Frequency and predictors of complications in neurological surgery: national trends from 2006 to 2011

Clinical article

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Object. Surgical complications increase the cost of health care worldwide and directly contribute to patient morbidity and mortality. In an effort to mitigate morbidity and incentivize best practices, stakeholders such as health insurers and the US government are linking reimbursement to patient outcomes. In this study the authors analyzed a national database to determine basic metrics of how comorbidities specifically affect the subspecialty of neurosurgery.

Methods. Data on 1,777,035 patients for the years 2006–2011 were acquired from the American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) database. Neurosurgical cases were extracted by querying the data for which the surgical specialty was listed as “neurological surgery.” Univariate statistics were calculated using the chi-square test, and 95% confidence intervals were determined for the resultant risk ratios. A multivariate model was constructed using significant variables from the univariate analysis ($p < 0.05$) with binary logistic regression.

Results. Over 38,000 neurosurgical cases were analyzed, with complications occurring in 14.3%. Cranial cases were 2.6 times more likely to have complications than spine cases, and African Americans and Asians/Pacific Islanders were also at higher risk. The most frequent complications were bleeding requiring transfusion (4.5% of patients) and reoperation within 30 days of the initial operation (4.3% of patients), followed by failure to wean from mechanical ventilation postoperatively (2.5%). Significant predictors of complications included preoperative stroke, sepsis, blood transfusion, and chronic steroid use.

Conclusions. Understanding the landscape of neurosurgical complications will allow better targeting of the most costly and harmful complications of preventive measures. Data from the ACS NSQIP database provide a starting point for developing paradigms of improved care of neurosurgical patients.

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KEY WORDS • complication • quality improvement • adverse event • error

As health care costs mount higher, invested stakeholders are scrutinizing surgical practices with an eye toward improving value—defined as the patient’s outcome relative to the cost of care.¹⁶ Insurers, patients, and government agencies are all beginning to make decisions about health care based on perceived value. Surgical complications are often broadly defined as “any deviation from the normal postoperative course.”⁷⁴ This definition is clearly subjective and prone to interobserver variability.¹¹ Within the past several years, nationwide databases, such as those hosted by the Cleveland Clinic (Cardiovascular Information Registry),¹¹ the Agency for Healthcare Research and Quality (Patient Safety Indicators),^{9,17} and the American College of Sur-

geons (ACS) (National Surgical Quality Improvement Program [NSQIP]), have begun prospectively collecting data on surgical complications using objective criteria.^{8,10}

In particular, the NSQIP database has strict criteria for defining a specified set of frequent postsurgical complications. Data are derived from hundreds of US hospitals in a wide range of settings, from small rural community hospitals to major academic medical centers. In 2006, there were 121 participating sites, and in 2013, there are more than 400 sites. All major surgical procedures performed are identified using Current Procedural Terminology (CPT) codes, and the standardized set of variables is collected from either all cases for low-volume hospitals or a sample group representing 20% of all cases performed for large-volume sites. The NSQIP utilizes trained raters to identify these complications directly from the medical records. The raters are frequently audited using test cases, and their data are ignored if they fail these auditing checks.¹⁹

Abbreviations used in this paper: ACS = American College of Surgeons; CPT = Current Procedural Terminology; NSQIP = National Surgical Quality Improvement Program.

Complications in neurosurgery

With the NSQIP data set, it is possible to determine the most frequent complications in neurological surgery. Identifying these complications will allow us to better distribute resources to prevent and mitigate the most costly and common adverse events in our patients. Moreover, understanding the type and frequency of complications in neurosurgery will allow us to better coordinate care with stakeholders—insurers, governmental institutions, and patients. In this study, we used the NSQIP database to examine trends and predictors of complications in neurosurgical patients.

Methods

Data for the years 2006 to 2011 were obtained from the ACS NSQIP database. Files were acquired in delimited text format and parsed using both SPSS version 20 (IBM Corp.) and Matlab R2012a (MathWorks Inc.). Neurosurgical cases were extracted by querying the data for which the primary surgeon's specialty was listed as "neurological surgery," and then each of the CPT codes was individually reviewed to determine whether the case was cranial or spinal (Table 1).

Descriptive statistics are represented as the means $\pm$ standard deviation. Univariate statistics were calculated using the chi-square test, and 95% confidence intervals are presented for the resultant risk ratios. A multivariate model was constructed with the significant variables from univariate analysis ($p < 0.05$) using binary logistic regression with a maximum number of iterations of 20. Significant predictors from this model were identified, and their risk ratios were presented, along with the 95% confidence intervals. Data were plotted using Matlab.

Results

Records from 1,777,035 surgical cases were compiled. Neurosurgeons performed 38,396 of these cases. Characteristics of the neurosurgical patients are presented in Table 2 and are compared with those of general surgical patients to reveal the unique features of neurosurgical patients while highlighting the landscape of complications encountered. Of note, compared with nonneurosurgical patients, the neurosurgical patients were more likely to be male and white. African American patients had a RR of 0.75 (95% CI 0.72–0.78) of undergoing neurosurgery as opposed to any other surgery, and Asians/Pacific Islanders had an RR of 0.75 (95% CI 0.70–0.81).

As might be expected, neurosurgical cases were far more likely to involve inpatient procedures rather than outpatient (outpatient RR 0.31, 95% CI 0.30–0.32). However, neurosurgery was less likely to be done emergently compared with nonneurosurgical procedures (RR 0.46, 95% CI 0.44–0.48). Moreover, neurosurgical procedures were significantly longer than nonneurosurgical ones, both in terms of anesthesia time (76.9 minutes, $p < 0.0001$) and operative time (52.6 minutes, $p < 0.0001$). Neurosurgical patients also stayed on average 0.5 day longer than the other surgical patients ($p < 0.0001$).

Other demographic features were also compared between neurosurgical and nonneurosurgical patients. Neu-

TABLE 1: CPT codes included in an analysis of neurosurgical complications

Spine Codes	Cranial Codes
0090T	21137
0092T	21139
0093T	21180
0095T	21299
0096T	35001–5
0163T	35201
0195T	35301
0196T	35800
0202T	37605
10121	37799
10140	49422
10180	60600
11000	61150–888
11042–4	62000–362
20005	69511
20100	
20696	
20902	
20922	
20930	
20931	
20936	
20938	
20999	
21026	
21501	
21510	
21610	
21615	
22010	
22015	
22100–14	
22206–26	
22318–27	
22520–95	
22600–32	
22800–99	
27080	
27202	
27218	
27280	
42725	
49215	
63001–308	
63685	
63700–41	
64573–85	

TABLE 2: Summary of characteristics in neurosurgical compared with nonneurosurgical patients

Characteristic	Neurosurgical Patients (%)	Nonneurosurgical Patients (%)	p Value	RR (95% CI)
total no. of patients	38,396	1,738,639		
mean age (yrs) $\pm$ SD	56.0 $\pm$ 15.0	55.7 $\pm$ 17.0	<0.0001	
mean height (in) $\pm$ SD	66.9 $\pm$ 4.2	66.2 $\pm$ 4.1	<0.0001	
mean weight (lb) $\pm$ SD	186.7 $\pm$ 46.9	186.2 $\pm$ 54.4	<0.0001	
mean anesthesia time (mins) $\pm$ SD	238.4 $\pm$ 129.2	161.5 $\pm$ 106.3	<0.0001	
mean op time (mins) $\pm$ SD	162.6 $\pm$ 110.1	110.0 $\pm$ 91.3	<0.0001	
mean length of stay (days) $\pm$ SD	4.8 $\pm$ 10.2	4.3 $\pm$ 9.9	<0.0001	
sex*				
male	19,521 (50.8)	737,714 (42.4)		1†
female	18,800 (49.0)	999,673 (57.5)		0.72 (0.70–0.73)‡
race*				
white	30,360 (79.1)	1,319,127 (75.9)		1†
black or African American	2,943 (7.7)	171,462 (9.9)		0.75 (0.72–0.78)‡
Asian/Pacific Islander	731 (1.9)	42,327 (2.4)		0.75 (0.70–0.81)‡
American Indian or native Alaskan	225 (0.6)	11,992 (0.7)		0.82 (0.72–0.93)‡
unknown	4,137 (10.8)	193,731 (11.1)		
inpatient vs outpatient*				
inpatient	32,871 (85.6)	1,121,524 (64.5)		1†
outpatient	5,525 (14.4)	617,112 (35.5)		0.31 (0.30–0.32)‡
diabetes*				
no	32,918 (85.7)	1,477,932 (85.0)		1†
yes	5,478 (14.3)	260,704 (15.0)		0.94 (0.92–0.97)‡
insulin-dependent	1,925 (5.0)	102,225 (5.9)		0.85 (0.81–0.89)‡
not insulin-dependent	3,553 (9.3)	158,479 (9.1)		1.00 (0.97–1.04)
tobacco use*				
no	28,693 (74.7)	1,391,997 (80.1)		1†
yes	9,702 (25.3)	346,621 (19.9)		1.35 (1.32–1.38)‡
hypertensive patient on antihypertensive(s)*				
no	20,392 (53.1)	936,936 (53.9)		1†
yes	18,004 (46.9)	801,689 (46.1)		1.03 (1.01–1.05)‡
emergency case*				
no	36,108 (94.0)	1,525,718 (87.8)		1†
yes	2,288 (6.0)	212,916 (12.2)		0.46 (0.44–0.48)‡

* Cases with unknown values, when encountered, were omitted from analysis.

† Reference.

‡ Denotes a statistically significant difference.

rosurgery patients were less likely to have diabetes (RR 0.94, 95% CI 0.92–0.97) but more likely to be on medication for hypertension (RR 1.03, 95% CI 1.01–1.05). Neurosurgery patients were also more likely to smoke (RR 1.35, 95% CI 1.32–1.38).

In neurosurgical patients alone, we evaluated the frequency of complications documented in the NSQIP database. Cases were split into spinal (28,017 cases) and cranial (10,041 cases) surgery groups, and complications were analyzed independently (Table 3); the other 338 cases represented peripheral nerve and nonneurosurgical cases performed by neurosurgeons. Complications occurred in 14.3% (5507 of 38,396) of neurosurgical cases.

Cranial procedures were significantly more likely to produce complications than spinal procedures (RR 2.575, 95% CI 2.386–2.779), with 23.6% of cranial procedures leading to complications compared with 11.2% of spinal procedures. The most frequent complication in the neurosurgical procedures overall or in either spinal or cranial procedures alone was bleeding requiring a transfusion, which occurred in 4.5% of patients, and was more likely to occur in cranial than in spinal patients (RR 1.255, 95% CI 1.136–1.385). The second most common complication was reoperation within 30 days of the initial operation, and this occurred in 4.3% of neurosurgical patients overall and was more likely in cranial than in spinal patients (RR 2.11,

TABLE 3: Frequency of complications in 38,058 neurosurgical cases*

Parameter	Cranial Op (%)	Spinal Op (%)	Cranial & Spinal Op Combined (%)	RR, Cranial vs Spinal (95% CI)
no. of cases	10,041	28,017		
complication				
superficial incisional infection	72 (0.7)	301 (1.1)	373 (1.0)	0.667 (0.517–0.862)†
deep incisional infection	45 (0.4)	166 (0.6)	211 (0.6)	0.756 (0.545–1.051)
organ/space infection	105 (1.0)	91 (0.3)	196 (0.5)	3.220 (2.434–4.259)†
wound dehiscence	24 (0.2)	82 (0.3)	106 (0.3)	0.817 (0.519–1.286)
postop pneumonia	367 (3.6)	212 (0.8)	579 (1.5)	4.830 (4.085–5.711)†
unplanned reintubation	300 (3.0)	182 (0.6)	482 (1.3)	4.599 (3.831–5.522)†
pulmonary embolism	137 (1.4)	107 (0.4)	244 (0.6)	3.573 (2.777–4.596)†
failure to wean from ventilator for >48 hrs postop	759 (7.6)	191 (0.7)	950 (2.5)	11.088 (9.477–12.973)†
progressive renal insufficiency	24 (0.2)	36 (0.1)	60 (0.2)	1.860 (1.110–3.116)†
acute renal failure requiring dialysis	21 (0.2)	20 (0.1)	41 (0.1)	2.930 (1.589–5.403)†
urinary tract infection	402 (4.0)	458 (1.6)	860 (2.3)	2.449 (2.146–2.795)†
stroke/CVA	219 (2.2)	42 (0.1)	261 (0.7)	14.549 (10.466–20.225)†
coma (>24 hrs)	113 (1.1)	5 (0.0)	118 (0.3)	63.060 (25.756–154.395)†
peripheral nerve injury	10 (0.1)	32 (0.1)	42 (0.1)	0.872 (0.429–1.773)
cardiac arrest requiring CPR	65 (0.6)	49 (0.2)	114 (0.3)	3.701 (2.556–5.359)†
myocardial infarction	34 (0.3)	54 (0.2)	88 (0.2)	1.757 (1.145–2.697)†
bleeding requiring transfusion	540 (5.4)	1201 (4.3)	1741 (4.6)	1.255 (1.136–1.385)†
graft/prosthesis/flap failure	2 (0.0)	7 (0.0)	9 (0.0)	0.797 (0.166–3.837)
deep venous thrombosis requiring therapy	259 (2.6)	225 (0.8)	484 (1.3)	3.212 (2.690–3.834)†
sepsis	363 (3.6)	251 (0.9)	614 (1.6)	4.035 (3.441–4.732)†
septic shock	128 (1.3)	80 (0.3)	208 (0.5)	4.464 (3.380–5.898)†
reop w/in 30 days	738 (7.3)	899 (3.2)	1637 (4.3)	2.113 (2.013–2.217)†
any complication	2373 (23.6)	3134 (11.2)	5507 (14.5)	2.575 (2.386–2.779)†

* CPR = cardiopulmonary resuscitation; CVA = cerebrovascular accident.

† Denotes a statistically significant difference.

95% CI 2.01–2.22). The third most common complication was failure to wean from mechanical ventilation for more than 48 hours postoperatively, which occurred in 2.5% of neurosurgical patients. In fact, all complications except 5 were more likely in cranial procedures than in spinal ones. Of these 5, there was no significant difference in 4 and only 1 in which spinal procedures were significantly more likely to generate a complication: superficial surgical site infection (cranial RR 0.67, 95% CI 0.52–0.86). The 5 nonsignificantly different complications were wound dehiscence, deep surgical site infection, peripheral nerve injury, and graft, prosthesis, or flap failure.

Using univariate analysis, we examined potential patient predictors that might be associated with the occurrence of a complication (Table 4). Many of these factors showed a significant association with complications. For example, African Americans were 1.51 times more likely to experience a complication than whites, and Asians/Pacific Islanders were 1.58 times more likely. Complications were also more likely to occur in inpatients (RR 4.95, 95% CI 4.28–5.73), patients with diabetes (RR 1.39, 95% CI 1.31–1.48), emergent cases (RR 3.83, 95%

CI 3.64–4.04), and frequent users of alcohol (RR 1.36, 95% CI 1.20–1.54). Altogether, 34 characteristics were significantly associated with complications on univariate analysis.

Using the predictors identified with univariate analysis, we then constructed a model using binary logistic regression to control for confounding. This analysis identified 15 significant predictors (Table 5). African American race continued to be a significant risk factor for developing complications (RR 1.24, 95% CI 1.10–1.41), whereas American Indian or Native Alaskan race continued to be protective (RR 0.53, 95% CI 0.28–0.98). However, Asian or Pacific Islander race was no longer a significant risk factor.

Many risk factors continued to be significantly associated with complications, such as diabetes, prior stroke, open wound, chronic steroid use, presurgical sepsis, and the need for a preoperative transfusion with > 4 units of red blood cells (Table 5). Cranial procedures still produced more complications than spinal procedures (RR 1.41, 95% CI 1.27–1.56), despite controlling for patient comorbidities.

TABLE 4: Univariate predictors of complications among 5495 neurosurgical patients*

Factor	No. of Complications (%)	RR (95% CI)
sex		
male	2685 (48.9)	1†
female	2810 (51.1)	1.09 (1.03–1.14)
race‡		
white	4083 (74.1)	1†
black or African American	596 (10.8)	1.51 (1.39–1.62)§
Asian or Pacific Islander	147 (2.7)	1.58 (1.36–1.82)§
American Indian or native Alaskan	21 (0.4)	0.70 (0.47–1.05)
spinal vs cranial		
spinal	3134 (56.9)	1†
cranial	2373 (43.1)	2.11 (2.01–2.22)§
inpatient vs outpatient		
outpatient	179 (3.3)	1†
inpatient	5328 (96.7)	4.95 (4.28–5.73)§
diabetes		
no	4470 (81.2)	1†
yes	1037 (18.8)	1.39 (1.31–1.48)§
insulin-dependent	439 (8.0)	1.68 (1.54–1.83)§
not insulin-dependent	598 (10.9)	1.24 (1.15–1.34)§
tobacco use		
no	4265 (77.4)	1†
yes	1242 (22.6)	0.86 (0.81–0.91)§
alcohol use‡		
no	3827 (94.8)	1†
yes	208 (5.2)	1.36 (1.20–1.54)§
dyspnea‡		
no	4985 (90.5)	1†
moderate exertion	405 (7.4)	1.32 (1.20–1.44)§
at rest	116 (2.1)	2.92 (2.53–3.36)§
ventilator dependent prior to op		
no	4977 (90.4)	1†
yes	530 (9.6)	6.06 (5.79–6.34)§
severe COPD		
no	5146 (93.4)	1†
yes	361 (6.6)	1.65 (1.50–1.81)§
current pneumonia‡		
no	3988 (99.0)	1†
yes	41 (1.0)	4.10 (3.37–4.99)§
congestive heart failure‡		
no	5538 (98.7)	1†
yes	69 (1.3)	3.79 (3.23–4.45)§
MI w/in 6 mos‡		
no	3992 (99.1)	1†
yes	37 (0.9)	3.31 (2.62–4.18)§
angina in past mo‡		
no	3998 (99.3)	1†
yes	30 (0.7)	1.44 (1.05–1.98)§

(continued)

TABLE 4: Univariate predictors of complications among 5495 neurosurgical patients* (continued)

Factor	No. of Complications (%)	RR (95% CI)
hypertensive patient on antihypertensive(s)		
no	2390 (43.4)	1†
yes	3117 (56.6)	1.48 (1.40–1.55)§
prior angioplasty/amputation for PVD‡		
no	3963 (98.4)	1†
yes	66 (1.6)	1.73 (1.40–2.14)§
renal failure on dialysis		
no	5428 (98.6)	1†
yes	79 (1.4)	3.49 (2.98–4.09)§
altered mental status‡		
no	3461 (85.9)	1†
yes	568 (14.1)	4.13 (3.87–4.40)§
coma prior to op‡		
no	3845 (95.4)	1†
yes	184 (4.6)	5.84 (5.46–.25)§
hemiplegia/hemiparesis prior to op‡		
no	3592 (89.2)	1†
yes	437 (10.8)	2.73 (2.52–2.95)§
history of transient ischemic attack(s)‡		
no	3888 (96.5)	1†
yes	141 (3.5)	1.49 (1.28–1.73)§
prior stroke w/ persistent neurological deficit‡		
no	3504 (87.0)	1†
yes	525 (13.0)	3.50 (3.26–3.75)§
prior stroke w/ no deficit‡		
no	3875 (96.2)	1†
yes	154 (3.8)	2.04 (1.78–2.34)§
CNS tumor‡		
no	3349 (83.1)	1†
yes	680 (16.9)	1.72 (1.60–1.85)§
paraplegia/paraparesis prior to op‡		
no	3731 (92.6)	1†
yes	298 (7.4)	1.90 (1.72–2.11)§
quadriplegia/quadruparesis prior to op‡		
no	3944 (97.9)	1†
yes	85 (2.1)	2.51 (2.11–2.98)§
disseminated/metastatic cancer‡		
no	5048 (92.3)	1†
yes	423 (7.7)	2.00 (1.83–2.17)§
open wound		
no	5279 (95.9)	1†
yes	228 (4.1)	2.56 (2.30–2.85)§
chronic steroid use		
no	4994 (90.7)	1†
yes	513 (9.3)	1.58 (1.46–1.71)§
>10% weight loss in last 6 mos		
no	5389 (97.9)	1†
yes	118 (2.1)	1.94 (1.66–2.26)§

(continued)

TABLE 4: Univariate predictors of complications among 5495 neurosurgical patients* (*continued*)

Factor	No. of Complications (%)	RR (95% CI)
bleeding disorder		
no	5124 (93.0)	1†
yes	383 (7.0)	2.53 (2.33–2.76)§
transfused >4 units RBCs prior to op		
no	5416 (98.3)	1†
yes	91 (1.7)	4.93 (3.87–4.99)§
chemotherapy in past mo‡		
no	3941 (97.8)	1†
yes	88 (2.2)	2.22 (1.87–2.65)§
radiotherapy in past 90 days‡		
no	3943 (98.6)	1†
yes	56 (1.4)	2.23 (1.80–2.78)§
sepsis prior to op‡		
no	4870 (89.0)	1†
SIRS	426 (7.8)	3.57 (3.32–3.84)§
sepsis	143 (2.6)	3.82 (3.40–4.30)§
septic shock	32 (0.6)	4.07 (3.22–5.16)§
emergency case		
no	4437 (80.6)	1†
yes	1070 (19.4)	3.83 (3.64–4.04)§
admission quarter		
1st	1201 (21.8)	1†
2nd	1127 (20.5)	1.00 (0.93–1.08)
3rd	1507 (27.4)	1.06 (0.99–1.13)
4th	1672 (30.4)	1.08 (1.00–1.15)§

* COPD = chronic obstructive pulmonary disease; MI = myocardial infarction; PVD = perivascular disease; RBC = red blood cell; SIRS = systemic inflammatory response syndrome.

† Reference.

‡ Cases with unknown values, when encountered, were omitted from analysis.

§ Denotes a statistically significant difference.

Discussion

Minimizing surgical complications has been a goal in neurosurgery ever since Harvey Cushing began rigorously documenting his own surgical errors more than a century ago.¹² However, understanding and mitigating complications has taken on renewed importance in the era of “pay for performance” and governmental and insurance reimbursement metrics.^{5,6,15,20,22} Therefore, we sought to describe the current state of complications in neurological surgery, to provide data to help understand how new regulations should be applied, and, of course, to better target interventions to improve patient well-being.

Complications occurred in 14.3% of neurosurgical cases. The most frequent complications, in either cranial or spinal operations, were blood loss requiring transfusion and reoperation within 30 days, followed, somewhat surprisingly, by failure to wean from mechanical ventilation for > 48 hours postoperatively, which occurred in 7.6% of cranial cases and 0.7% of spinal cases. This latter complication deserves note because, in our experience, it is seldom explicitly discussed with patients preoperative-

ly, even though empirically it is one of the most frequent complications. The reasons for the high prevalence of this complication deserve more study.

Overall, complications were far more likely to occur in cranial procedures than in spinal ones (23.6% cranial vs 11.2% spinal). Even when accounting for other patient risk factors, cranial procedures were still 1.41 times more likely to involve complications than spinal procedures (95% CI 1.27–1.56). The source of this discrepancy is unclear from the data captured within the NSQIP data set. It should be stressed, however, that the NSQIP is only an incomplete reflection of patient characteristics. The nature of diseases bringing one to cranial neurosurgery (for example, glioma, hydrocephalus) are far different from those for spine surgery (for example, herniated intervertebral discs, spinal instability), and additional data on patient characteristics and risk factors not present in the NSQIP database could contribute to the observed difference in complication frequencies.

Many of the predictors of complications were expected and are traditionally considered as high-risk comorbidities from a pathophysiological standpoint (for ex-

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TABLE 5: Significant multivariate predictors of complications

Factor	OR (95% CI)
sex	
female	1*
male	0.90 (0.83–0.97)
race	
white	1*
black or African American	1.24 (1.10–1.41)†
Asian or Pacific Islander	1.28 (0.98–1.65)†
American Indian or native Alaskan	0.53 (0.28–0.98)†
spinal vs cranial	
spinal	1*
cranial	1.41 (1.27–1.56)†
inpatient vs outpatient	
inpatient	1*
outpatient	0.31 (0.26–0.37)†
diabetes	
no	1*
insulin-dependent	1.30 (1.11–1.53)†
not insulin-dependent	1.08 (0.95–1.23)
alcohol use	
no	1*
yes	1.25 (1.04–1.52)†
dyspnea	
no	1*
moderate exertion	1.05 (0.71–1.56)
at rest	1.17 (1.00–1.37)†
ventilator dependent prior to op	
no	1*
yes	5.16 (3.79–7.03)†
severe COPD	
no	1*
yes	1.34 (1.12–1.60)†
congestive heart failure	
no	1*
yes	1.73 (1.01–2.96)†
hypertensive patient on antihypertensive(s)	
no	1*
yes	1.16 (1.06–1.27)†
renal failure on dialysis	
no	1*
yes	2.03 (1.29–3.21)†
altered mental status	
no	1*
yes	1.59 (1.33–1.91)†
prior stroke w/ persistent neurological deficit	
no	1*
yes	1.60 (1.34–1.91)†
prior stroke w/ no deficit	
no	1*
yes	1.81 (1.44–2.28)†

(continued)

TABLE 5: Significant multivariate predictors of complications (continued)

Factor	OR (95% CI)
paraplegia/paraparesis prior to op	
no	1*
yes	1.92 (1.63–2.26)†
quadriplegia/quadruparesis prior to op	
no	1*
yes	2.63 (1.93–3.59)†
open wound	
no	1*
yes	1.60 (1.25–2.04)†
chronic steroid use	
no	1*
yes	1.28 (1.10–1.48)†
preop transfusion w/ >4 units RBCs	
no	1*
yes	5.02 (3.07–8.22)†
sepsis prior to op	
no	1*
SIRS	2.07 (1.69–2.54)†
sepsis	2.37 (1.70–3.31)†
septic shock	0.82 (0.41–1.65)
brain or spine tumor	
no	1*
yes	1.42 (1.24–1.61)†
emergency case	
no	1*
yes	2.27 (1.96–2.64)†

* Reference.

† Denotes a statistically significant difference.

ample, presurgical sepsis, prior stroke, diabetes). Others were somewhat harder to explain. For example, African Americans are significantly more likely to experience complications than whites, with an RR of 1.24 (95% CI 1.10–1.41). This racial/ethnic disparity in surgical complication rates has been described across multiple surgical disciplines; however, the exact source of this bias is unknown.^{3,7,14,18,21} Although many comorbid conditions were controlled for in our multivariate model, it is possible that some untracked characteristics in African Americans make them more vulnerable to complications (for example, disease type or severity) or that socioeconomic factors (for example, access to care) are leading to more complications. In either case, we must seek the cause of this disparity to improve the health of our patients.

Several limitations to our study are worth noting. The NSQIP database is a well-curated set of records in which trained analysts enter every complication using strict criteria. Nonetheless, it has several inherent limitations, especially as regards neurosurgical patients. First, the 30-day analysis of complications that is standardized across all sites from which data are gathered is a major strength of the NSQIP database; however, a number of complications

unique to the neurosurgical population may not be accurately represented. For example, delayed hemorrhage from an incompletely treated vascular malformation would not be recorded, and there would be no distinction between a postoperative neurological deficit that is permanent versus one that resolves over time. Tracked complications are, by necessity, general and cover a wide range of categories: incision related (both infection and dehiscence), pulmonary (pneumonia, failure to wean from ventilator, and so forth), urinary tract infections, strokes, cardiac arrest or myocardial infarction, renal failure, bleeding, peripheral nerve injury, deep venous thrombosis or pulmonary embolism, sepsis, and reoperation. The NSQIP data set is used by many surgical disciplines, and complications unique to neurosurgery and related disciplines are irrelevant to the majority of the database's users (for example, CSF leaks, pseudomeningoceles). Similarly, counting complications by using broad measures may not reflect the nuances encountered in neurosurgical care. For example, rates of failure to wean from a ventilator within 48 hours probably included patients with planned postoperative mechanical ventilation to manage seizures or to control intracranial pressure. In addition, preoperative morbidity variables are similarly generalized and broad. The categories include race, sex, history of tobacco or alcohol use, history of bleeding disorders, transfusions, chemo- or radiotherapy, sepsis, diabetes, disseminated malignancy, and a host of common pulmonary, cardiac, and renal conditions. Variables more relevant to neurosurgery included an altered mental status, history of stroke or transient ischemic attack, paralysis (hemiplegia, paraplegia, quadriplegia), or a CNS tumor. However, the presence of a CNS tumor is a "yes/no" field in the NSQIP database, which ignores distinctions between benign tumors such as meningiomas versus aggressive tumors such as glioblastomas. The database could have even greater value for the neurosurgical community if it included complications that are unique to, but represent a significant burden, to neurosurgical patients, such as postoperative seizures or meningitis. In the same regard, to facilitate more refined risk adjustment in the neurosurgical population, we must collect risk adjustment variables long suspected to be predictors of complications in neurosurgery such as history of prior craniotomies or cranial/spinal radiation or radiosurgery.

These issues highlight the need for neurosurgery-specific databases, which will track relevant complications and comorbidities. Some exciting progress has been made on such databases, particularly with the development of the National Neurosurgery Quality and Outcomes Database (N²QOD), sponsored by the NeuroPoint Alliance and managed by Vanderbilt's Institute for Medicine and Public Health.^{1,2,13} Neurosurgery-specific databases will go a long way in addressing these concerns, and current efforts to prospectively collect neurosurgery-specific data are important steps toward optimizing the care of patients.

Conclusions

Complications endanger patients and deplete scarce health care resources. To defend against complications,

we attempted, first, to understand their prevalence and, second, to identify factors predictive of their occurrence. Analyzing data from more than 38,000 neurosurgical patients in the NSQIP database, we found that the most frequent complications were blood loss requiring transfusion and reoperation within 30 days, followed by failure to wean from mechanical ventilation postoperatively. We also found that complications were more frequent in cranial than in spinal procedures and more likely to occur in African Americans than in whites. The sources of these disparities remain to be determined, and further research with particular attention to complications unique to neurosurgery is clearly necessary. Once we define the most costly and harmful complications, we can begin to rationally direct our quality improvement efforts.

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