Relationship between patient safety indicator events and comprehensive stroke center volume status in the treatment of unruptured cerebral aneurysms

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OBJECTIVE The Agency of Healthcare Research and Quality (AHRQ) has defined Patient Safety Indicators (PSIs) for assessments in quality of inpatient care. The hypothesis of this study is that, in the treatment of unruptured cerebral aneurysms (UCAs), PSI events are less likely to occur in hospitals meeting the volume thresholds defined by The Joint Commission for Comprehensive Stroke Center (CSC) certification.

METHODS Using the 2002–2011 National (Nationwide) Inpatient Sample, patients treated electively for a nonruptured cerebral aneurysm were selected. Patients were evaluated for PSI events (e.g., pressure ulcers, retained surgical item, perioperative hemorrhage, pulmonary embolism, sepsis) defined by AHRQ-specified ICD-9 codes. Hospitals were categorized by treatment volume into CSC or non-CSC volume status based on The Joint Commission's annual volume thresholds of at least 20 patients with subarachnoid hemorrhage and performance of 15 or more endovascular coiling or surgical clipping procedures for aneurysms.

RESULTS A total of 65,824 patients underwent treatment for an unruptured cerebral aneurysm. There were 4818 patients (7.3%) in whom at least 1 PSI event occurred. The overall inpatient mortality rate was 0.7%. In patients with a PSI event, this rate increased to 7% compared with 0.2% in patients without a PSI event ($p < 0.0001$). The overall rate of poor outcome was 3.8%. In patients with a PSI event, this rate increased to 23.3% compared with 2.3% in patients without a PSI event ($p < 0.0001$). There were significant differences in PSI event, poor outcome, and mortality rates between non-CSC and CSC volume-status hospitals (PSI event, 8.4% vs 7.2%; poor outcome, 5.1% vs 3.6%; and mortality, 1% vs 0.6%). In multivariate analysis, all patients treated at a non-CSC volume-status hospital were more likely to suffer a PSI event with an OR of 1.2 (1.1–1.3). In patients who underwent surgery, this relationship was more substantial, with an OR of 1.4 (1.2–1.6). The relationship was not significant in the endovascularly treated patients.

CONCLUSIONS In the treatment of unruptured cerebral aneurysms, PSI events occur relatively frequently and are associated with significant increases in morbidity and mortality. In patients treated at institutions achieving the volume thresholds for CSC certification, the likelihood of having a PSI event, and therefore the likelihood of poor outcome and mortality, was significantly decreased. These improvements are being driven by the improved outcomes in surgical patients, whereas outcomes and mortality in patients treated endovascularly were not sensitive to the CSC volume status of the hospital and showed no significant relationship with treatment volumes.

<https://thejns.org/doi/abs/10.3171/2017.5.JNS162778>

KEY WORDS aneurysm; comprehensive stroke center; National (Nationwide) Inpatient Sample; patient safety; vascular disorders

ABBREVIATIONS AHRQ = Agency for Healthcare Research and Quality; BAC = Brain Attack Coalition; CSC = Comprehensive Stroke Center; NIS = National (Nationwide) Inpatient Sample; PSC = Primary Stroke Center; PSI = Patient Safety Indicator; SAH = subarachnoid hemorrhage; UCA = unruptured cerebral aneurysm.

SUBMITTED November 3, 2016. **ACCEPTED** May 8, 2017.

INCLUDE WHEN CITING Published online October 20, 2017; DOI: 10.3171/2017.5.JNS162778.

FOLLOWING the passing of the Healthcare Research and Quality Act,¹⁹ which created the Agency for Healthcare Research and Quality (AHRQ), and reports from the Institute of Medicine identifying the significant morbidity and mortality caused by medical errors,^{21,26} a rapidly accelerating wave of interest to find ways to improve the quality and safety of health care has developed. The AHRQ has been at the forefront of these efforts, defining the standards by which quality and safety are currently measured (<https://www.qualityindicators.ahrq.gov>). Through their definitions of Prevention Quality Indicators, Inpatient Quality Indicators, Patient Safety Indicators (PSIs), and Pediatric Quality Indicators, agencies and organizations gained the ability to track and measure variations in quality and safety on both national and regional levels.³⁹ While originally created to allow for measurement in quality improvement processes, the use of these indicators has quickly expanded to include accreditation, public reporting, and provider payments.³⁹

Working in parallel and focusing specifically on improving the quality of care and patient outcomes related to stroke, the Brain Attack Coalition (BAC) recommended the development of Primary Stroke Centers (PSCs). In 2003, this recommendation came to fruition through a joint venture between the American Heart Association/American Stroke Association and The Joint Commission, and hospitals could begin to acquire certification as a PSC.^{16,24} The formation of these PSCs produced significant improvements in rates of patients appropriately receiving intravenous tissue plasminogen activator, compliance with published guidelines, and stroke mortality.^{22,28,31,44} In 2005, the BAC expanded on the idea of specialized care in stroke with the proposal of Comprehensive Stroke Centers (CSCs). Per the BAC, CSCs are facilities with the unique and specialized expertise necessary to treat stroke patients requiring a higher intensity of medical and surgical care.² In 2012, criteria for CSC certification were released. Through the analysis of data demonstrating decreases in mortality and complication rates in centers treating anywhere from 19 to 30 subarachnoid hemorrhage (SAH) patients per year, CSC certification was partially based on treatment volume thresholds.^{3,12,41} The current CSC annual volume requirements are treatment of 20 or more SAH patients, performance of 15 or more endovascular coiling or surgical clipping procedures for aneurysms, and administration of intravenous tissue plasminogen activator in 25 or more eligible patients.²³

Evidence that increasing treatment volume improves outcomes has been shown across a number of neurological diagnoses and procedures, including cerebral aneurysms,^{3,6,8,9,11,12,20,27,30,36–38,41} carotid endarterectomy,^{1,10,35} carotid artery stenting,³⁴ craniotomy for brain tumors⁴ and microvascular decompression,²⁵ and treatment of stroke.^{7,13,29,40} The studies directed at cerebral aneurysms have all shown positive improvements in the outcomes of patients treated at higher-volume centers. Some caveats to these studies are their significant heterogeneity in defining “high-volume centers,” ranging from 20 aneurysms per year to more than 100 aneurysms per year, and the fact that they focused primarily on the treatment of SAH. Thus far, only 2 studies have analyzed factors associated

with PSI events.^{14,15} PSIs were developed by the AHRQ as a set of measurable indicators of postsurgical complications and adverse events (e.g., pressure ulcers, retained surgical item, central venous catheter–related bloodstream infection, perioperative hemorrhage, perioperative pulmonary embolism or deep vein thrombosis, postoperative sepsis) (https://www.qualityindicators.ahrq.gov/Modules/psi_resources.aspx). Finally, no study has analyzed the effect of volume as defined by the CSC criteria on outcomes in the treatment of unruptured cerebral aneurysms.

The hypothesis of this study is that in the treatment of unruptured cerebral aneurysms (UCAs), PSI events, a surrogate for quality care, are less likely to occur in hospitals meeting the volume thresholds defined by The Joint Commission for CSC certification. In addition, we further look to understand the relationship between treatment volumes and PSI events in this patient population. It is important to note that while this study uses the current CSC annual volume requirements to assess the impact of treatment volume, we are not examining the effect of CSC, PSC, or uncertified status.

Methods

Patient Population

The patient population for this study is from the National (Nationwide) Inpatient Sample (NIS) database, years 2002 through 2011 (<https://www.hcup-us.ahrq.gov/nisoverview.jsp>). This database was developed in an effort to provide accurate patient-level data for improvement in providing quality and effective health care. Data within the NIS are an approximation of a 20% stratified sample of all United States community-based inpatient health care facilities and is generated from administrative data from patient discharges. Information available through the NIS includes diagnoses and procedures, patient demographics, total charges, length of stay, discharge status, and hospital characteristics.

The NIS database was queried, and all hospital stays were extracted in which the patient was 18 years or older, had an ICD-9 (*International Classification of Diseases, 9th Revision, Clinical Modification*) primary diagnostic code for UCA (437.3), and was admitted electively. From this data set, all hospital stays with an ICD-9 procedure code for craniotomy for clipping (39.51 or 39.52) or endovascular treatment (39.72, 39.75, or 39.76) of the UCA were selected.

Calculation of Hospital Treatment Volumes

For each patient record, we calculated the associated treating hospital’s annual volume for each of the following: 1) total aneurysms treated, 2) SAHs treated, 3) surgical clipping procedures performed, and 4) endovascular procedures performed. Volumes were calculated for the calendar year of the patient’s admission. If a hospital achieved the annual volume requirements set forth by The Joint Commission (treatment of ≥ 20 SAH patients and performance of ≥ 15 endovascular coiling or surgical clipping procedures for aneurysms), it was characterized as a “CSC volume-status” hospital.² For the determination of SAH volume, SAH patients were identified based on their

primary diagnosis being aneurysmal subarachnoid hemorrhage (ICD-9 code 430). Patients were excluded if they possessed diagnoses consistent with head trauma (ICD-9 codes 800.0–801.9, 803.0–804.9, 850.0–854.1, 873.0–873.9) or arteriovenous malformation/fistula (diagnosis: ICD-9 code 747.81, procedures: ICD-9 codes 39.53, 92.30). SAH patients were also excluded if their length of stay was less than 1 day with an associated discharge to home.

Primary End Points

There were 3 primary end points of interest for the study: PSI events, poor outcome, and in-hospital mortality. PSI events considered within our analyses were pressure ulcers, retained surgical item, iatrogenic pneumothorax, central venous catheter–related bloodstream infection, postoperative hip fracture, perioperative hemorrhage, postoperative physiological and metabolic derangement, postoperative respiratory failure, perioperative pulmonary embolism or deep vein thrombosis, postoperative sepsis, accidental puncture, and transfusion reaction. These were individually classified for each patient record as defined by the ICD-9 diagnosis/procedure codes and inclusion/exclusion criteria provided by AHRQ Patient Safety Indicators Technical Specifications version 5.0 (https://www.qualityindicators.ahrq.gov/Modules/PSI_TechSpec.aspx).

Poor outcome was defined by a dichotomous variable, classifying patients as having either a “good” or “poor” outcome as previously described by Washington et al.⁴³ Good outcome was defined as a discharge to home or rehabilitation facility/hospital. Poor outcome was defined as in-hospital mortality, discharge to a nursing facility, extended care facility, or hospice, placement of a tracheostomy (ICD-9 procedure codes 31.1, 31.2, 31.21, 31.29); and/or placement of a gastrostomy (ICD-9 procedure codes 43.1, 43.11, 43.19, 44.32, 44.38, 44.39). In-hospital mortality was provided by the NIS through the variable “Died.”

Statistical Analysis

The proportions of patients treated for a UCA who experienced a PSI event, poor outcome, and/or in-hospital mortality were calculated. We further calculated the absolute number and proportion of patients with each of the individual PSI events listed above. Differences in age, sex, treatment modality (surgical clipping vs endovascular therapy), and treatment location (at a CSC or non-CSC volume-status hospital) were evaluated using either univariate t-test or chi-square analysis. Relationships between PSI events and poor outcome and mortality were assessed using univariate chi-square analysis. These and subsequent analyses were weighted based on the NIS-provided DISCWT discharge weight variable, which is used for calculating national estimates.

To understand the role of treatment at a CSC versus a non-CSC volume-status hospital, we evaluated differences between these centers in their rates of poor outcome and mortality in patients with and without PSI events using chi-square analysis. This was initially completed for all patients and then separately for clip-treated patients and endovascularly treated patients. To further analyze the impact of PSI events and CSC volume status on outcome,

we followed the univariate analysis with a multivariate analysis using stepwise backward elimination logistical regression models predicting poor outcome and in-patient mortality. The logistic regression model controlled for age, sex, treatment modality, and patient comorbidities (via the APR-DRG [All Patient Refined Diagnosis-Related Group] Severity and Mortality indices). The odds ratio of having a poor outcome or in-hospital death was calculated for both 1) PSI event versus no PSI event and 2) non-CSC versus CSC hospital volume status with associated 95% confidence intervals for both.

The analysis of the role that treatment volume has on the occurrence of PSI events was first completed with univariate t-tests assessing differences in means of total aneurysm, SAH, clipping procedure, and endovascular procedure volumes between patients with and without PSI events. This was done for all patients, patients who underwent clipping, and endovascularly treated patients. Volumes that were found to be significant from the univariate analyses were entered into a multivariate logistical regression model predicting a PSI event. The logistic regression model controlled for age, sex, treatment modality, and patient comorbidities. Significant results from these analyses are demonstrated by showing the change in the odds of having a PSI event versus the treatment volume.

All statistical analyses were completed using SAS (version 9.3, SAS Institute Inc.). Statistical significance was defined for each test as $p < 0.005$.

Results

A total of 65,824 patients were identified based on the selection criteria (Table 1). There were 4818 patients (7.3%) in whom at least 1 PSI event occurred, with a total of 5410 PSI events occurring in these patients (Table 2). The average age of the patient population was 56 years with a significant difference between patients with a PSI event and those without a PSI event (59 vs 56 years, $p < 0.0001$). The vast majority of patients were female (76%),

TABLE 1. Patient demographics

Variable	w/ PSI Event	w/o PSI Event	p Value
No. of patients	4818 (7.3)	61,006 (92.7)	
Mean age (SD) in yrs	59 (27)	56 (26)	<0.0001*
Sex			0.798†
Male	1145 (7.3)	14,607 (92.7)	
Female	3672 (7.3)	46,399 (92.7)	
Treatment modality			<0.0001†
Surgical	2500 (8.5)	27,012 (91.5)	
Endovascular	2318 (6.4)	33,995 (93.6)	
Treated at CSC			<0.0001†
Yes	4070 (7.2)	52,864 (92.9)	
No	748 (8.4)	8142 (91.6)	

Values are presented as number (%) unless otherwise indicated.

* t-test analysis.

† Chi-square analysis.

TABLE 2. Patient safety events and impact on outcomes

Variable	No.	Overall Rate (%)	Poor Outcome		Mortality	
			Rate in Patients w/ PSI (%)	OR (95% CI)*	Rate in Patients w/ PSI (%)	OR (95% CI)*
PSI event†						
Pressure ulcer	10	0.02	100.0	NA	0.0	NA
Retained foreign body	19	0.03	0.0	NA	0.0	NA
Pneumothorax	73	0.11	22.5	7.4 (4.2–12.8)	0.0	NA
Catheter-associated infection	67	0.1	37.3	15.2 (9.2–25.0)	0.0	NA
Hip fracture	0	0	0.0	NA	0.0	NA
Periop hemorrhage	1783	2.7	9.3	2.7 (2.3–3.2)	1.9	3.1 (2.2–4.3)
Physiological & metabolic derangement	5	0.01	100.0	NA	100.0	NA
Respiratory failure	2272	3.45	40.5	26.6 (24.1–29.3)	13.3	67.6 (55.1–82.9)
Pulmonary embolism or deep vein thrombosis	631	0.96	20.2	6.7 (5.4–8.2)	3.9	6.2 (4.1–9.4)
Sepsis	186	0.28	61.3	41.9 (31.1–56.5)	21.4	43.9 (30.5–63.2)
Accidental puncture or laceration	364	0.55	16.5	5.1 (3.8–6.7)	8.0	13.7 (9.3–20.2)
Transfusion reaction	0	0	0.0	NA	0.0	NA
Patients w/ PSI event‡	4818	7.3	23.3	13.1 (12.1–14.3)	7.0	43.7 (35.1–54.5)

NA = not applicable.

* Chi-square analysis comparing patients with a PSI event versus patients without a PSI event.

† Values are based on the number of events (n = 5410).

‡ Values are based on the number of patients with events.

but there was no significant difference in the rate of PSI events between males and females ($p = 0.798$).

An endovascular procedure was the treatment modality in 55% of patients, while surgery was the treatment modality in 45% of patients. There was a significant difference in PSI rates between endovascular and surgical treatment: 6.4% and 8.5% ($p < 0.0001$), respectively. The majority of aneurysm patients were treated at centers meeting the volume threshold for CSC status (86%).

Impact of PSI Events on Patient Outcome

The overall inpatient mortality rate was 0.7%. In patients with a PSI event, this rate increased to 7% compared with 0.2% in patients without a PSI ($p < 0.0001$). This resulted in an OR (95% CI) of inpatient mortality of 43.7 (35.1–54.5) when comparing patients with versus without a PSI event. The overall rate of poor outcome was 3.8%. In patients with a PSI event, this rate increased to 23.3% versus 2.3% in patients without a PSI ($p < 0.0001$). This resulted in an OR (95% CI) of poor outcome of 13.1 (12.1–14.3) when comparing patients with versus those without a PSI event. The individual counts for the different PSI events and their associated impacts on poor outcome and

mortality can be seen in Table 2. The most frequent PSI events were respiratory failure occurring in 3.5% of patients and perioperative hematoma occurring in 2.7%. The most significant predictors of poor outcome and mortality were respiratory failure (OR for poor outcome 26.6 and OR for mortality 67.6) and sepsis (OR for poor outcome 41.9 and OR for mortality 43.9).

Impact of CSC Status on PSI Events

There were significant differences in PSI event, poor outcome, and mortality rates between non-CSC and CSC volume-status hospitals (PSI event, 8.4% vs 7.2%; poor outcome, 5.1% vs 3.6%; and mortality, 1% vs 0.6%) (Table 3). From univariate analysis, comparing non-CSC versus CSC volume-status hospitals, the OR (95% CI) for a PSI event was 1.2 (1.1–1.3); for poor outcome, 1.4 (1.3–1.6); and for mortality, 1.7 (1.3–2.1). The differences in poor outcome and mortality were significantly accentuated in patients experiencing a PSI event. At non-CSC volume-status hospitals, the OR (95% CI) for poor outcome in patients with a PSI versus those without was 21.1 (17.1–25.9) compared with 11.8 (10.8–13.0) at CSC volume-status hospitals. For mortality, this difference was even more de-

TABLE 3. Impact of CSC volume status on patient outcomes

Impact of CSC Outcomes Among All Patients	Overall PSI %	Overall Poor Outcome %	Overall Mortality %	PSI w/ Poor Outcome %	OR of Poor Outcome w/ PSI vs w/o PSI (95% CI)*	PSI w/ Mortality %	OR of Mortality w/ PSI vs. w/o PSI (95% CI)*
Non-CSC	8.4	5.1	1	34.1	21.1 (17.1–25.9)	11.6	216.7 (87.0–540.1)
CSC	7.2	3.6	0.6	21.3	11.8 (10.8–13.0)	6.2	34.7 (27.5–43.9)

* Chi-square analysis.

TABLE 4. Multivariate analysis predicting outcomes

Multivariate Analysis	PSI Event			Poor Outcome			Mortality		
	OR	95% CI	p Value	OR	95% CI	p Value	OR	95% CI	p Value
All patients									
PSI vs no PSI	NA	NA	NA	2.6	2.3–3.0	<0.0001	6.9	5.2–9.1	<0.0001
Non-CSC vs CSC	1.2	1.1–1.3	<0.0001	1.2	1.1–1.4	0.0018	1.6	1.2–2.0	0.0005
Surgical patients									
PSI vs no PSI	NA	NA	NA	3	2.6–3.5	<0.0001	5.8	3.9–8.6	<0.0001
Non-CSC vs CSC	1.4	1.2–1.6	<0.0001	1.3	1.1–1.5	<0.0001	1.6	1.1–2.1	0.0043
Endovascular patients									
PSI vs no PSI	NA	NA	NA	2.4	2–3.0	<0.0001	9.3	6.1–13.9	<0.0001
Non-CSC vs CSC	NS	NS	NS	NS	NS	NS	1.7	1.1–2.8	0.0271

NS = not significant.

monstrable with an OR (95% CI) of 216.7 (87–540.1) at non-CSC volume-status hospitals versus 34.7 (27.5–43.9) for those treated at a CSC volume-status hospital.

In the multivariate analysis, patients treated at a non-CSC volume-status hospital were more likely to suffer a PSI event with an OR of 1.2 (1.1–1.3) when compared with CSC volume-status hospitals (Table 4). In surgically treated patients, this relationship was more substantial with an OR of 1.4 (1.2–1.6). The relationship was not significant in the endovascularly treated patients. Both PSI events and treatment at a non-CSC volume-status hospital were significant predictors of poor outcome and mortality (Table 4). In subgroup analysis, the presence of a PSI event continued to be a significant predictor of both poor outcome and mortality in clip-treated and endovascularly treated patients. However, CSC volume status of the hospital only had a significant impact on outcomes for surgically treated patients.

Impact of Treatment Volumes on PSI Events

In univariate analysis, there were significant differences in the treating hospitals' mean treatment volumes when comparing all patients with and without a PSI event (Table 5). Patients who did not suffer a PSI event were treated at hospitals with significantly higher mean annual volumes of total aneurysms treated (133 vs 121, $p = 0.0002$), surgical clipping procedures (42 vs 38, $p = 0.0011$), and endovascular procedures (51 vs 47, $p = 0.0005$). There was a trend in annual SAH admission volume (79 vs 75, $p = 0.0101$), but this difference did not meet our threshold of $p < 0.005$. In subgroup analysis, a similar finding was discovered in surgical patients for mean volumes of total annual aneurysm (133 vs 113, $p < 0.0001$), SAH admission (81 vs 73, $p = 0.0019$), and surgical clipping (51 vs 39, $p < 0.0001$). In surgical patients, there was no significant difference in endovascular procedural volumes, and in endovascularly treated patients there were no significant differences in any of the annual treatment volumes (Table 5).

Results of the multivariate logistical regression model analyzing the impact of treatment volumes on PSI events are shown in Figs. 1–3. Among all patients, there are sta-

tistically significant linear relationships between total aneurysm volume, SAH admission volume, and clipping procedural volume and the odds of suffering a PSI event. For each respective volume, there is a progressive decline in the likelihood of suffering a PSI event as the treatment volume increases. A similar, but more pronounced relationship was identified for patients who underwent surgery. Compared with all patients, those who underwent surgical clipping were more sensitive to the hospital's treatment volumes (Figs. 1–3). There was a measurable and statistically significant difference in sensitivity to a hospital's total aneurysm volume and surgical clipping procedural

TABLE 5. Relationship between PSI events and hospital treatment volumes

Variable*	Mean (SD)		p Value†
	w/ PSI Event	w/o PSI Event	
All patients			
Total aneurysm vol	121 (191)	133 (202)	0.0002
SAH vol	75 (118)	79 (119)	0.0101
Surgical vol	38 (82)	42 (92)	0.0011
Endovascular vol	47 (88)	51 (92)	0.0005
Surgical patients			
Total aneurysm vol	113 (196)	133 (222)	<0.0001
SAH vol	73 (122)	81 (130)	0.0019
Surgical vol	39 (84)	51 (99)	<0.0001
Endovascular vol	37 (86)	41 (91)	0.0498
Endovascular patients			
Total aneurysm vol	130 (184)	133 (186)	0.5343
SAH vol	77 (112)	78 (109)	0.721
Surgical vol	35 (79)	35 (83)	0.7104
Endovascular vol	57 (85)	60 (89)	0.1273

There were 29,511 surgical patients and 36,313 endovascularly treated patients, totaling 65,824 patients.

* Vol refers to the mean number of procedures performed in hospitals per year.

† t-test.

FIG. 1. Graph demonstrating the relationships between annual total aneurysm volume (unruptured and ruptured) and the odds of suffering a PSI event in all patients (*solid line*) and surgical patients (*dashed line*). The difference in response between all patients and surgical patients was statistically significant. A volume of 1/year served as the reference for the OR calculations. Figure is available in color online only.

volume between all patients and those who underwent surgery (Figs. 1 and 3). Both groups showed a decrease in the odds of a PSI event with increased SAH volume, with surgery patients appearing to be slightly more sensitive, but this difference was not significant.

Discussion

Using the data provided within the NIS database, we analyzed the impact of hospitals' total annual aneurysm, annual SAH, and annual procedural volumes (surgical clipping and endovascular) on the in-patient results from 65,824 patients electively treated for an unruptured cerebral aneurysm. Within this group, we found a relatively high rate of PSI events (7.3%). With regard to PSI events, the data provide evidence that they are highly associated with poor outcome (PSI vs no PSI event: OR of poor outcome 13.1) and in-hospital mortality (PSI vs no PSI event: OR of mortality 43.7). Novel to this study is the analysis demonstrating that patients are less likely to suffer a PSI event at hospitals that achieve the volume thresholds set forth by The Joint Commission for CSC certification (non-CSC vs CSC volume status: OR of PSI event of 1.2). Further evidence suggesting benefit from CSC volume status is the significant decrease in morbidity and mortality related to these events at a CSC versus non-CSC volume-status hospital. In those patients treated at a CSC volume-status hospital who experienced a PSI event, their poor outcome rate was 21.3% compared with 34.1% at non-CSC volume-status hospitals, and their mortality was 6.2% versus 11.6%.

Analyzing the associations between PSI events and outcomes, it was found that the presence of a PSI event was significantly associated with an increase in the odds of a poor outcome (OR 2.6) and inpatient mortality (OR 6.9). With regard to the relationships between CSC volume status and outcomes, we discovered an increased likelihood of poor outcome (OR 1.2) and inpatient mortality (OR 1.6) when comparing non-CSC with CSC volume-status centers. In subgroup analyses, the presence of a PSI event continued to have a strong relationship with poor outcome

FIG. 2. Graph demonstrating the relationships between annual SAH volume and the odds of suffering a PSI event in all patients (*solid line*) and surgical patients (*dashed line*). The difference in response between all patients and surgical patients was not statistically significant. The vertical dashed line represents 20 SAH/year, which is the current threshold for CSC certification. A volume of 1/year served as the reference for the OR calculations. Figure is available in color online only.

and mortality (Table 4) in surgically and endovascularly treated patients. Yet, the CSC volume status of a hospital was only significant in surgically treated patients. In endovascularly treated patients, mortality did approach significance within the multivariate model ($p = 0.0271$) but did not meet our threshold of $p < 0.005$.

The analyses evaluating the relationships of total annual aneurysm, SAH, surgical procedure, and endovascular procedure volumes mirrored the aforementioned findings and showed that there is a significant linear relationship between treatment volumes and odds of suffering a PSI event (Figs. 1–3). These figures show that as volume continuously increases, the likelihood of having a PSI event declines significantly. It is also important to note that this decline extends beyond the 20 SAH per year and 15 surgical and endovascular treatments per year. Again, these relationships were significant among all treated patients and even more pronounced among those who underwent surgical treatment. However, we again see that treatment volumes were not significant predictors of PSI events in the endovascularly treated patients.

There have been a number of previous studies demonstrating clear volume-outcome relationships in the treatment of cerebral aneurysms.^{3,6,8,9,11,12,20,27,30,36–38,41} The original data used to define the CSC thresholds showed a 17% decrease in mortality and a 20% decrease in adverse outcome at hospitals treating at least 21 ruptured cerebral aneurysms per year.³ Since the original CSC description,² a number of studies have evaluated the SAH volume-outcome relationship.^{8,17,27,30,36–38} Barker et al.⁵ in their analysis of the treatment of UCA within the NIS, found that hospitals with a treatment volume of at least 20/year had significantly more discharges to home and lower mortality. Brinjikji et al.⁹ showed that in UCA, outcomes were significantly improved when considering high volume as at least 45/year. Most recently, Pandey et al.³⁷ demonstrated a strong relationship between SAH treatment volume

FIG. 3. Graph demonstrating the relationships between annual total aneurysm volume (solid line) and annual clipping procedure volume (dashed line) and the odds of suffering a PSI event in surgical patients. The difference in response of surgical patients to total aneurysm volume and clipping procedure volume was significantly different. A volume of 1/year served as the reference for the OR calculations. Figure is available in color online only.

and outcome, with mortality rates decreasing from 28.4% at hospitals treating 20 SAH patients per year to 18.7% at hospitals treating 100 SAH patients per year. With regard to PSI events, Fargen et al.^{14,15} found that in the treatment of both UCAs and ruptured cerebral aneurysms, PSI events were associated with significant increases in length of stay, hospital costs, and mortality. However, they found no relationship between hospital size and the occurrence of these events.

To our knowledge, the results from this study are the first to provide evidence that outcomes are improved and PSI events are less frequent when patients with UCAs are treated at hospitals that achieve the volume status defined for CSC certification. Interestingly, we identified—at least within this patient population—that the improved outcomes are being driven by improvements seen in the patients treated with surgical clipping, and endovascular treatments are less sensitive to these volume thresholds. This finding was reiterated by the results looking at the continuous relationship between specific treatment volumes and PSI events, which showed decreasing rates of PSI events as treatment volumes increase. Again, this relationship between volume and PSI events appeared to be propelled by improvements gained in the surgical clipping patient population. These findings mirror the results of Berman et al.,⁶ who found in their analysis of the New York State hospital discharge database that the total aneurysm volume of a hospital had a greater impact on UCA than SAH and a greater impact on surgically versus endovascularly treated patients. The exact cause as to why outcomes after endovascular therapy are less sensitive to treatment volume remains unclear. In subarachnoid hemorrhage trials, while the long-term results demonstrate good outcomes in both surgically and endovascularly treated patients, there is clear evidence that surgery has a higher morbidity in the short-term, postoperative period.^{32,33,44} It will be important for future studies to analyze the source of this difference in the volume-outcome relationship between surgery and endovascular treatments.

Two points of discussion generated by the results of this

study relate to 1) the role of volume in defining criteria for CSC certification and 2) the role of neurosurgery in the new federally mandated paradigm of value-based health care. With regard to CSC certification, thus far the studies used by The Joint Commission in its formulation of volume thresholds have focused primarily on the role of SAH volume and inpatient mortality. Also, volumes for treatment modality (i.e., surgical clipping vs endovascular treatment) are treated equally. There is now increasing evidence that the benefits of increased volume extend well beyond the threshold of 20 SAHs per year. Furthermore, the question remains as to the “clinical significance” of this benefit, as the identified difference in mortality between CSC and Non-CSC volume-status hospitals was 0.4%. It might be that outcomes are more closely tied to overall aneurysm volume rather than SAH volume. In addition, based on the results from this study and others, there is clear evidence that there is a differential between the surgical clipping–volume relationship and the endovascular treatment–volume relationship. The equivalent treatment of these is almost certainly inaccurate. It is our opinion that future guidelines for certification should be based on clinically significant and meaningful differences in outcome and should consider an institution’s experience in each of these modalities separately rather than as a lumped sum.

Second, today’s health care policy landscape is rapidly shifting, with greater and more intense focus being placed on hospitals and physicians to provide “quality” patient care. This attention has resulted in a number of federal strategies (such as Hospital Inpatient Quality Reporting, Hospital Value Based Purchasing, and Hospital-Acquired Condition Reduction Program) that tie “quality” to reimbursement, and in these programs, PSI events, “hospital-acquired conditions,” and the Centers for Medicare and Medicaid Services’ “never events” are the surrogate markers for this quality measure.^{18,45} Across all specialty groups, neurosurgery has some of the highest rates of these adverse events,⁴⁵ and while the specialty makes up a relatively small portion of the health care system, these high rates have resulted in increased scrutiny being placed on neurosurgery from hospitals and insurance providers to achieve the expected results of these mandates. Therefore, if neurosurgery is to have a voice in this arena, it is imperative that an active and coordinated effort to collect and understand these data be made.

There are a number of acknowledged limitations to this study, many of which are inherent in the use of any large administrative database, including the NIS. In this study, a number of potentially relevant but unavailable factors are not considered, including hospital size, location, and type, as well as available ancillary staff, intensive care services, and physician experience. In addition, diagnoses based on ICD-9 codes are imperfect, and coding errors exist. Despite this, many of the current measures of hospital quality are based on these codes. Therefore, to be consistent in our findings with these measures, we categorized PSI events using the strict definitions provided by the AHRQ. We also used very stringent criteria in defining the UCA population in an effort to limit any misclassifications of patients. Another consideration is that outcomes were

based on “discharge” and not long-term follow-up. This issue is only a factor in considering the results related to our definition of poor outcome. As stated, the PSI events are based on accepted criteria, and long-term follow-up clearly has no bearing on inpatient mortality. Our definition of CSC volume status was based purely on volume thresholds. There are a number of criteria by which hospitals are assessed for determination of CSC certification. Therefore, it is likely that some of the hospitals identified as “CSC volume-status centers” are in fact not certified as CSCs based on other requirements. Conversely, those hospitals included in this study that are CSC certified by definition must offer a number of higher-level services that would likely contribute to improved outcomes and confound the task of isolating treatment volume as a variable. Lastly, while this is not a limitation, it does warrant clarification: the study does not assert a causal relationship between CSC certification and outcomes or CSC certification and PSI events, but rather is noting the existence of strong relationships between the volume thresholds and these factors.

Conclusions

In the treatment of UCAs, PSI events occur relatively frequently and are associated with significant increases in morbidity and mortality. In patients treated at institutions achieving the volume thresholds for CSC certification, both the likelihood of having a PSI event and the morbidity/mortality associated with these events were significantly decreased. Further analyses in the PSI event-volume relationship indicated that these improvements in outcome are being driven by the improved outcomes related to volume found in surgical patients. Endovascularly treated patients were insensitive to the CSC volume status of the hospital and showed no significant relationship with treatment volumes. The development of future guidelines for CSC certification will need to consider this differential response when defining new volume thresholds.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Washington. Acquisition of data: Washington. Analysis and interpretation of data: all authors. Drafting the article: Washington. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Washington. Statistical analysis: Washington. Administrative/technical/material support: Washington. Study supervision: Washington.

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