Thirty-day readmission and reoperation after surgery for spinal tumors: a National Surgical Quality Improvement Program analysis

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OBJECTIVE The goal of this study was to use a large national registry to evaluate the 30-day cumulative incidence and predictors of adverse events, readmissions, and reoperations after surgery for primary and secondary spinal tumors.

METHODS Data from adult patients who underwent surgery for spinal tumors (2011–2014) were extracted from the prospective National Surgical Quality Improvement Program (NSQIP) registry. Multivariable logistic regression was used to evaluate predictors of reoperation, readmission, and major complications (death, neurological, cardiopulmonary, venous thromboembolism [VTE], surgical site infection [SSI], and sepsis). Variables screened included patient age, sex, tumor location, American Society of Anesthesiologists (ASA) physical classification, preoperative functional status, comorbidities, preoperative laboratory values, case urgency, and operative time. Additional variables that were evaluated when analyzing readmission included complications during the surgical hospitalization, hospital length of stay (LOS), and discharge disposition.

RESULTS Among the 2207 patients evaluated, 51.4% had extradural tumors, 36.4% had intradural extramedullary tumors, and 12.3% had intramedullary tumors. By spinal level, 20.7% were cervical lesions, 47.4% were thoracic lesions, 29.1% were lumbar lesions, and 2.8% were sacral lesions. Readmission occurred in 10.2% of patients at a median of 18 days (interquartile range [IQR] 12–23 days); the most common reasons for readmission were SSIs (23.7%), systemic infections (17.8%), VTE (12.7%), and CNS complications (11.9%). Predictors of readmission were comorbidities (dyspnea, hypertension, and anemia), disseminated cancer, preoperative steroid use, and an extended hospitalization. Reoperation occurred in 5.3% of patients at a median of 13 days (IQR 8–20 days) postoperatively and was associated with preoperative steroid use and ASA Class 4–5 designation. Major complications occurred in 14.4% of patients: the most common complications and their median time to occurrence were VTE (4.5%) at 9 days (IQR 4–19 days) postoperatively, SSIs (3.6%) at 18 days (IQR 14–25 days), and sepsis (2.9%) at 13 days (IQR 7–21 days). Predictors of major complications included dependent functional status, emergency case status, male sex, comorbidities (dyspnea, bleeding disorders, preoperative systemic inflammatory response syndrome, preoperative leukocytosis), and ASA Class 3–5 designation ($p < 0.05$). The median hospital LOS was 5 days (IQR 3–9 days), the 30-day mortality rate was 3.3%, and the median time to death was 20 days (IQR 12.5–26 days).

CONCLUSIONS In this NSQIP analysis, 10.2% of patients undergoing surgery for spinal tumors were readmitted within 30 days, 5.3% underwent a reoperation, and 14.4% experienced a major complication. The most common complications were SSIs, systemic infections, and VTE, which often occurred late (after discharge from the surgical hospitalization). Patients were primarily readmitted for new complications that developed following discharge rather than exacerbation of complications from the surgical hospital stay. The strongest predictors of adverse events were comorbidities, preopera-

ABBREVIATIONS ACS = American College of Surgeons; ASA = American Society of Anesthesiologists; AUROC = area under the receiver operating curve; BMI = body mass index; CI = confidence interval; COPD = chronic obstructive pulmonary disease; CPT = *Current Procedural Terminology*; GI = gastrointestinal; GU = genitourinary; ICD-9-CM = *International Classification of Diseases, Ninth Revision, Clinical Modification*; INR = international normalized ratio; IQR = interquartile range; LOS = length of stay; NSQIP = National Surgical Quality Improvement Program; PTT = partial thromboplastin time; SIRS = systemic inflammatory response syndrome; SSI = surgical site infection; UTI = urinary tract infection; VTE = venous thromboembolism; WBC = white blood cell.

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tive steroid use, and higher ASA classification. These models can be used by surgeons to risk-stratify patients preoperatively and identify those who may benefit from increased surveillance following hospital discharge.

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KEY WORDS readmission; reoperation; spinal tumor; surgical site infection; venous thromboembolism; complication; metastases

SPINAL tumors are a major cause of morbidity and mortality among oncology patients. The incidence of tumors of the spinal column is estimated to be 0.62 per 100,000 individuals in the US.^{33,85} Metastatic spinal tumors make up the majority of spinal tumors and are found in as many as 70% of cancer patients.^{48,52,65,74,86,93,98} In addition to classification by histology, spinal tumors are generally stratified by location as extradural, intradural extramedullary, or intramedullary. The goals of surgical treatment of spinal tumors are to improve functional—particularly ambulatory—status, decrease pain, and in some patients with isolated metastases or primary tumors, improve survival.^{1,13,14,16,17,26,27,30,31,38,63,93,95–98} However, surgical approaches to spinal tumors often necessitate extensive reconstruction of the spinal column and may require adjuvant chemotherapy or radiation; therefore, perioperative complication rates after spinal tumor surgery are higher than in other spinal operations.^{34–36,46–48,50,52,65,67,68,78,80,81,86–88,95,100}

It is especially important to understand the incidence and predictive factors for adverse events in spinal oncology patients, as a single complication may be associated with morbidity, mortality, and costs.^{1,31,37,46,47,52,62,70,72,79,86,95} Risk stratification of patients preoperatively is important to optimize outcomes,^{48,52,65,74,86,93,98} and prior studies have identified anatomical location, tumor size, tumor histology, extent of resection, surgical approaches, age, functional status, comorbidities, preoperative medication (steroid use, morphine), longer operative time, insurance status, early postoperative complications, and adjuvant chemotherapy and radiotherapy as factors associated with postoperative morbidity and mortality.^{1,18–24,39,41,42,44,48,51,52,56,58,66,69,78,92,99} Nevertheless, many of these previous publications were retrospective, institutional studies,^{10,11,55,60,65,87,95} and additional prospective data are needed.

The American College of Surgeons–National Surgical Quality Improvement Program (ACS-NSQIP) is a large, prospectively collected registry that collects data on 30-day postoperative outcomes from patients undergoing surgical intervention at 517 institutions across the US.^{3,7,9,49,59,60,61,71,77,90,91} Despite its utility in evaluating perioperative complications and adverse outcomes, few studies have used the NSQIP to analyze the outcomes of patients undergoing surgery for spinal tumors. The goal of this study was to evaluate the 30-day cumulative incidence, time to event, and predictors of major complications, unplanned reoperations, and readmissions after surgery for primary and secondary spinal tumors.

Methods

Data Source

The prospective NSQIP registry was used from the years 2011 to 2014. Maintained by the ACS, trained sur-

gical reviewers prospectively collect data for the NSQIP using a uniform protocol. Patients enrolled in the NSQIP are followed for 30 days postoperatively, and all complications (among those collected in the NSQIP algorithm) that occurred during this period are recorded; there is no administrative censoring or loss to follow-up of patients entered. The accuracy of data collection by the NSQIP (including cumulative incidence and reasons for readmission) has been externally validated,⁸⁴ and this data source has been previously used to evaluate patients undergoing neurosurgical intervention,^{4,8,12,14,15,28,29,45,54,83} including spine surgery.^{2,6,9,10,25,40,53,59,61,82,91} Our institutional review board has exempted the de-identified NSQIP data set from individual review.

Inclusion and Exclusion Criteria

Patients were included who met the following criteria: 1) were aged 18 years or greater; 2) had a *Current Procedural Terminology* (CPT) code indicating they underwent laminectomy for excision or biopsy of an extradural (63275–8), intradural extramedullary (63280–3) or intramedullary (63285–7) tumor or they underwent corpectomy for excision of an intraspinal lesion (CPT code 63300–7) and had an *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) code indicating a spinal neoplasm (170.2, 170.6, 198.3–5, 213.2, 213.6); 3) the attending surgeon was a neurosurgeon or an orthopedic surgeon; and 4) the procedure was performed under general anesthesia.

Covariates

Pertinent covariates collected by the NSQIP were extracted. Age was examined categorically by quartile. Tumor location was evaluated as extradural, intradural extramedullary, or intramedullary. Additionally, location was stratified by involvement of the cervical, thoracic, lumbar, or sacral spine. Sex, race/ethnicity, American Society of Anesthesiologists (ASA) physical classification (1–2, 3, 4–5, or missing), and preoperative functional status (dependent vs independent) were assessed.

Comorbidities collected by the NSQIP—present in at least 20 patients, and missing in less than 10% of patients—were evaluated: smoking (within the past year), hypertension requiring medication, chronic obstructive pulmonary disease (COPD), dyspnea, diabetes mellitus, and a bleeding disorder (defined by the NSQIP as vitamin K deficiencies, hemophilias, thrombocytopenia, and long-term anticoagulant usage), and unintentional weight loss of more than 10% within 6 months. Body mass index (BMI) was determined based on height and weight, with obesity defined using WHO criteria: Class I obesity as 30–34.99 kg/m² and Class II or III as > 35 kg/m². Disseminated cancer is defined by the NSQIP as multiple metastases indicat-

ing that the cancer is widespread. Pertinent preoperative laboratory values were extracted and stratified: sodium (by 135 mEq/L), creatinine (by 1.4 mg/dl), albumin (by 3.5 g/dl), white blood cell (WBC) count (by 4000/ μ l and 12,000/ μ l), hematocrit (by 36%), international normalized ratio (INR; by 1.4), and partial thromboplastin time (PTT; by 40 seconds). Preoperative steroid use (within 30 days) was also extracted. Although data were missing on both recent chemotherapy (within 30 days) and radiation treatment (within 90 days), they were evaluated given the clinical relevance of these variables in oncology patients. An open wound is defined by the NSQIP as any incision that directly communicates with air. Preoperative systemic inflammatory response syndrome (SIRS) is indicated in any patient with at least 2 of the following criteria: temperature greater than 38°C or less than 36°C, heart rate greater than 90 beats per minute, respiratory rate greater than 20 breaths per minute, leukocytosis or leukopenia (WBC count > 12,000/ μ l and < 4000/ μ l, respectively), or anion gap acidosis. Preoperative transfusion of greater than 4 units of packed red blood cells in the 72 hours preoperatively is also recorded by the NSQIP. Admission type, preoperative intubation (within 48 hours), case urgency (emergency or elective), and operative time (by quartile) were also extracted. Wound classification compared Class I (clean) operations to Class II (clean-contaminated), III (contaminated), and IV (dirty) designations.

Outcomes

The outcomes evaluated were major complications, unplanned reoperation, and unplanned readmission. A major complication was defined according to a published categorization as: death; an intracranial (new postoperative coma or stroke), cardiac (cardiac arrest or myocardial infarction), pulmonary (reintubation or prolonged postoperative mechanical ventilation), or renal (acute renal failure) complication; symptomatic venous thromboembolism (VTE); surgical site infection (SSI); sepsis; or reoperation.⁵⁷ Additional minor complications extracted were pneumonia, urinary tract infections (UTIs), and perioperative packed red blood cell transfusions.

Unplanned reoperation (within 30 days) was available for patients from the 2012–2014 years of the NSQIP, and therefore only patients from these years were evaluated for this outcome. The CPT codes associated with the reoperations were also extracted.

Finally, an unplanned hospital readmission, which the NSQIP collects regardless of whether the admission is to the same or to a different facility, was examined. Only unplanned readmissions were evaluated because some patients may require early planned readmission for oncological treatment. Additionally, the NSQIP began collecting data on the primary admission diagnosis associated with the readmission in 2012, some of which (including SSIs, VTE events, and systemic infections) are encoded directly, and others of which are designated through ICD-9-CM codes. When evaluating predictors of unplanned readmission, complications during the surgical hospitalization, length of the index hospitalization, and discharge disposition were also evaluated. Readmission was only assessed among patients who were discharged from the surgical

hospitalization alive and therefore at risk for unplanned readmission.

Missing Data

Patients with missing demographic data were placed in a separate category for that variable, allowing for appropriate use of missing data in logistic regression. Data on the diagnosis associated with readmission were available from 2012 to 2014 but missing for some patients within this time period; a sensitivity analysis compared major complications among patients with a recorded and missing readmission diagnosis, to evaluate if any selection bias was introduced by the missing data.

Statistical Analysis

Statistical analyses were conducted in SPSS (version 23, IBM Corp.). Descriptive statistics were performed on baseline variables, and univariable logistic regression assessed their association with the specific outcome evaluated. Multivariable logistic regression models were thereafter constructed minimizing statistical optimism, maximizing parsimony, and avoiding overfitting by following the rule of a maximum of 1 covariate for 10 events. Variables were screened with univariable logistic regression to evaluate for differences within any strata of categorical variables, and those with a *p* value < 0.10 were evaluated for inclusion in the final model, which was determined using backward selection with the likelihood ratio test. Concordance statistics determined the discrimination of logistic regression constructs, which range between 0.50, where a model has no greater discrimination than chance alone, to 1.0, where the model has perfect discrimination. Calibration of models was assessed using the Hosmer-Lemeshow test, which tests the null hypothesis that the observed and expected counts in each decile are equal; a model is accepted when the probability value indicates failure to reject the null hypothesis. A probability value < 0.05 was determined to be statistically significant.

Results

Demographics of the Study Population

Within the study population, 2207 patients were included and 51.4% of tumors were extradural, 36.4% were intradural extramedullary, and 12.3% were intramedullary. Tumors by location were 20.7% cervical, 47.4% thoracic, 29.1% lumbar, and 2.8% sacral. The baseline characteristics and treatment variables are compared by unplanned readmission in Table 1.

Cumulative Incidence and Time to Event of Complications

The 30-day cumulative incidence and time to event of complications (that are recorded by the NSQIP algorithm) are listed in Table 2. Major complications occurred in 14.4% of patients. The most common complications and their median times to occurrence were VTE (4.5%) at 9 days (interquartile range [IQR] 4–19 days) postoperatively, SSIs (3.6%) at 18 days (IQR 14–25 days), sepsis (2.9%) at 13 days (IQR 7–21 days), and pneumonia (2.7%) at 9 days (IQR 3–15 days). The median hospital length of stay

TABLE 1. Demographics of the study population, stratified by 30-day readmission*

Definition	Unplanned Readmissions					
	Total	Yes	No	OR	95% CI	p Value
Spinal level						
Cervical	20.7	18.9	20.9	Ref		
Thoracic	47.4	55.0	46.5	1.31	0.90–1.89	0.16
Lumbar	29.1	23.9	29.7	0.89	0.58–1.36	0.60
Sacral	2.80	2.30	2.90	0.86	0.33–2.27	0.77
Location						
Extradural	51.4	62.2	50.1	Ref		
Intradural extramedullary	36.4	24.8	37.7	0.53	0.38–0.74	<0.001
Intramedullary	12.3	13.1	12.2	0.87	0.57–1.32	0.51
Sex						
Female	45.5	41.4	46.0	Ref		
Male	54.5	58.6	54.0	1.20	0.91–1.60	0.20
Race/ethnicity						
Caucasian	70.8	74.8	70.4	Ref		
African-American	8.30	9.90	8.10	1.15	0.71–1.84	0.58
Asian	4.80	3.60	4.90	0.69	0.33–1.45	0.33
Hispanic	6.70	7.20	6.70	1.02	0.59–1.76	0.95
Not reported	9.30	4.50	9.90	0.43	0.22–0.83	0.01
Age quartile (yrs)						
Lower (<46)	25.2	19.0	25.9	Ref		
Second (46–58)	24.8	23.1	25.1	1.25	0.82–1.92	0.30
Third (58–67)	25.1	26.2	24.9	1.43	0.95–2.17	0.09
Upper (>67)	24.9	31.7	24.1	1.79	1.20–2.68	0.005
BMI						
Non-obese	62.7	62.2	62.8	Ref		
Class I (30–35 kg/m ²)	19.0	19.8	18.9	1.06	0.74–1.52	0.75
Class II/III (≥35 kg/m ²)	15.5	14.4	15.7	0.93	0.62–1.39	0.72
Missing	2.70	3.60	2.60	1.38	0.64–2.98	0.41
Functional health status						
Independent	91.1	86.5	91.6	Ref		
Dependent	8.50	12.6	8.00	1.67	1.09–2.57	0.02
Missing	0.40	0.90	0.40	2.64	0.55–12.8	0.28
Diabetes mellitus						
No	88.2	86.9	88.3	Ref		
Insulin	4.80	7.20	4.50	1.61	0.93–2.80	0.09
Non-insulin	7.00	5.90	7.20	0.83	0.46–1.49	0.53
Current smoker	17.2	21.2	16.8	1.33	0.95–1.88	0.10
Dyspnea	5.80	13.5	50.0	3.00	1.94–4.64	<0.001
COPD	3.20	5.40	2.90	1.88	0.99–3.57	0.05
Hypertension	42.8	50.9	41.9	1.44	1.09–1.90	0.01
Disseminated cancer	29.8	46.4	27.8	2.24	1.69–2.97	<0.001
Recent chemotherapy or radiotherapy						
No	11.9	8.60	12.3	Ref		
Yes	1.20	2.30	1.10	3.00	1.02–8.83	0.047
Missing	86.9	89.2	86.6	1.48	0.91–2.42	0.91
Open wound	1.90	2.70	1.80	1.51	0.63–3.63	0.36
Steroid use	9.70	18.0	8.80	2.29	1.57–3.33	<0.001
Weight loss	3.60	5.00	3.50	1.46	0.76–2.80	0.26

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TABLE 1. Demographics of the study population, stratified by 30-day readmission*

Definition	Unplanned Readmissions					
	Total	Yes	No	OR	95% CI	p Value
Bleeding disorders	3.40	7.20	3.00	2.52	1.42–4.46	0.002
Preop transfusion	1.90	5.40	1.40	3.90	1.95–7.78	<0.001
Preop SIRS	4.20	7.20	3.90	1.93	1.10–3.38	0.02
Wound class						
Class I	97.9	97.3	98.0	Ref		
Class II–IV	2.10	2.70	2.00	1.35	0.57–3.23	0.50
ASA Class						
1–2	36.2	20.7	38	Ref		
3	53.7	62.2	52.7	2.16	1.53–3.06	<0.001
4–5	10.0	17.1	9.20	3.40	2.15–5.38	<0.001
Emergency case	9.50	14.4	9.00	1.71	1.14–2.56	0.01
Total op time quartile (min)						
Lower (<136)	24.2	23.9	24.3	Ref		
Second (136–196)	25.5	23.9	25.7	0.95	0.63–1.41	0.79
Third (196–272)	25.1	22.1	25.4	0.88	0.59–1.33	0.55
Upper (>272)	25.2	30.2	24.6	1.25	0.85–1.83	0.26
Preop labs						
Creatinine (mg/dl)						
<1.4	89.4	92.3	89.0	Ref		
>1.4	4.80	5.90	4.7	1.20	0.66–2.19	0.55
Not obtained	5.80	1.80	6.30	0.28	0.10–0.76	0.01
Sodium (mEq/L)						
>135	78.0	75.7	78.2	Ref		
<135	15.5	22.5	14.7	1.58	1.12–2.22	0.009
Not obtained	6.50	1.80	7.00	0.27	0.10–0.72	0.01
Albumin (g/dl)						
>3.5	36.0	40.1	35.6	Ref		
<3.5	16.1	29.7	14.5	1.81	1.28–2.57	0.001
Not obtained	47.8	30.2	49.9	0.54	0.39–0.75	<0.001
WBC (count/ μ l)						
4–12,000	79.2	75.2	79.7	Ref		
<4000	4.00	5.90	3.80	1.65	0.89–3.04	0.11
>12,000	12.7	17.6	12.1	1.54	1.06–2.23	0.025
Not obtained	4.10	1.40	4.40	0.32	0.10–1.03	0.06
Hematocrit (%)						
<36	71.9	61.7	73.1	Ref		
>36	24.4	36.9	22.9	1.91	1.42–2.56	<0.001
Not obtained	3.70	1.40	4.00	0.40	0.13–1.29	0.13
PTT (sec)						
<40	69.4	72.5	69.1	Ref		
>40	1.80	1.80	1.80	0.98	0.34–2.80	0.97
Not obtained	28.8	25.7	29.2	0.84	0.61–1.15	0.27
INR						
<1.4	81.4	84.7	81.0	Ref		
>1.4	1.40	2.70	1.20	2.10	0.84–5.18	0.11
Not obtained	17.2	12.6	17.7	0.68	0.45–1.03	0.07

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TABLE 1. Demographics of the study population, stratified by 30-day readmission*

Definition	Unplanned Readmissions					
	Total	Yes	No	OR	95% CI	p Value
Preop labs (<i>continued</i>)						
LOS quartile (days)						
Lower (<3)	28.7	14.0	30.4	Ref		
Second (3–5)	22.5	20.3	22.7	1.94	1.21–3.12	0.006
Third (5–9)	25.9	32.9	25.1	2.86	1.84–4.42	<0.001
Upper (>9)	23.0	32.9	21.8	3.27	2.11–5.07	<0.001
Complications during surgical hospitalization						
Cardiopulmonary	1.40	0.90	1.50	0.60	0.14–2.53	0.49
VTE	2.10	3.60	1.90	1.92	0.88–4.18	0.10
Infectious	4.40	4.10	4.40	0.91	0.45–1.84	0.79
Transfusion	19.5	26.1	18.7	1.54	1.11–2.11	0.009
Discharge destination						
Home	64.9	53.6	66.2	Ref		
Nonroutine	34.6	46.4	33.2	1.73	1.30–2.28	<0.001
Missing	0.50	0.00	0.60	—	—	—

Ref = reference.

* Boldface type indicates statistical significance.

(LOS) was 5 days (IQR 3–9 days). The 30-day mortality rate was 3.3%, with the median time to death being 20 days (IQR 12.5–26 days) postoperatively. The discharge disposition of patients was home for 64.9% of patients and nonroutine (rehabilitation or an acute care facility) for the remaining 34.6%.

A multivariable logistic regression model was constructed to evaluate the predictors of a major complication, defined as death, postoperative stroke or coma, cardiopulmonary complications, symptomatic venous thrombosis stroke, acute renal failure, sepsis, or an SSI (Table 3). The independent predictors of a major complication were (by descending effect size): ASA Class 4–5 designation, bleeding disorders, ASA Class 3 designation, preoperative SIRS, preoperative leukocytosis (> 12,000/ μ l), emergency surgery, dependent functional health status, longer opera-

tive time (upper quartile > 272 minutes), preoperative dyspnea, and male sex ($p < 0.05$); preoperative steroid use was predictive of a major complication (of borderline significance). The model had good discrimination (area under the receiver operating curve [AUROC] = 0.73), and appropriate calibration (Hosmer-Lemeshow test = 0.39).

Readmission

Unplanned readmission occurred in 10.2% ($n = 222$) of patients discharged from the surgical hospital alive, and occurred at a median of 18 days (IQR 12–23 days) postoperatively and 10 days (IQR 5–15 days) after discharge. Multivariable logistic regression models were constructed and the independent predictors of readmission, in descending effect size, were preoperative transfusions, LOS > 3 days, preoperative dyspnea, preoperative steroid administration, disseminated cancer, and hypertension (Table 4). The model was found to have moderate discrimination (AUROC = 0.678) and good calibration (Hosmer-Lemeshow test = 0.67).

Of patients who were readmitted between 2012 and 2014, 65.9% ($n = 118$) had a documented diagnosis associated with readmission. The most common reasons for unplanned readmission were SSIs (23.7%), systemic infections (17.8%), VTE (12.7%), CNS complications (11.9%), gastrointestinal (GI)/genitourinary (GU) complications (7.6%), pain (5.1%), fever (4.2%), pulmonary or cardiac complications (4.1%), and other (12.7%). Among SSIs requiring readmission, superficial infections were the most common (42.9%) while the remaining (57.1%) were deep (Fig. 1 left). Of the patients with systemic infections that required readmission, 38.0% were for sepsis, 28.5% were for pneumonia, and the remaining for other systemic infections including UTIs and meningitis. Kaplan-Meier

TABLE 2. Cumulative incidence and time to event of postoperative complications

Variable	Cumulative Incidence (%)	Time to Event (days)	
		Median	IQR
Cardiac complication	0.5	8.0	3.5–16.5
CNS complication	0.2	18.5	3.8–23.8
Pneumonia	2.7	9.0	3.0–15.0
Pulmonary complication	2.2	5.0	2.0–13.0
Renal complication	0.3	13.0	9.0–15.0
Sepsis	2.9	13.0	7.0–21.0
SSI	3.6	18.0	14.0–25.0
Transfusions	19.7	0.0	0.0–0.0
VTE	4.5	9.0	4.0–19.0
UTI	3.7	11.0	6.0–17.8

TABLE 3. Multivariable logistic regression evaluating predictors of a major complication*

Variable	Serious Adverse Events		
	OR	95% CI	p Value
Sex			
Female	Ref		
Male	1.33	1.02–1.73	0.03
Functional health status			
Independent	Ref		
Dependent	1.72	1.18–2.51	0.005
Missing	2.05	0.40–10.5	0.39
Current smoker	1.33	0.96–1.82	0.08
Dyspnea	1.62	1.04–2.52	0.03
Steroid use	1.43	0.99–2.07	0.05
Bleeding disorders	2.87	1.74–4.74	<0.001
Preop transfusion	1.86	0.95–3.66	0.07
Preop SIRS	1.85	1.14–3.01	0.01
Wound class			
Class I	Ref		
Class II–IV	1.97	0.96–4.03	0.06
ASA Class			
1–2	Ref		
3	2.01	1.44–2.80	<0.001
4–5	3.07	1.97–4.80	<0.001
Emergency case	1.73	1.20–2.50	0.003
Total op time quartile (min)			
Lower (<136)	Ref		
Second (136–196)	0.98	0.68–1.43	0.93
Third (196–272)	1.03	0.70–1.50	0.90
Upper (>272)	1.63	1.14–2.32	0.007
WBC (count/ μ l)			
4000–12,000	Ref		
<4000	1.21	0.68–2.17	0.52
>12,000	1.82	1.30–2.53	<0.001
Not obtained	1.17	0.57–2.43	0.67

* Boldface type indicates statistical significance. Hosmer-Lemeshow test = 0.39, AUROC = 0.728.

curves depicting time to event analysis of unplanned readmissions, as well as SSI, VTE, and unplanned reoperations, are depicted in Fig. 2.

Because the ICD-9-CM code associated with readmission was not recorded in 2011 or available in all patients from 2012 to 2014, a sensitivity analysis was performed of patients who were readmitted, evaluating if those with a known diagnosis experienced a differential complication rate compared with those without a recorded diagnosis. Recorded readmission diagnosis was not significantly associated with the development of a major complication, suggesting that missing data on readmission diagnosis did not introduce a selection bias (data not shown).

Reoperation

Unplanned reoperation occurred in 5.3% (n = 95) of pa-

tients at a median of 13 days (IQR 8–20 days) postoperatively. Independent predictors of reoperation were preoperative steroid use and ASA classification 4–5. The CPT code indicating the procedure that was performed at the time of reoperation was documented in 97.9% (n = 93) of patients. The most common reason for unplanned reoperation was SSI (32%, Fig. 1 right). Additional reasons for reoperation were spinal reoperation (26%), extraspinal operation (25%), CSF leak repair (13%), and CNS-related reoperation (4%).

Discussion

The NSQIP database has been increasingly used to examine patient outcomes following spine surgery, including readmission after reconstruction of spinal deformity and after spinal fusion.^{59,91} Nevertheless, few studies have used the NSQIP database to evaluate the outcome of patients undergoing surgery for spinal tumors. Schoenfeld et al. used the NSQIP database to validate the ability of the New England Spinal Metastasis Score to predict adverse outcomes including mortality, complications, and failure to rescue in patients with secondary spinal tumors; the score is based on extent of malignant spread, preoperative albumin, and ambulatory capacity.⁷⁷ Nevertheless, this study did not build predictive models of adverse outcomes or evaluate the reasons for reoperation or readmission, and it was restricted to patients with metastatic lesions. There is a relative dearth of literature evaluating the incidence and predictors of adverse events after surgery for spinal tumors, and prior publications have been primarily based on retrospective, institutional studies. The goal of this analysis was to specifically evaluate the 30-day cumulative incidence, time to event, and predictors of readmission, reoperation, and postoperative complications for patients undergoing surgery for primary and secondary spinal tumors.

In our analysis, the 30-day readmission rate was 10.2%; the most common reasons for readmission were SSIs (23.7%), systemic infections (17.8%), VTE (12.7%), and CNS complications (11.9%). A recent meta-analysis of 13 retrospective studies reported a pooled 30-day readmission rate of 6.1% (95% confidence interval [CI] 4.1%–8.9%) in studies with patients undergoing surgery for all spinal levels for elective or emergency procedures.¹⁰ Another national database study of 343,068 patients over the age of 65 with public insurance (Medicare) who underwent elective spinal surgery for degenerative conditions demonstrated a 30-day readmission rate of 7.9% for patients undergoing cervical spine surgery and 7.3% for those undergoing lumbar spine surgery.⁹⁴ In this study, there was a higher 30-day readmission rate compared with studies evaluating other spinal pathologies, highlighting that oncology patients suffer a greater burden of systemic illness than patients with other spinal pathologies, thereby resulting in their increased readmission rates. Allaudeen et al. showed in multivariable analysis of more than 10,000 consecutive general medicine patients in a tertiary care academic medical center that cancer with or without metastasis was a factor associated with readmission.⁵ A retrospective single-institution cohort study by Schairer et al. similarly found a higher rate of readmission for patients with primary and metastatic tumors of the spine. In their study, they reported a readmission rate of 14.2%⁹⁴

TABLE 4. Multivariable logistic regression models evaluating predictors of unplanned readmission and unplanned reoperation*

Variable	Unplanned Readmission†			Unplanned Reoperation‡		
	OR	95% CI	p Value	OR	95% CI	p Value
Location						
Extradural	—	—	—	Ref		
Intradural extramedullary	—	—	—	0.60	0.35–1.02	0.06
Intramedullary	—	—	—	1.24	0.67–2.31	0.50
Dyspnea	2.17	1.37–3.43	0.001	—	—	—
Hypertension	1.38	1.04–1.84	0.03	—	—	—
Disseminated cancer	1.53	1.13–2.09	0.007	—	—	—
Steroid use	1.77	1.19–2.62	0.005	2.06	1.20–3.54	0.009
Preop transfusion	2.60	1.26–5.40	0.01	—	—	—
Preop SIRS	—	—	—	1.94	0.93–4.03	0.08
ASA Class						
1–2	—	—	—	Ref		
3	—	—	—	1.60	0.94–2.73	0.09
4–5	—	—	—	2.58	1.29–5.18	0.007
LOS quartile (days)						
Lower (<3)	Ref.			—	—	—
Second (3–5)	1.80	1.11–2.91	0.02	—	—	—
Third (5–9)	2.32	1.48–3.65	<0.001	—	—	—
Upper (>9)	2.36	1.48–3.74	<0.001	—	—	—

* Boldface type indicates statistical significance.

† Hosmer-Lemeshow Test = 0.67, AUROC = 0.678.

‡ Hosmer-Lemeshow Test = 0.96, AUROC = 0.654.

and also confirmed that infectious complications were the most common cause for readmission.¹⁰ Similar to previous prognostic single- and multiinstitutional studies, on multivariate analysis we identified comorbidities (dyspnea, hypertension, anemia), disseminated cancer, preoperative steroid use, and an extended hospitalization as predictors of readmission after spine tumor surgery. In contrast to the meta-analysis by Bernatz and Anderson of factors predicting readmission in any type of spine surgery, ASA classifi-

cation of 4+ was not a significant predictor in this NSQIP database sample of spinal tumors studied.¹⁰ In addition, limitations of the NSQIP database prevented the ability to assess the predictive value of demographical factors such as preoperative insurance status on postoperative outcomes.

In spine surgery, rates of reoperation have varied by surgical approach, extent of the procedure, and patient population demographics.^{43,55,73,75} For example, Kukreja

FIG. 1. Pie chart depicting the reasons for unplanned readmissions (**left**) and unplanned reoperations (**right**). The primary reason for readmission was available for 65.9% of readmitted patients from 2012 to 2014. The primary reason for reoperation was available for 97.9% of reoperated patients from 2012 to 2014.

FIG. 2. Kaplan-Meier curves depicting time to event analysis of SSI (A), VTE (B), unplanned readmissions (C), and unplanned reoperations (D).

et al. found in a single-institution retrospective study that 41.3% of patients who underwent decompressive lumbar spine surgeries for on-the-job injuries required reoperation, usually within 2 years.⁵⁵ A different retrospective study reported a 6.1% reoperation rate at 1 year for patients who underwent surgery for degenerative spondylolisthesis.⁷³ Scheer et al. performed a retrospective review of an adult spinal deformity database and found that 17% of patients underwent any reoperation, and 5% underwent reoperation within 30 days.⁷⁵ In our study, we found that reoperation occurred in 5.3% of patients with primary and secondary spinal tumors at a median of 13 days postoperatively. A recent single-institution ambispective review of 289 patients who underwent surgery for spinal metastases revealed a 10.7% reoperation rate, the majority of which took place during the same admission.⁷² In our study, reoperation was also found to be associated with preoperative steroid use and ASA classification 4–5.

Surgery for spinal tumors is known to be associated with a higher rate of complications compared with degenerative procedures, partially due to the burden of disease of cancer patients, particularly those with metastases. In a prospective study of patients undergoing emergency oncological spinal surgery, Dea et al. reported that 76.2% of patients had 1 or more adverse events and 10.9% died during admis-

sion.³² In our study, the most common complications were VTE (4.5%), SSIs (3.6%), and sepsis (2.9%). Predictors of an adverse event were dependent functional status, preoperative steroid use, leukocytosis, SIRS, ASA Class 3–5 designation, emergency operation, and longer operative time.

While the predictors of adverse events, reoperations, and readmissions are noteworthy, equally interesting were variables screened but not found to be associated with adverse events. First, neither tumor location (extradural, intradural extramedullary, or intramedullary) nor spinal location was predictive of complications, reoperations, or readmissions. Moreover, race/ethnicity was not associated with differential outcomes, despite the fact that disparities are well-known in oncology patients.³¹ While obesity has been shown to be associated with adverse events among patients undergoing surgery for degenerative spinal conditions,⁸⁹ in this analysis body habitus was not associated with differential outcomes. Additionally, neither complications during the surgical hospitalization nor discharge disposition were predictive of readmission.

The data on complications and readmission highlight the frequency of SSIs, VTE, and systemic infections in patients undergoing surgery for spinal tumors. The chronological association of these complications showed that they occurred late, often after discharge from the surgical hos-

pital stay. Additionally, complications during the surgical hospital stay were not predictive of readmission, emphasizing that patients are readmitted for new postdischarge complications, rather than for exacerbations of postoperative complications that occurred during the surgical hospitalization. Therefore, patients undergoing resection of spinal tumors require particular surveillance for these infectious and venous thromboembolic complications after discharge. Moreover, postdischarge VTE prophylaxis has been used in oncology patients undergoing other surgical procedures, and future studies may be merited to evaluate if there is utility to similar practice among patients undergoing spinal tumor surgery.^{64,76}

However, there are many limitations to using the NSQIP database to evaluate outcomes following spine surgery. Data are not collected on the neurological or functional outcomes after surgery and intraoperative complications are not tracked. Additionally, tumor size and preoperative neurological function could not be assessed, and data on preoperative chemotherapy or radiation were missing for many patients (as they are not collected in the most recent NSQIP database algorithms). Therefore, the NSQIP database lacks a certain degree of clinical granularity to discern outcomes of neurosurgical patients. Moreover, the NSQIP database only tracks patients for 30 days postoperatively, and therefore long-term outcomes including mortality, neurological function, and pseudarthrosis could not be evaluated.

Nevertheless, there are many distinct advantages to using the NSQIP database to evaluate the outcomes of patients with spinal tumors. The large patient population accrued by the NSQIP database provides the statistical power to discern many predictors of complications. Additionally, the national perspective increases the generalizability of results beyond single-center reports. Future studies will be needed to evaluate transitional care programs that may reduce the readmission rate of patients undergoing spine surgery.

Conclusions

In this national multiinstitution analysis of patients undergoing spine surgery for primary and secondary spinal tumors, 10.2% were readmitted within 30 days after discharge. The most common reasons for readmission were SSIs, systemic infections, and VTE, which were late complications that often occurred after discharge from the surgical hospitalization. Additionally, patients were primarily readmitted for new complications that developed following discharge rather than exacerbation of complications from the initial surgical hospital stay. Overall, 5.3% underwent reoperation, 14.4% experienced a major complication, and 3.3% died within 30 days postoperatively. This analysis provides predictive models for surgeons to identify and risk-stratify patients who may benefit from increased surveillance following discharge, including transitional care programs.

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Disclosures

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Author Contributions

Conception and design: Smith, Karhade, Vasudeva. Acquisition of data: Karhade, Dasenbrock. Analysis and interpretation of data: Karhade, Vasudeva, Dasenbrock. Drafting the article: Karhade, Vasudeva, Dasenbrock. Critically revising the article: Karhade, Vasudeva, Dasenbrock, Chi. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Smith. Statistical analysis: Smith, Karhade, Dasenbrock. Administrative/technical/material support: Lu, Gormley, Groff, Chi. Study supervision: Smith, Lu, Gormley, Groff, Chi.

Supplemental Information

Videos

Video Abstract. <https://vimeo.com/173610430>.

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