.9	2.9	2.2	1.8	1.3	<0.0001

* Subsets of the most common PSIs are described.

TABLE 6. The aOR and 95% CI for factors associated with the occurrence of a PSI*

Variable	aOR	95% CI†	p Value
Greater age in decade increments	1.1	1.1–1.1	<0.0001
Sex (ref: male)			
Female	0.8	0.8–0.9	<0.0001
CCI, per increment	1.2	1.2–1.2	<0.0001
Tumor type (ref: benign)			
Malignant	0.7	0.7–0.8	<0.0001
Teaching hospital (ref: no)			
Yes	0.9	0.8–1.0	0.05
Hospital bed size (ref: large)			
Small	1.0	0.8–1.2	0.90
Medium	1.1	1.0–1.2	0.10
Hospital surgical vol (ref: V1 [lowest vol])			
V2	0.9	0.8–1.0	0.21
V3	0.9	0.7–1.0	0.03
V4 (highest vol)	0.9	0.8–1.0	0.04
Mean LOS in days	1.2	1.2–1.3	<0.0001

* The occurrence of an HAC, race, and income were nonsignificant predictors of a PSI.

† Estimates in the CIs were rounded up and therefore may include 1.0 even when $p \leq 0.05$.

TABLE 7. The aOR and 95% CI for factors associated with the occurrence of an HAC*

Variable	aOR	95% CI†	p Value
Greater age in decade increments	1.2	1.1–1.3	0.0002
Sex (ref: male)			
Female	1.3	1.0–1.6	0.03
CCI, per increment	1.3	1.2–1.4	<0.0001
Tumor type (ref: benign)			
Malignant	0.9	0.7–1.1	0.28
Teaching hospital (ref: no)			
Yes	0.9	0.7–1.3	0.89
Hospital bed size (ref: large)			
Small	0.7	0.4–1.2	0.39
Medium	0.8	0.6–1.1	0.24
Hospital vol (ref: V1 [lowest vol])			
V2	0.7	0.5–0.9	0.03
V3	0.6	0.4–0.9	0.003
V4 (highest vol)	0.5	0.3–0.8	0.02
Mean LOS in days	1.1	1.1–1.1	<0.0001

* The occurrence of a PSI, race, and income were nonsignificant predictors of an HAC.

† Estimates in the CIs were rounded up and therefore may include 1.0 even when $p \leq 0.05$.

tality had lower rates of surgical readmission than other hospitals.³⁷ Further studies have also reported a strong association between complications and volume.^{7,22,32} With respect to PSIs and HACs, ours is one of the first studies to establish a correlation between these metrics and procedural volume for any patient population. In a smaller-sample-size study (2002–2009), Zacharia et al. showed higher rates of HACs in higher-volume centers.³⁸

We found that the highest-volume hospitals had fewer PSIs and HACs than the lowest-volume ones. Even after adjusting for factors such as a patient's age, preexisting conditions, and tumor type, among others, superior outcomes (lowest rates of mortality, PSIs, and HACs) among high-volume hospitals persisted. Differences in our results from Zacharia et al.'s study of HACs may be partially explained by the fact that they included DVT/PE as part of the HACs, whereas we did not. However, more important may be the fact that they dichotomized hospital volume into 2 categories (≤ 50 and > 50 cases per year), whereas we opted for more stratifications. Although it is difficult to discern the factors driving this volume-outcome trend, it is possible that greater awareness in protecting patients from postoperative complications, as previously noted, may in part provide a reasonable explanation for this relationship.^{7,20} More experienced neurosurgeons, ancillary personnel, and advanced imaging technology available at high-volume hospitals may also account for the improved short-term outcomes.

Despite numerous efforts to provide equal access to health care, studies continue to highlight disparities in the management of this disease in adult and pediatric pa-

tients.^{15,26,30,31} In their 2010 study, Mukherjee et al. showed that Hispanic children in whom a brain tumor was diagnosed were less likely to receive high-quality treatment at specialized neurosurgery hospitals than other children with the same condition.³¹ Epstein et al. also found that minority patients were substantially less likely to be treated at high-volume hospitals with reported lower mortality rates.¹⁵ Disparities in access to specialized surgical care may additionally be part of the complex factors involved in this volume-outcome relationship. Future studies aimed at deciphering factors involved in outcome differences between high- and low-volume hospitals may consider factors such as differences in hospital referrals and in a patient's insurance and preferences.

In a technical review prepared by the UCSF-Stanford EPC for the AHRQ, it is reported that PSIs capture adverse events that may be related to medical care, but that also may be a result of other factors.²⁹ For example, the ability of PSIs to differentiate between preexisting conditions and those acquired during hospital admission remains open to debate.⁵ As Bahl et al. reported, the rate of PSI occurrence in their cohort decreased on inclusion of a "present on admission" variable. This variable accounts for conditions that were present at admission, therefore minimizing false positives in reported PSI occurrence rates. Once patients' condition on admission was corrected for, the rates of a subset of PSIs were significantly reduced.

Although this study is limited by our inability to determine when a PSI occurred, a thorough inclusion of specific postsurgical PSIs and the confirmation that a procedure giving rise to a PSI occurred within the index hospital stay gives validity to the assertion that these condi-

tions occurred during the hospitalization of interest rather than as preexisting conditions. As with any retrospective administrative database study, there are several strengths and inherent limitations.^{3,4,14,24,36} In our study we adjusted for preexisting comorbidities by calculating the Elixhauser index score, yet we recognize that the reliability of this metric is strongly dependent on comprehensive documentation. Although we conjectured on several possibilities for the volume-outcome association, our study, similar to other national cohorts, was unable to identify the precise factors driving this interaction. A major strength of this study was our ability to assess PSIs and HACs across a wide variety of hospitals nationwide.

Quality indicators such as PSIs, HACs, and in-hospital mortality were developed with the goal of reflecting quality of care based on hospital administrative data that are collected as a standard effort of health care delivery (AHRQ). Our study showed that hospitals with a higher volume of craniotomies also had lower mortality, PSI, and HAC rates. However, caution must be exercised when generalizing this association of hospital performance to one of quality of care. High-volume, high-performance hospitals may not necessarily correspond to hospitals providing the highest quality of surgical care. The Institute of Medicine has defined quality of health care as “the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge.”²³ Therefore, the definition of quality of care is two-sided, because it relies on both the demonstration of superior outcomes as well as adherence to current standards for quality of care. Because this study queried patients from the NIS, an administrative database, we did not have access to data regarding the quality of care. Therefore, due to this limitation, we are only able to comment on the performance of hospitals by volume in terms of these established metrics, rather than the quality of care provided.

Conclusions

Patient safety–related adverse events were strongly associated with in-hospital mortality rates, whereas HACs were not. Moderate to strong correlations were found between PSI, HAC, and hospital procedural volume. Patients treated at the highest-volume hospitals had consistently lower rates of mortality, PSIs, and HACs compared with those treated at the lowest-volume facilities. In-hospital mortality, PSIs, and HACs all have been proposed as metrics of surgical quality. However, as per the dual definition of quality of care proposed by the Institute of Medicine, further work is required to establish a connection between performance metrics and the quality of surgical care in this patient population.

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