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Predictors of Surgical Site Infection After Non-Emergent Craniotomy: A Nationwide Readmission Database Analysis

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Abstract

Objective—Surgical site infections (SSIs) carry significant patient morbidity and mortality and are a major source of readmissions after craniotomy. Because of their deleterious effects on health care outcomes and costs, identifying modifiable risk factors holds tremendous value. However, because SSIs after craniotomy are rare and most existing data comprise single-institution studies with small sample sizes, many are likely underpowered to discern for such factors. The objective of this study was to use a large heterogeneous patient sample to determine SSI incidence after nonemergent craniotomy and identify factors associated with readmission and subsequent need for wound washout.

Methods—We used the 2010–2014 Nationwide Readmissions Database cohorts to discern for factors predictive of SSI and washout.

Results—We identified 93,920 nonemergent craniotomies. There were 2079 cases of SSI (2.2%) and 835 reoperations for washout (0.89%) within 30 days of index admission and there were 2761 cases of SSI (3.6%) and 1220 reoperations for washout (1.58%) within 90 days. Several factors were predictive of SSI in multivariate analysis, including tumor operations, external ventricular drain (EVD), age, length of stay, diabetes, discharge to an intermediate-care facility, insurance type, and hospital bed size. Many of these factors were similarly implicated in reoperation for washout.

Conclusions—SSI incidence in neurosurgery is low and most readmissions occur within 30 days. Several factors predicted SSI after craniotomy, including operations for tumor, younger age,

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hospitalization length, diabetes, discharge to institutional care, larger hospital bed size, Medicaid insurance, and presence of an EVD. Diabetes and EVD placement may represent modifiable factors that could be explored in subsequent prospective studies for their associations with cranial SSIs.

Keywords

craniotomy; infection; meningitis; nationwide database; postoperative infection; readmission; surgical site infection (SSI)

Introduction

Surgical site infections (SSIs) are a major concern in neurosurgery given the proximity of the wound to the central nervous system. When they do occur, they carry substantial patient morbidity and mortality with higher resultant length of stays (LOS) and hospital costs¹. SSIs are one of the most common healthcare-associated infections (HAIs) with a fiscal footprint equivalent to roughly \$3 billion dollars annually². Their reported incidence after craniotomy is variable, ranging from 0.8 to 5.6%^{3–9}. Various risk factors have been implicated, however, much of the data is inconsistent³. This is likely attributable to immense variation in study inclusion criteria and SSI definitions employed throughout the literature. Furthermore, as cranial SSIs are considered relatively rare events, many studies are likely underpowered to discern for key predictors of infection^{10,11}.

Besides antibiotic prophylaxis, no standardized guidelines exist for reducing post-craniotomy SSI¹¹. Their devastating consequences, coupled with burgeoning healthcare costs and insurers moving away from covering SSIs, mean that identifying modifiable risk factors has ever-increasing value. We therefore queried the newly available Nationwide Readmissions Database (NRD) to elucidate patient, procedure and hospital characteristics associated with readmission for SSI after non-emergent craniotomy. The NRD is a multi-state resource that assigns anonymized linkage numbers, effectively allowing patients to be tracked after discharge throughout the state and within a calendar year. It is unique from other national samples because it is not limited to cross-sectional analysis of hospital admissions. Rather, it affords the ability to longitudinally follow patients after an index admission and to define time-to-event variables (e.g. readmission with SSI). Consequently, the NRD circumvents the issue of different-hospital follow-up inherent to many single-institution investigations, provided follow-up is sought within state lines.

Since postoperative wound complications tend to manifest within the first month of an operation¹², the NRD is ideally suited to analyzing nationwide estimates of SSI. This database has previously been employed in neurosurgery to characterize readmission trends after subarachnoid hemorrhage¹³, malignant brain tumor resection¹⁴, stroke¹⁵ and spine surgery¹⁶. Here we report on its use for characterizing SSI after craniotomy. The goals of this investigation were (1) to define 30- and 90-day SSI incidence after non-emergent craniotomy, (2) to determine patient and hospital factors that were predictive of SSI and (3) to characterize factors associated with reoperation for washout.

Methods

Data Source

The 2010–2014 cohorts of the NRD by the Healthcare Cost and Utilization Project (HCUP) were queried for this investigation. The database is comprised of all hospital discharges meeting quality assurance standards from 20–27 member states and approximates 50% of discharges in the US. No IRB/ethics approval was required for use of the publicly available NRD database.

Study Population

Primary inclusion criteria were adults >18 years of age who underwent non-emergent craniotomy. We excluded transphenoidal approaches and craniotomies for trauma, ventricular shunting and deep brain stimulation (DBS) because of the increased risk for infection associated with traversing the nasal passage, emergency cases^{6,17} and hardware implantation. The resulting cohort mainly comprised craniotomies for tumor, cerebrovascular disorders and epilepsy. Patients were extracted using the relevant ICD-9CM diagnosis and procedures (Table 1).

The index admission was defined as the initial hospitalization on which craniotomy was performed. Patients with a diagnosis of SSI (998.30, 998.31, 998.32, 998.5X, 998.83, 998.1x, 998.81, 320.0–322.9, 324.0) on index admission, who died or were missing key data (e.g. LOS or time to procedure) were excluded. From this initial cohort, the NRD was queried for two clinical outcomes at 30- and 90-days: (1) readmission with SSI and (2) readmission with SSI requiring washout (86.22, 01.xx). Because NRD only tracks patients in a single calendar year, those with insufficient time for follow-up were excluded. Hence, for 30-day readmissions only patients discharged between January and November were included and for 90-day readmissions only those discharged between January and September were included.

See Figure 1. for a schematic of study design.

Patient and Hospital Demographics

Various patient and hospital characteristics were included in association analyses with the infectious outcomes of interest. Independent variables associated with the outcome ($p < 0.15$) in univariate analysis were included in the multiple regression model and stepwise logistic regression employed with caution for confounders. Hospital factors consisted of bed size, teaching status, and annual procedural volume. Craniotomy volume was dichotomized with high volume centers being at or above the 90th percentile per year. Patient factors included: age, gender, insurance, underlying comorbidities, LOS and discharge disposition. Age is present as a continuous variable in the NRD and was categorized as follows for analysis: 18–44, 45–59, 60–74, 75. Underlying comorbidities were inferred via the Elixhauser index, which has been dichotomized in the NRD to the presence or absence of a comorbidity. Underlying medical conditions were also queried such as: obesity (278.0, V85.3, V85.4), diabetes (250.xx) and tobacco use (305.1, V15.82). Additionally, clinical

factors with the potential to influence SSI were included: extracranial infection (001.00–139.99, 995.91–92), EVD presence (2.21) and ventricular shunt (2.32–2.35).

Statistical Analysis

The primary outcomes were readmission within 30- and 90-days for: (1) SSI, and (2) SSI requiring washout. Readmissions were extracted using standard HCUP methodology. In instances where multiple readmissions were identified, only the first was included for analysis. Multivariable analysis was performed using two-level mixed-effects modeling accounting for clustering and reported using odds ratios (OR) with 95% confidence intervals (CI). Statistical significance was defined as $p < 0.05$. All analysis was conducted with SAS 9.4 (Cary, NC).

Results

Patient and hospital baseline characteristics

From 2010–2014, there were 93,920 craniotomies that met our inclusion criteria. Most were for tumor (81.2%, $n = 76,265$) followed by cerebrovascular conditions (17.8%, $n = 16,703$) and lastly, epilepsy (1%, $n = 952$). The median LOS for the entire cohort on index admission was 5 days with a median index hospitalization cost of \$99,586. The majority of patients were between 45 and 74 years: 18–44 (20.1%), 45–59 (35.2%), 60–74 (34.9%) and 75 (9.8%). There was slight female predominance in the index cohort: females (56.4%, $n = 52,821$) and males (43.6%, $n = 41,099$). 69% of patients in the index population ($n = 64,799$) had underlying comorbidities as determined by the Elixhauser index. Most had private (47.2%) or Medicare insurance (33.3%) and were treated at hospitals with large bed size (80.2%).

SSI incidence, readmission demographics

There were 2079 readmissions for SSI within 30 days of index hospitalization, corresponding to an SSI incidence of 2.2% (Table 2). For the cohort readmitted, their median LOS on index admission was 6 days with a median cost of \$110,776. The median time to 30-day readmission was 13 days with a median readmission cost of \$62,072. Of those readmitted for postoperative infection at 30 days, 40.2% ($n = 835$) required takeback for wound washout.

Within 90 days, there were 2761 readmissions for SSI, corresponding to a 90-day SSI incidence of 3.6%. The median time to 90-day readmission was 23 days with a median readmission cost of \$60,841. Of SSI readmissions, 44.2% ($n = 1220$) required reoperation for washout. See Figure 2.

Factors associated with SSI within 30- and 90-days

In multivariate models, various procedure-, patient- and hospital-related factors were associated with SSI. We did not subdivide SSI into its various types (e.g. abscess, empyema, wound breakdown) because of the potential for variability in ICD-9 coding across institutions and the fact that the goal of our investigation was to identify modifiable risk factors of infection, which are not likely to differ substantially between the various SSI

types. Craniotomy for tumor resection had higher odds for SSI at both 30 days (OR 1.46–1.93, $p < 0.0001$) and 90 days (OR 1.48–1.83, $p < 0.0001$) compared to cerebrovascular operations. The latter was used as the reference cohort here due to similarities in operative duration between both groups minus attendant factors that complicate management and that *a priori* would be expected to increase infection risk (e.g. chemotherapy, radiation). Other procedure-related factors implicated in SSI include the presence of an EVD on index admission. While significant at 30-days (OR 1.33, $p = 0.01$), the association between EVD and SSI was non-significant at 90-days.

Several patient-related factors were predictive for SSI. Younger age correlated with increased likelihood for SSI at 30 and 90 days (OR 2.09–2.15, $p < 0.0001$), with those aged 18–44 years having more than twice the odds relative to the elderly (> 75 years). Diabetes also significantly increased the odds of infection at both time points (OR 1.29, $p < 0.0001$ and 1.23, $p = 0.0001$). Additional patient-related factors that were predictive for SSI include: male gender, having Medicaid insurance, hospital LOS (greater than 3, but fewer than 11 days) and discharge to an intermediate care facility (e.g. SNF) or with home health care. The relationship between cranial SSI and concomitant extra-cranial infections (pneumonia, urinary tract infections etc.) was explored and found to be non-significant.

Hospital-related factors were evaluated as well, namely teaching status, surgical volume and bed size. Teaching status did not influence likelihood for readmission with SSI. Bed size inversely correlated with SSI, with larger hospitals having lower chances of SSI at 30 and 90 days (OR 0.72–0.74, $p < 0.001$). Procedural volume held significance at 30-days with high-volume centers (i.e. those above the 90th percentile) carrying an increased risk for SSI (OR 1.16, $p = 0.003$).

See Tables 3 and 4 for details.

Factors associated with reoperation for washout within 30- and 90- days

Many of the factors associated with SSI were again implicated in reoperation for wound washout. Significant predictors at 30- and 90- days, respectively, include: craniotomy for tumor (OR 1.91–2.06, $p < 0.0001$ and 1.72–2.01, $p < 0.0001$), discharge to intermediate care facility (OR 1.41, $p = 0.0007$ and OR 1.44, $p < 0.0001$), discharge with home health care (OR 1.43, $p < 0.0001$ and 1.27, $p = 0.002$), younger age and male gender. Diabetes (OR 1.39, $p = 0.0005$), presence of EVD during index hospitalization (OR 1.47, $p = 0.02$), having Medicaid insurance (OR 1.30, $p = 0.01$) and high procedural volume (OR 1.19, $p = 0.02$) correlated with reoperation for washout within 30-days, but were not significant at 90-days.

See Tables 5 and 6 for details.

Discussion

Hospital readmissions are a substantial burden on healthcare expenditure, accounting for 20% of Medicare payments¹⁸. In an era of value-based Medicine where reimbursement is increasingly being linked to performance and quality of care, reducing unplanned readmissions has become a central focus of hospital administrators and policymakers. SSIs

are a major culprit behind unplanned readmissions and are associated with unwanted sequelae including reoperation, prolonged LOS and added patient morbidity, if not mortality¹⁹. Their true cost is borne out not only in higher hospital charges, but in lost economic productivity from delays in return to the workforce. In light of these ramifications, and SSIs being viewed as a litmus test for surgeon and hospital quality, identifying modifiable risk factors is of paramount importance. We therefore queried the NRD database to elucidate patient and hospital characteristics that influence readmissions for SSI and reoperation for washout.

Cranial neurosurgery generally has a low SSI incidence¹⁰. For example, a retrospective study from one of the highest volume neurosurgical centers in North America found only 82 cases of infection requiring reoperation among 16,450 cranial surgeries performed between January 1997 and December 2007¹¹. Because of the small number of infections, sample sizes thus have to be fairly large in order to generate an accurate estimate of SSI incidence and even larger to discern for predictors of infection¹⁰. Prospective studies, which generally span shorter time intervals, fare even worse and multicenter analyses on SSI are sparse²⁰. The NRD provides a large heterogeneous sample of patients, circumventing this issue of sample size. Moreover, it provides the unique ability to track patients within a state regardless of the hospital at which care is rendered. This is particularly useful in studying post-craniotomy SSI since the urgent nature of the diagnosis often dictates that patients present to the nearest, rather than the original, treatment facility.

In our study, the overall SSI incidence among non-emergent craniotomies was 2.2% at 30 days and 3.6% at 90 days. These figures are on the lower end of the spectrum (0.8–5.6%) reported by single-institution retrospective and prospective studies^{3–9}, but in line with values published by other national database investigations (1.8–2.04%)^{17,21}. The former can partly be attributed to the shorter follow-up specified in our analysis vis-à-vis the much longer period—years to decades—over which many single-institution studies are conducted. Additionally, we determined the rate of SSI takeback for washout to be 0.89% and 1.58% at 30- and 90 days, respectively. These values are also in agreement with the existing literature¹¹.

Craniotomies for tumor were independently associated with readmission for postoperative infection and need for washout. This relationship has previously been described by others^{22,23}. One explanation for this finding is that these patients are more likely to have had recent exposure to radiation therapy or pharmacotherapies (e.g. chemotherapy, steroids) that might reasonably be expected to compromise wound healing. Other procedure-related factors that significantly correlated with SSI in our study include presence of an EVD on index admission. EVDs have been implicated in neurosurgical SSIs many times throughout the literature^{8,9,24–26}. This is not surprising given the potential for drain colonization with seeding of bacteria into the CSF and deeper CNS. These data intimate that close vigilance be maintained for infection throughout the perioperative period, particularly when patients have undergone surgery for tumor and have an EVD in place. Current neurocritical care guidelines do not advocate for antibiotic prophylaxis beyond a single dose at the time of insertion²⁷. However, further studies may offer opportunity to expand upon our findings, perhaps exploring both duration of EVD placement and utility of routine CSF surveillance.

It is well known that diabetes mellitus (DM) figures prominently as a key player in SSI^{28–30}. However, data addressing the role of diabetes in cranial neurosurgery are conflicting. Some studies suggest a correlation between the two¹⁷. Others have found no relationship whatsoever²¹. And yet still, others suggest that it is the presence of intraoperative hyperglycemia at the time of craniotomy rather than a history of underlying DM that predisposes to SSI³¹. We found diabetes to be a significant predictor for both SSI and takeback for washout. These results advocate for optimal DM control, especially in scenarios where delay of the craniotomy would not otherwise cause irreparable harm.

Discharge with home health care or to an intermediate care facility (e.g. SNF) were also significant predictors of infection and washout. Discharge to an intermediate care facility implies that patients have not achieved their pre-morbid functional state and thus require additional resources to meet their needs. It is plausible then that there are greater lapses in local wound care in the context of such diminished functionality, ultimately predisposing to SSI. Furthermore, extra-cranial infections (e.g. UTIs, pneumonia) are quite common in intermediate care facilities with a high prevalence of colonization by antimicrobial-resistant organisms among residents³². These could serve as a source for secondary seeding of the surgical site through systemic spread. The higher rates of SSI in patients discharged to intermediate care facilities indicate that a high index of suspicion should be maintained in this cohort perhaps by scheduling earlier and more frequent office visits in the immediate postoperative period.

Younger age also had a significant association with readmission for SSI and washout in our multivariate analyses. Both older age^{17,33,34} and younger age^{7,21} have been directly correlated with SSI risk following neurosurgery. One putative explanation for the inverse relationship between age and SSI we observed is that older patients (i.e. 75 years) might be less likely to undergo complex surgeries with protracted operative times, which are an independent risk factor for SSI. Hardy *et al* have shown that for each additional hour spent in a craniotomy for tumor resection, the odds of infection increased by 43%³⁵. Because the NRD does not provide details regarding operative length, we are unable to adjust for multiple confounders associated with this variable.

There is a growing body of evidence demonstrating inferior outcomes and higher complication rates among patients with public insurance relative to those with commercial insurance^{14,36–39}. We found that patients with Medicaid were more likely to get readmitted for SSI and undergo reoperation for washout. Similar findings have been reported in spine surgery by Manoso *et al*, in which Medicaid payer status conferred twice the risk of SSI compared to the privately insured⁴⁰. Why Medicaid status results in poorer clinical outcomes likely has to do with these patients having poorer baseline health, more limited access to providers and unreasonable out-of-pocket expenses that decrease treatment compliance⁴⁰. This observation has given rise to the concept of ‘underinsurance’^{41,42} with some suggesting that it is as big a challenge to public health as having no insurance at all⁴³. Because there are 74 million Medicaid enrollees⁴⁴, one concern here is that higher complication rates among this subset of patients could lead to the institutions that care for them being unfairly penalized under value-based reimbursement models. Ultimately, this could have the unintended consequence of further limiting access to care, as institutions

place caps on the number of patients treated with Medicaid. This relationship between Medicaid and SSI deserves further investigation.

Limitations are inherent in this study. First, NRD only tracks patients within a single calendar year. Consequently, 30- and 90-day readmissions exclude data beyond November and September, respectively. This has the potential to underestimate SSI incidence, particularly any seasonality effects on infection. Second, NRD does not afford the ability to track patients across state lines, which could skew readmission figures in an era where patients often travel outside their home state for care at specialized centers. Third, NRD specifically censors important demographic variables like race that would have allowed for more detailed socioeconomic analyses. Additionally, there are concerns that would apply to any database study such as clerical errors during data entry, ICD-9 miscoding and incomplete hospital records. Because the user does not have access to patient records or clinical outcomes, there is no way to formally validate the information extracted with actual patient data. Nonetheless, the NRD has been extensively employed throughout the literature as a tool for exploring readmission trends across a wide range of subspecialties^{45–49}.

Conclusions

Using the newly available NRD we determined the incidence of SSI after non-emergent craniotomy to be 2.2% at 30 days and 3.6% at 90 days. Various patient-, procedure- and hospital-related factors were significant predictors of SSI. They include craniotomy for tumor, EVD presence, younger age, LOS, diabetes, patient disposition to an intermediate-care facility (e.g. SNF), Medicaid insurance and large hospital bed size. Many of these factors were similarly linked to subsequent reoperation for washout. Detailed randomized prospective studies may be warranted to evaluate modifiable risk factors such as EVD placement and diabetes and their associations with infection. Furthermore, the relationship between Medicaid insurance and SSI is novel and merits further investigation since it suggests that hospitals may be unfairly penalized under value-based healthcare reimbursement models.

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Abbreviations

NRD	Nationwide Readmissions Database
ICD-9CM	International Classification of Diseases, Ninth Edition, Clinical Modification
SSI	surgical site infection
HAI	healthcare associated infection
EVD	external ventricular drain
SNF	skilled nursing facility

DBS	deep brain stimulation
CSF	cerebrospinal fluid
CNS	central nervous system

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Figure 1.
Schema of study design for analyzing post-craniotomy surgical site infection using the Nationwide Readmission Database

Figure 2.
Probability of 90-day readmission for SSI (A) and reoperation for washout (B)

Table 1.

International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9CM) diagnosis and procedures employed for patient extraction from the NRD database

Craniotomy cohort		Diagnosis code	Procedure code
Tumor	Benign	192.1, 225.2, 237.6	1.51
		225.1	4.01
		237.0	7.61, 7.64
		225.0	1.59
	Malignant	191.0–191.9	1.53, 1.59
		198.3	1.59
Vascular	Aneurysm	430, 437.3	39.51
	Moya-Moya disease	437.5	39.28
	Cerebro-occlusive disease	433.00, 433.10, 433.20, 433.30, 433.80, 433.90, 434.10, 434.90, 437.0, 433.01, 433.11, 433.21, 433.31, 433.81, 433.91, 434.01, 434.11, 434.91, 435.x, 437.1	39.28
	AVM	747.81	1.59
Epilepsy		345.x	1.53, 1.52

Table 2.

Demographics of patients readmitted within 30 days of index hospitalization

Variables		N	%
Diagnosis	Malignant Tumor	1055	50.75
	Benign Tumor	745	35.83
	Epilepsy	16	0.77
	Vascular	263	12.65
	Total	2079	2.2
Shunt Procedure	Yes	32	1.54
	No	2047	98.46
Age	18–44	534	25.69
	45–59	778	37.42
	60–74	617	29.68
	>=75	150	7.22
Gender	Male	1083	52.09
	Female	996	47.91
Primary insurance	Medicare	602	28.96
	Medicaid	329	15.82
	Private insurance	989	47.57
	Self-pay	74	3.56
Hospital bedsize	No charge, Other	78	3.75
	Small	143	6.88
	Medium	290	13.95
	Large	1646	79.17
Teaching Status	Teaching	1765	84.9
	Non-Teaching	314	15.1
Volume	Above 90th percentile	1185	57
	<= 90th percentile (97 / year)	894	43
Disposition	Routine	1295	62.29
	Short-term Hospital	23	1.11
	Transfer Other	361	17.36
	Home Health Care	395	19
Elixhauser comorbidity	Against Medical Advice	DS	DS
	Yes	1462	70.32
	No	617	29.68
Medical complication	Yes	90	4.33
	No	1989	95.67
Neurological complication	Yes	426	20.49
	No	1653	79.51
Extra cranial infection	Yes	186	8.95

Variables		N	%
	No	1893	91.05
Obesity	Yes	DS	DS
	No	2070	99.57
Tobacco	Yes	682	32.8
	No	1397	67.2
Diabetes	Yes	358	17.22
	No	1721	82.78
External ventricular drain (EVD)	Yes	96	4.62
	No	1983	95.38
Index Length of Stay	0–3 days	572	27.51
	4–6 days	572	27.51
	7–11 days	449	21.6
	≥12 days	486	23.38
Median household income for patient's ZIP code, based on current year	0–25 percentile	442	21.26
	26–50 percentile	486	23.38
	51–75 percentile	563	27.08
		541	26.02

* DS = Data Suppressed according to HCUP/NRD regulations

Table 3.

Predictors of 30-day readmissions for SSI by multivariate analysis using survey-adjusted logistic regression

Variables		Odds Ratio	95% CI		p-value
Craniotomy cohort	Malignant Tumor	1.46	1.26	1.68	<0.0001
	Benign Tumor	1.93	1.66	2.24	<0.0001
	Epilepsy	0.94	0.56	1.57	0.8066
	Vascular	Ref			
Age	18–44	2.15	1.72	2.68	<.0001
	45–59	1.77	1.43	2.18	<.0001
	60–74	1.31	1.08	1.58	0.0053
	≥75	Ref			
Gender	Male	Ref			
	Female	0.69	0.63	0.75	<.0001
Primary insurance	Medicare	1.02	0.90	1.17	0.7506
	Medicaid	1.29	1.13	1.47	0.0002
	Self-pay	1.04	0.81	1.33	0.7836
	No charge, Other	0.84	0.66	1.07	0.1614
	Private insurance	Ref			
Hospital bedsize	Small	Ref			
	Medium	0.74	0.59	0.93	0.0087
	Large	0.72	0.59	0.87	0.0008
Disposition	Routine	Ref			
	Short-term Hospital	0.91	0.59	1.41	0.6821
	Transfer Other (e.g. SNF)	1.31	1.14	1.50	0.0001
	Home Health Care	1.20	1.06	1.36	0.004
	Against Medical Advice	1.53	0.63	3.77	0.3508
Procedural volume	Above 90th percentile	1.16	1.05	1.29	0.0034
	≤ 90th percentile (115 / year)	Ref			
Diabetes	Yes	1.29	1.14	1.46	<.0001
	No	Ref			
External ventricular drain (EVD)	Yes	1.33	1.07	1.67	0.0115
	No	Ref			
Index Length of stay	0–3 days	Ref			
	4–5 days	1.21	1.07	1.38	0.0036
	6–11 days	1.28	1.13	1.45	0.0001
	≥12 days	1.12	0.97	1.29	0.1228
Median household income for patient's ZIP code, based on current year	0–25 percentile	Ref			
	26–50 percentile	1.07	0.94	1.23	0.2883
	51–75 percentile	1.09	0.96	1.24	0.1759

Variables		Odds Ratio	95% CI		p-value
	76–100 percentile	0.93	0.81	1.06	0.2612

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Table 4.

Predictors of 90-day readmissions for SSI by multivariate analysis using survey-adjusted logistic regression

Variables		Odds Ratio	95% CI		p-value
Craniotomy cohort	Malignant Tumor	1.48	1.31	1.68	<0.0001
	Benign Tumor	1.83	1.61	2.08	<0.0001
	Vascular	Ref			
	Epilepsy	0.91	0.58	1.45	0.6991
Age	18–44	2.09	1.72	2.54	<.0001
	45–59	1.91	1.59	2.29	<.0001
	60–74	1.37	1.16	1.62	0.0002
	≥75	Ref			
Gender	Male	Ref			
	Female	0.75	0.69	0.81	<.0001
Primary insurance	Medicare	1.04	0.93	1.16	0.5009
	Medicaid	1.29	1.15	1.45	<.0001
	Private insurance	Ref			
	Self-pay	1.06	0.86	1.31	0.5927
	No charge, Other	0.91	0.75	1.11	0.3715
	Disposition	Ref			
	Short-term Hospital	1.00	0.69	1.45	0.9915
	Transfer Other (e.g. SNF)	1.39	1.23	1.56	<.0001
	Home Health Care	1.18	1.05	1.31	0.0036
	Against Medical Advice	2.15	1.08	4.27	0.029
Diabetes	Yes	1.23	1.10	1.37	0.0001
	No	Ref			
Hospital bedsize	Small	Ref			
	Medium	0.75	0.61	0.91	0.0032
	Large	0.74	0.62	0.88	0.0005
Index Length of stay	0–3 days	Ref			
	4–5 days	1.10	0.99	1.23	0.082
	6–11 days	1.11	1.00	1.24	0.056
	≥12 days	0.98	0.86	1.10	0.6868

Table 5.

Predictors of 30-day readmissions for SSI requiring reoperation for washout by multivariate analysis using survey-adjusted logistic regression

Variables		Odds Ratio	95% CI		p-value
Craniotomy cohort	Malignant Tumor	1.91	1.51	2.41	<0.0001
	Benign Tumor	2.06	1.61	2.63	<.0001
	Epilepsy	1.73	0.89	3.37	0.1042
	Vascular	Ref			
Age	18–44	2.62	1.82	3.75	<.0001
	45–59	2.22	1.57	3.13	<.0001
	60–74	1.57	1.14	2.14	0.0051
	≥75	Ref			
Gender	Male	Ref			
	Female	0.66	0.58	0.76	<.0001
Primary insurance	Medicare	1.00	0.82	1.23	0.9812
	Medicaid	1.30	1.06	1.59	0.0104
	Private insurance	Ref			
	Self-pay	1.14	0.79	1.65	0.4731
	No charge, Other	0.72	0.48	1.07	0.1023
Disposition	Routine	Ref			
	Short-term Hospital	0.44	0.16	1.18	0.1017
	Transfer Other (e.g. SNF)	1.41	1.16	1.73	0.0007
	Home Health Care	1.43	1.19	1.70	<.0001
	Against Medical Advice	1.52	0.37	6.19	0.5569
Volume	Above 90th percentile	1.19	1.02	1.38	0.0247
	≤ 90th percentile (115 / year)	Ref			
Diabetes	Yes	1.39	1.15	1.67	0.0005
	No	Ref			
External ventricular drain (EVD)	Yes	1.47	1.06	2.04	0.0227
	No	Ref			

Table 6.

Predictors of 90-day readmissions for SSI requiring reoperation for washout by multivariate analysis using survey-adjusted logistic regression

Variables		Odds Ratio	95% CI		p-value
Craniotomy cohort	Malignant Tumor	1.721	1.421	2.084	<0.0001
	Benign Tumor	2.012	1.65	2.454	<0.0001
	Vascular	Ref			
	Epilepsy	1.294	0.693	2.415	0.4181
Age	18–44	2.374	1.826	3.087	<.0001
	45–59	2.162	1.689	2.769	<.0001
	60–74	1.473	1.15	1.887	0.0022
	≥75	Ref			
Gender	Male	Ref			
	Female	0.69	0.614	0.774	<.0001
Disposition	Routine	Ref			
	Short-term Hospital	0.672	0.345	1.308	0.2418
	Transfer Other (e.g. SNF)	1.444	1.229	1.698	<.0001
	Home Health Care	1.272	1.091	1.482	0.0021
	Against Medical Advice	2.167	0.793	5.919	0.1316
Diabetes	Yes	1.156	0.986	1.357	0.0744
	No	Ref			