Hospital-acquired conditions: predictors and implications for outcomes following spine tumor resection

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OBJECTIVE Hospital-acquired conditions (HACs) significantly compromise patient safety, and have been identified by the Centers for Medicare and Medicaid Services as events that will be associated with penalties for surgeons. The mitigation of HACs must be an important consideration during the postoperative management of patients undergoing spine tumor resection. The purpose of this study was to identify the risk factors for HACs and to characterize the relationship between HACs and other postoperative adverse events following spine tumor resection.

METHODS The 2008–2014 American College of Surgeons' National Surgical Quality Improvement Program database was used to identify adult patients undergoing the resection of intramedullary, intradural extramedullary, and extradural spine lesions via current procedural terminology and ICD-9 codes. Demographic, comorbidity, and operative variables were evaluated via bivariate statistics before being incorporated into a multivariable logistic regression model to identify the independent risk factors for HACs. Associations between HACs and other postoperative events, including death, readmission, prolonged length of stay, and various complications were determined through multivariable analysis while controlling for other significant variables. The c-statistic was computed to evaluate the predictive capacity of the regression models.

RESULTS Of the 2170 patients included in the study, 195 (9.0%) developed an HAC. Only 2 perioperative variables, functional dependency and high body mass index, were risk factors for developing HACs (area under the curve = 0.654). Hospital-acquired conditions were independent predictors of all examined outcomes and complications, including death (OR 2.26, 95% CI 1.24–4.11, $p = 0.007$), prolonged length of stay (OR 2.74, 95% CI 1.98–3.80, $p < 0.001$), and readmission (OR 9.16, 95% CI 6.27–13.37, $p < 0.001$). The areas under the curve for these models ranged from 0.750 to 0.917.

CONCLUSIONS The comorbidities assessed in this study were not strongly predictive of HACs. Other variables, including hospital-associated factors, may play a role in the development of these conditions. The presence of an HAC was found to be an independent risk factor for a variety of adverse events. These findings highlight the need for continued development of evidence-based protocols designed to reduce the incidence and severity of HACs.

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KEY WORDS discharge destination; NSQIP; National Surgical Quality Improvement Program; readmissions; adverse events; morbidity; hospital-acquired conditions

DESPITE advances in oncological care, the treatment of spinal cord tumors remains difficult, and patients who undergo resection often face a challenging recovery.^{13,14,21,24} The risk of poor functional outcomes is compounded by the high rate of postoperative complications, which occur significantly more frequently than in other spine surgery cohorts.^{3,8,11,12,20} Of particular frequency and concern are a set of surgical complications classified as hospital-acquired conditions (HACs), which

have been targeted by recent research investigations and policy initiatives.^{9,16,18,25,26} Hospital-acquired conditions encompass various adverse events, including surgical site infection, deep venous thrombosis, and urinary tract infection, that have been deemed by the Centers for Medicare and Medicaid Services (CMS) to be provider-preventable conditions.¹⁵ The development of an HAC has been shown to double the hospital costs for an episode of care, as well as increase the likelihood of patient morbidity and mor-

ABBREVIATIONS ACS NSQIP = American College of Surgeons' National Surgical Quality Improvement Program; ASA = American Society of Anesthesiologists; AUC = area under the curve; BMI = body mass index; CMS = Centers for Medicare and Medicaid Services; COPD = chronic obstructive pulmonary disease; HAC = hospital-acquired condition; ICD-9 = *International Classification of Diseases, Ninth Revision*; LOS = length of stay.

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tality.^{9,28} In accordance with a policy enacted in 2008, Medicare no longer provides reimbursements for any additional costs associated with the treatment of these conditions if they are not present on admission.⁵ In addition, under the Hospital-Acquired Condition Reduction Program (HACRP) implemented in 2015 under the Affordable Care Act, certain hospitals that rank poorly in risk-adjusted HAC quality metrics will be subject to payment reductions.⁶ These financial penalties for hospitals are designed to promote care practices that limit the occurrence of these complications and improve patient safety and outcomes.¹⁵

Given the significant consequences of HACs for both patients and providers, several studies have been conducted to identify the predictors of these conditions for higher-risk cohorts, including surgical oncology patients and those with spinal deformity.^{8,17} Efforts have also been made to better understand associations between HACs and other variables relevant to the postoperative period, including readmissions and prolonged length of stay (LOS).^{8,9,28} However, despite the high complication rate among patients undergoing spine tumor resection, the incidence and risk factors for HACs as well as their implications for patient outcomes have yet to be explored for this patient population. Thus, the purpose of this study was to identify independent perioperative risk factors for HACs, as well as to characterize the relationship between HACs and other postoperative events.

Methods

This study was performed using data extracted from the 2008–2014 American College of Surgeons' National Surgical Quality Improvement Program (ACS NSQIP) registry. This database is prospectively collected from hundreds of participating hospitals by trained surgical clinical reviewers and has been widely used in surgical outcomes research.¹⁰ Adult patients undergoing resection of intramedullary, intradural extramedullary, or extradural spinal cord tumors of primary or secondary origin were included in this cohort. As per a prior study, cases were isolated using relevant current procedural terminology codes (63275–8, 63280–3, 63285–7, and 63300–7) and *International Classification of Diseases, Ninth Revision* (ICD-9) codes (170.2, 170.6, 198.3–5, 213.2, and 213.6).¹²

Demographic and operative information, such as sex, age, body mass index (BMI), American Society of Anesthesiologists (ASA) score, operative time, and hospital LOS were recorded for each patient. The presence of any comorbidities, including functional dependency, hypertension, diabetes, steroid use, cigarette use, chronic obstructive pulmonary disease (COPD), dialysis, dyspnea, ascites, ventilator use, prior transfusion, bleeding disorder, history of myocardial infarction, congestive heart failure, percutaneous coronary intervention, cerebrovascular accident, transient ischemic attack, renal failure, peripheral vascular disease, rapid preoperative weight loss, and sepsis was also noted. The specific criteria for these comorbidities are outlined in the ACS NSQIP user guide.¹ The current procedural terminology and ICD-9 coding was used to classify tumors as primary or secondary as well

as intramedullary, intradural extramedullary, or extradural lesions.

The primary outcome variable in our analysis was the development of an HAC, which consisted of superficial or deep surgical site infection, urinary tract infection, deep venous thrombosis, or pulmonary embolism, as outlined in prior studies and guidelines in the literature.^{8,15,17} The relationship between HACs and the development of other postoperative adverse events, such as death, complications, readmission, reoperation, and prolonged LOS was also assessed. Complications were categorized into pulmonary (pneumonia, unplanned reintubation, or duration of ventilator-assisted respiration ≥ 48 hours); renal (progressive renal insufficiency or acute renal failure); cardiac (cardiac arrest requiring cardiopulmonary resuscitation, or myocardial infarction); CNS (cerebrovascular accident or coma); and sepsis, as previously described.⁸ Prolonged LOS was defined as exceeding the 75th percentile for total hospital stay.²

Statistical Analysis

Preoperative and intraoperative variables were assessed via bivariate analysis to test their association with the development of an HAC. Chi-square analysis was used for categorical variables, whereas univariate logistic regression was used for continuous variables. Variables that resulted in $p < 0.1$ were included as covariates in a multivariable, binary logistic regression model to identify independent predictors of HACs. This analysis was replicated to determine whether the occurrence of an HAC is an independent risk factor for other postoperative adverse events, while controlling for a variety of perioperative variables. Separate multivariable analyses were performed for each postoperative outcome of interest, including death, prolonged LOS, pulmonary complications, renal complications, cardiac complications, CNS complications, readmission, and reoperation as the dependent variables for the different models. These analyses were repeated for each anatomical tumor cohort, including intramedullary, intradural extramedullary, and extradural tumors. For all multivariable analyses, the area under the curve (AUC) was calculated to assess each model's predictive capacity, and Hosmer-Lemeshow testing was performed to evaluate models for lack of goodness-of-fit to the data. Statistical software (IBM SPSS Statistics version 22) was used for all computations.

Results

Case Series Characteristics

The cohort consisted of 2170 patients undergoing spine tumor resection, with a mean age of 55 ± 16 years and a mean BMI of 28 ± 8 (mean $\pm$ SD). The ratio of males to females was 1171:996 (the sex was not reported in 3). Of these patients, 41.3% had hypertension, 26.1% presented with disseminated cancer, 18.0% used cigarettes, 11.4% had diabetes, and 10.6% were functionally dependent. The most common tumor location was extradural, which occurred in 45.2% of patients, followed by intradural extramedullary, and intramedullary, which occurred in 40.5% and 14.3% of patients, respectively. The mean operative time was 211

TABLE 1. Case series characteristics in 2170 patients after spine tumor resection

Characteristic	Value
Demographics	
Age, mean $\pm$ SD	55 $\pm$ 16 yrs
BMI, mean $\pm$ SD	28 $\pm$ 8
Sex, M/F	1171:996*
Select comorbidities	
Hypertension	896 (41.3%)
Disseminated cancer	567 (26.1%)
Cigarette use	390 (18.0%)
Diabetes	247 (11.4%)
Functionally dependent	229 (10.6%)
Tumor characteristics	
Intramedullary	311 (14.3%)
Intradural extramedullary	879 (40.5%)
Extradural	980 (45.2%)
Primary tumor	768 (35.4%)
Secondary tumor	1402 (64.6%)
Periop variables	
Op time, mean $\pm$ SD	211 $\pm$ 113 mins
Hospital LOS	7 $\pm$ 8 days
ASA score $\leq$ 2	838 (38.7%)
ASA score $>$ 2	1330 (61.3%)
Postop adverse events	
Death	97 (4.5%)
Any complication	531 (24.5%)
HAC	195 (9.0%)
Pulmonary complication	76 (3.5%)
Renal complication	9 (0.4%)
Cardiac complication	10 (0.5%)
CNS complication	6 (0.3%)
Sepsis	49 (2.3%)
Prolonged LOS	556 (25.6%)
Readmission	190 (8.8%)
Reop	93 (4.3%)

* Sex was not reported for 3 patients.

$\pm$ 113 minutes and the mean hospital LOS was 7 $\pm$ 8 days (mean $\pm$ SD). A total of 97 (4.5%) patients died within 30 days of surgery, 195 (9.0%) developed an HAC, and 190 (8.8%) were readmitted to the hospital. The complete case series characteristics can be found in Table 1.

The perioperative variables that resulted in $p < 0.1$ when tested for association with HACs via bivariate analysis are reported in Table 2. When these variables were incorporated into a multivariable model, dependent functional status (OR 1.54, 95% CI 1.01–2.34, $p = 0.047$); BMI (OR 1.03, 95% CI 1.01–1.05, $p = 0.009$); operative time (OR 1.002, 95% CI 1.001–1.003, $p = 0.001$); and ASA score (OR 1.40, 95% CI 1.09–1.80, $p = 0.008$) were found to be independent risk factors for HACs. The AUC for this model was 0.653. These findings are outlined in Table 3.

Development of an HAC was found to be significantly

TABLE 2. Variables resulting in $p < 0.1$ when examined for association with HACs

Periop Variable	OR (95% CI)
Dyspnea	2.08 (1.26–3.44)
Dependent functional status	1.92 (1.29–2.86)
COPD	1.88 (0.97–3.63)
Congestive heart failure	6.87 (1.92–245.7)
Hypertension	1.33 (0.99–1.79)
Weight loss	1.88 (0.97–3.63)
Bleeding disorder	2.53 (1.41–4.53)
Age	1.02 (1.01–1.03)
BMI	1.03 (1.01–1.05)
Op time	1.002 (1.001–1.003)
ASA score*	—

* The ASA score was assessed as part of a 4 $\times$ 2 table, and thus the OR could not be computed.

associated with all adverse events via bivariate analysis (Table 4). This relationship was subsequently analyzed via multivariable modeling. The occurrence of an HAC was found to be an independent predictor for all examined outcomes when controlling for demographics, comorbidities, and other perioperative variables. The HACs were significantly associated with death (OR 2.26, 95% CI 1.24–4.11, $p = 0.007$); prolonged LOS (OR 2.74, 95% CI 1.98–3.80, $p < 0.001$); readmission (OR 9.16, 95% CI 6.27–13.37, $p < 0.001$); and reoperation (OR 6.89, 95% CI 4.32–10.99, $p < 0.001$). The HACs were also significantly associated with a range of complications, including pulmonary complications (OR 2.77, 95% CI 1.55–4.97, $p = 0.001$); renal complications (OR 11.05, 95% CI 2.82–43.26, $p = 0.001$); cardiac complications (OR 11.93, 95% CI 2.79–50.96, $p = 0.001$); CNS complications (OR 8.90, 95% CI 1.69–47.05, $p = 0.010$); and sepsis (OR 15.43, 95% CI 8.28–28.75, $p < 0.001$). The AUCs ranged from 0.750 to 0.917 and are listed for each model in Table 5.

These analyses were repeated for each anatomical tumor subgroup. The specific factors that were independent predictors of HACs following the resection of each tumor type are reported in Table 6. Of note, no perioperative variables were predictive of HACs for patients with intramedullary tumors. When the relationship between HACs and patient outcomes was assessed for each tumor subgroup, HACs were similarly found to be independent predictors of a wide range of adverse events. These findings are depicted in Table 7.

TABLE 3. Significant predictors of HACs

Periop Risk Factor	OR	95% CI	p Value
Dependent functional status	1.54	1.01–2.34	0.047
BMI	1.03	1.01–1.05	0.009
Op time	1.002	1.001–1.003	0.001
ASA score	1.40	1.09–1.80	0.008

Predictors significant at $p < 0.05$. The AUC was 0.653.

TABLE 4. Outcome variables associated with HACs via bivariate analysis (cutoff $p < 0.1$)

Outcome Variable	OR (95% CI)
Death	2.63 (1.55–4.44)
Prolonged LOS	3.11 (2.3–4.20)
Pulmonary complication	3.63 (2.11–6.24)
Renal complication	12.97 (3.45–48.70)
Cardiac complication	10.37 (2.98–36.14)
CNS complication	10.27 (2.06–51.24)
Sepsis	13.06 (7.29–23.38)
Readmission	9.37 (6.51–13.49)
Reop	7.63 (4.83–12.05)

Discussion

Due to the high morbidity and long hospital stays prevalent among patients undergoing spine tumor resection, the mitigation of HACs should be an important consideration in the postoperative period.^{4,11,12,20,27} Although the CMS designates HACs as preventable events, we found that 9.0% of patients in this series developed one or more of these conditions within 30 days of the procedure. This is the first study to evaluate the predictors of these conditions and their ramifications for outcomes in this high-risk neurosurgical group. These data demonstrate that several patient and operative characteristics are independent predictors of HACs following spine tumor resection. Additionally, the occurrence of an HAC was associated with a significantly higher risk of other adverse events, such as death, readmission, prolonged LOS, and various types of complications.

Due to the negative implications of HACs for patient outcomes and resource utilization, the ability to preoperatively identify which patients are predisposed to developing these conditions would be particularly valuable. Several patient characteristics, specifically ASA score, dependent functional status, larger BMI, and operative time were found to be independent predictors of HACs in these multivariable models. These findings align with previously reported associations in the literature.^{8,17} An investigation that used a large national database to evaluate HACs following spinal deformity surgery concluded that dependent functional status, BMI, ASA score, and operative time were also risk factors for HACs in their series.⁸ Another ACS NSQIP study that included a variety of surgical oncology procedures similarly identified the association between dependent functional status, ASA score, BMI, and the development of HACs.¹⁷ In addition, several of these comorbidities have been previously linked to specific complications designated as HACs.^{19,22,23} Consequently, it may be advantageous to provide greater surveillance and perioperative resources to patients with these perioperative profiles.

However, the majority of comorbidities examined were not found to be predictive of HACs. Demographic characteristics and variables including male sex, dyspnea, bleeding disorders, and steroid use have been shown to be independent predictors of major complications follow-

TABLE 5. Postoperative adverse events for which an HAC is an independent risk factor

Outcome Variable	OR	95% CI	p Value	AUC
Death	2.26	1.24–4.11	0.007	0.863
Prolonged LOS	2.74	1.98–3.80	<0.001	0.756
Pulmonary complication	2.77	1.55–4.97	0.001	0.813
Renal complication	11.05	2.82–43.26	0.001	0.821
Cardiac complication	11.93	2.79–50.96	0.001	0.917
CNS complication	8.90	1.69–47.05	0.010	0.851
Sepsis	15.43	8.28–28.75	<0.001	0.814
Readmission	9.16	6.27–13.37	<0.001	0.763
Reop	6.89	4.32–10.99	<0.001	0.750

ing spine tumor resection.¹² However, these factors, as well as a wide range of other comorbidities, did not achieve significance when tested for association with HACs via bivariate or multivariable modeling. Patients who would be considered to be at greater risk for complications following spine tumor resection may thus not be more likely to experience the specific conditions classified as HACs. Furthermore, the multivariable model assessing the risk factors for HACs was associated with a lower AUC (0.653) compared with those of the other analyses. It thus may be difficult to use traditional comorbidity profiles in predicting which patients are at a greater risk for experiencing these events. Based on the CMS classification of HACs as preventable conditions, the main driver of HAC risk may instead be factors associated with hospital-specific postoperative care. The preoperative variables that were significantly associated with HACs, such as functional dependence and larger BMI are conditions that could necessitate more intensive care by the hospital staff. Further studies are needed to explore the relationship between postoperative treatment protocols and the incidence of HACs in neurosurgical patients.

Although HACs are inherently unfavorable outcomes for patients, it has been suggested that these conditions may also be associated with an increased incidence of other adverse postoperative events. In these multivariable models, the development of an HAC was an independent

TABLE 6. Predictors of HACs among the 3 anatomical tumor cohorts

Periop Risk Factor (AUC)	OR	95% CI	p Value
Intramedullary (0.635)			
No significant predictors	NA	NA	NA
Intradural extramedullary (0.655)			
COPD	3.22	1.12–9.25	0.030
BMI	1.03	1.00–1.07	0.048
Op time	1.003	1.001–1.005	0.008
Extradural (0.659)			
Age	1.02	1.01–1.04	0.012
ASA score	1.53	1.06–2.20	0.023

NA = not applicable.

TABLE 7. Outcomes predicted by HACs among the 3 anatomical tumor cohorts

Outcome Variable	OR	95% CI	p Value	AUC
Intramedullary				
Death	12.56	1.71–92.26	0.013	0.906
Prolonged LOS	3.01	1.34–6.78	0.008	0.757
Pulmonary complication	8.25	1.57–43.45	0.013	0.711
Sepsis	29.48	2.78–312.38	0.005	0.752
Readmission	7.45	2.93–18.95	<0.001	0.733
Reop	19.62	6.55–58.80	<0.001	0.821
Intradural extramedullary				
Prolonged LOS	2.32	1.32–4.09	0.004	0.748
Pulmonary complication	5.17	1.58–16.87	0.007	0.895
Cardiac complication	14.68	1.11–194.78	0.042	0.963
Sepsis	28.45	9.49–85.31	<0.001	0.876
Readmission	19.89	9.57–41.24	<0.001	0.846
Reop	5.98	2.41–14.86	<0.001	0.740
Extradural				
Prolonged LOS	2.91	1.79–4.75	<0.001	0.745
Renal complication	8.69	2.05–36.71	0.003	0.738
Sepsis	7.26	3.11–16.91	<0.001	0.793
Readmission	6.82	4.00–11.66	<0.001	0.743
Reop	5.60	2.86–10.95	<0.001	0.732

predictor of all tested events, including death, prolonged LOS, and readmission. These results are corroborated by studies that have been conducted in other neurosurgical cohorts. It was previously reported that the in-hospital mortality rate for patients who developed an HAC following resection of cranial neoplasms was 6.47%, which was significantly greater than the 1.53% mortality rate for patients without HACs.²⁸ Patients who develop HACs following spine surgery have also been shown to be significantly more likely to experience a wide variety of complications.⁸ The strong relationship between HACs and poor short-term outcomes demonstrates the need for metrics associated with prevention and early detection of HACs in the postoperative period. Generating and adhering to evidence-based practices for neurosurgical patients, as well as rigorous collection and assessment of institutional data may provide avenues for reducing the incidence of HACs.

These conclusions must be examined in the context of existing limitations in study design. Although the registry data are collected prospectively by trained reviewers at each hospital site, the cases included in our analysis were analyzed retrospectively and may thus be subject to selection bias. Additionally, the postoperative outcomes that could be examined were limited by the variables collected in the database. Therefore, factors including socioeconomic status and neurosurgery-specific outcome metrics could not be included. Only complications that occur within 30 days of surgery are recorded, and no information is collected regarding changes in neurological status. Finally, we could not evaluate the postoperative care practices that were in place for these patients, which can impact the complication rate and may vary by institution.

Conclusions

Nevertheless, these data highlight the predictors of, and relationship between, HACs and postoperative outcomes following spine tumor resection. However, the absence of predictive comorbidities in the model suggests that HACs may be influenced by other variables, including hospital-related factors not captured in the national registry. The HACs were also found to be risk factors for a variety of events that compromise patient safety. This study demonstrates the need for continued development of evidence-based protocols designed to reduce the incidence and severity of HACs in this high-risk population. It is imperative that neurosurgeons who treat patients with spine tumors play an active role in the process of implementing these protocols at their respective institutions.

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Disclosures

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Author Contributions

Conception and design: both authors. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: Lakomkin. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Statistical analysis: Lakomkin. Administrative/technical/material support: Hadjipanayis. Study supervision: Hadjipanayis.

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