Perioperative outcomes for pediatric neurosurgical procedures: analysis of the National Surgical Quality Improvement Program–Pediatrics

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OBJECTIVE Existing studies have shown a high overall rate of adverse events (AEs) following pediatric neurosurgical procedures. However, little is known regarding the morbidity of specific procedures or the association with risk factors to help guide quality improvement (QI) initiatives. The goal of this study was to describe the 30-day mortality and AE rates for pediatric neurosurgical procedures by using the American College of Surgeons (ACS) National Surgical Quality Improvement Program–Pediatrics (NSQIP-Peds) database platform.

METHODS Data on 9996 pediatric neurosurgical patients were acquired from the 2012–2014 NSQIP-Peds participant user file. Neurosurgical cases were analyzed by the NSQIP-Peds targeted procedure categories, including craniotomy/craniectomy, defect repair, laminectomy, shunts, and implants. The primary outcome measure was 30-day mortality, with secondary outcomes including individual AEs, composite morbidity (all AEs excluding mortality and unplanned reoperation), surgical-site infection, and unplanned reoperation. Univariate analysis was performed between individual AEs and patient characteristics using Fischer's exact test. Associations between individual AEs and continuous variables (duration from admission to operation, work relative value unit, and operation time) were examined using the Student t-test. Patient characteristics and continuous variables associated with any AE by univariate analysis were used to develop category-specific multivariable models through backward stepwise logistic regression.

RESULTS The authors analyzed 3383 craniotomy/craniectomy, 242 defect repair, 1811 laminectomy, and 4560 shunt and implant cases and found a composite overall morbidity of 30.2%, 38.8%, 10.2%, and 10.7%, respectively. Unplanned reoperation rates were highest for defect repair (29.8%). The mortality rate ranged from 0.1% to 1.2%. Preoperative ventilator dependence was a significant predictor of any AE for all procedure groups, whereas admission from outside hospital transfer was a significant predictor of any AE for all procedure groups except craniotomy/craniectomy.

CONCLUSIONS This analysis of NSQIP-Peds, a large risk-adjusted national data set, confirms low perioperative mortality but high morbidity for pediatric neurosurgical procedures. These data provide a baseline understanding of current expected clinical outcomes for pediatric neurosurgical procedures, identify the need for collecting neurosurgery-specific risk factors and complications, and should support targeted QI programs and clinical management interventions to improve care of children.

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KEY WORDS risk-adjustment; quality improvement; surgical outcome; National Surgical Quality Improvement Program

ABBREVIATIONS ACS = American College of Surgeons; AE = adverse event; AOR = adjusted OR; ASA = American Society of Anesthesiologists; CI = confidence interval; CPT = Current Procedural Terminology; IQR = interquartile range; NICU = neonatal intensive care unit; NSQIP = National Surgical Quality Improvement Program; NSQIP-Peds = NSQIP-Pediatrics; OR = odds ratio; PICU = pediatric intensive care unit; QI = quality improvement; SSI = surgical site infection; WBC = white blood cell; wRVU = work relative value unit.

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PEDIATRIC neurosurgery has one of the highest morbidity rates among pediatric surgical subspecialties.¹⁵ As health care costs rise, focus has increased on improving surgical outcomes through quality improvement (QI) initiatives. Advancements in the use of large risk-adjusted national databases allow for better delineation of relationships between patient risk factors and quality measures, such as postoperative adverse events (AEs). Understanding these correlations can support targeted QI programs as well as enhance clinical management.

The American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) has created landmark transformations in the ability to reliably predict risk-adjusted postoperative complications for adults.^{4,6} Based on its success in the Veterans Affairs system and the private sector⁷ to provide surgical quality benchmarks and inform QI interventions, the ACS has partnered with the American Pediatric Surgical Association to create a similar database platform for the pediatric population, the National Surgical Quality Improvement Program–Pediatrics (NSQIP-Peds).³ Although NSQIP-Peds has numerous challenges unique to pediatric surgical outcomes, such as low mortality rates, differential clinical weighting of AEs, and the low volume of high-risk procedures, it provides an understanding of expected perioperative outcomes in children.¹²

To date, analysis of pediatric surgical subspecialty outcomes has been limited.¹⁶ Given the high morbidity following pediatric neurosurgical procedures,² a critical analysis in this field at the procedural class level may identify contributors to AEs and identify opportunities for neurosurgical QI initiatives. Sherrod et al. recently reported various postoperative complications to be significant risk factors for unplanned readmission in pediatric neurosurgery using NSQIP-Peds, and identified actionable QI opportunities to mitigate risks of unplanned readmission.¹⁷ However, understanding of risk factors that are either associated with or causative of postoperative complications or unplanned reoperation remains quite limited. The purpose of this study was to describe outcomes following pediatric neurosurgical procedures using NSQIP-Peds. Furthermore, we wanted to identify patient risk factors and differences in measures of efficiency of care and procedural complexity associated with AEs.

Methods

Data Source and Measures

The data source for our study was the 2012–2014 participant use files of the NSQIP-Peds program. Currently, more than 100 hospitals are enrolled in the ACS NSQIP-Peds program. At each participating institution, a systematic sampling process is used to ensure proportional case mix selection through 8-day sampling cycles. Readers are referred to previous reports of the NSQIP for case sampling procedures;^{2,12} however, in brief, 1400 pediatric surgical cases are collected at each participating institution annually based on 40 8-day cycles, during each of which 35 cases are reviewed. The first 10 “essential” cases are collected in consecutive order utilizing the ACS NSQIP-Peds Current Procedural Terminology (CPT) Code inclu-

sion list. The subsequent 25 cases are procedure targeted and assigned to specific services by CPT (American Medical Association) code of the principal operative procedure. Continuing by date/time, each targeted case from the subspecialty CPT code inclusion list is selected until the following service limit is met for each subspecialty: general surgery 10 cases, neurosurgery 3 cases, orthopedic surgery 5 cases, otolaryngology 2 cases, plastic surgery 2 cases, and urological surgery 3 cases. To ensure that 35 cases per reporting cycle are collected each sampling cycle, additional cases in any subspecialty are collected consecutively to fill any service quota that was not met. At each site, a certified Surgical Clinical Reviewer, who received NSQIP-Peds training and quality control supervision to ensure reliable and accurate data capture, collects and enters patient data through medical chart review.¹⁸ More than 150 variables are collected, which include demographic information, preoperative risk factors, intraoperative variables, and 30-day postoperative mortality and morbidity events (“occurrences”) for patients undergoing select surgical procedures.³ The data definitions and methodology for NSQIP-Peds have been described previously, and all occurrences are generally treated as dichotomous variables with unique data fields.^{3,12,13} Data from each institution are submitted electronically to the ACS for processing and compiled into annual participant use files, which are accessible to all participating institutions.

Case Selection

As a study using only de-identified data, this project was granted exemption from review by the Duke University Institutional Review Board. Inclusion criteria for this study were any child (under 19 years of age) undergoing any neurosurgical procedures accrued within the data set.¹² Any child with incomplete age data was excluded from the study. Pediatric neurosurgical cases were defined using CPT codes that are within the ACS NSQIP-Peds data set. Patients were delineated into the NSQIP-Peds designated neurosurgical procedure categories as used in January 2015: craniotomy/craniectomy, defect repair, laminectomy, and shunts and implants. Only CPT codes with captured patient cases were presented and analyzed. For example, in the defect repair procedure category, 7 CPT codes are included in this procedure targeted list, but only CPT codes 63704 and 63706, both for myelomeningocele repair, had recorded cases, whereas the others (CPT 61680, 61682, 61684, 61686, and 62201) had no reported cases. CPT codes for craniotomy/craniectomy (percentage of case volume in that category, in decreasing order) include: 61343 (33.8%), 61510 (21.5%), 61518 (16.8%), 61559 (14.6%), 61550 (6.2%), 61557 (3.8%), 61558 (2.1%), and 61545 (1.2%). CPT codes for defect repairs include: 63706 (51.7%) and 63704 (48.3%). CPT codes for laminectomy include: 63200 (87.1%), 63272 (6.2%), 63287 (2.2%), 63286 (2.0%), 63285 (1.9%), and 63273 (0.6%). CPT codes for shunts and implants include: 62230 (34.0%), 62223 (23.8%), 62225 (19.1%), 62258 (9.1%), 61210 (7.2%), and 62362 (6.8%). Note that no cases were extracted for the epilepsy category, because the CPT codes (61885, 61888, 64568, 64569) for this procedure group were only recently added to the NSQIP-Peds CPT code inclusion list.

Outcome Measures

Our primary outcome measure was 30-day mortality. Secondary outcomes were individual 30-day AEs as well as composite morbidity as previously defined¹⁵: superficial, deep, and organ space surgical site infections (SSI), superficial and deep wound dehiscence, systemic inflammatory response syndrome/sepsis/septic shock, unplanned reintubation, pneumonia, ventilator dependence > 24 hours, pulmonary embolism, cardiac arrest, urinary tract infection, progressive renal insufficiency, acute renal failure, cerebrovascular accident, coma for > 24 hours, seizure, nerve injury, venous thromboembolism, and intra- or postoperative blood transfusion.

SSIs were analyzed as a separate individual outcome. In addition, unplanned reoperation, which traditionally has not been included in measures of composite morbidity, was evaluated as an individual outcome, given its increasing use as a proxy for surgical quality in neurosurgery.^{9,10,19} Unplanned reoperation as defined by the NSQIP-Peds protocol excludes cases with preoperative or intraoperative documentation that specifies the need for a patient to return to the operating room following the principal operative procedure, such as return to the operating room for planned CSF diversion following repair of a spinal defect. Finally, we summarized patients who experienced any of the previously mentioned AEs, including unplanned reoperation. Each patient was only counted once, regardless of the total number of AEs experienced.

System Efficiency and Procedural Complexity Measures

Measures of efficiency of care included length of stay and time to operation since admission. These variables, along with other process measures, are increasingly used as proxies for quality of care and for their contribution to patient outcome.⁵ Measures of procedural complexity included work relative value unit (wRVU) and total operation time.

Laboratory Data

Collected laboratory data included baseline albumin, alkaline phosphatase, bilirubin, blood urea nitrogen, creatinine, hematocrit, international normalized ratio, platelets, partial thromboplastin time, prothrombin time, serum glutamic oxaloacetic transaminase, sodium, and white blood cells (WBCs).

Statistical Analysis

Statistical analyses were performed using Stata version 14.0 (Stata Corp). Associations of patient risk factors with the occurrence of any AE were analyzed with cross-tabulation and the Fisher's exact test. Univariate associations significant at the $p < 0.05$ level were used to construct multivariable models. Continuous variables (admission to operation days, length of hospital stay, operation time, and wRVU) are represented by their median with observed interquartile range (IQR), or by their means $\pm$ standard deviation as appropriate. Associations between continuous variables and any AE were first analyzed using the Student t-test, with variables having a p value < 0.05 entered into each category-specific multivariable model with

the exception of length of stay, which was only presented as a descriptive statistic. Adjusted odds ratios (ORs), 95% confidence intervals (CIs), and p values were generated using backward stepwise multivariable logistic regression analysis at the $p < 0.05$ level.

Because of a substantial amount of missing laboratory data, we did not include any laboratory variable for multivariable analysis. Only hematocrit, platelets, and WBC variables had fewer than 33% missing data, and we compared these variables between patients with no AEs versus patients with any AE by using the Student t-test.

For the craniotomy/craniectomy category, 11 patients were excluded out of 3382 cases for multivariable analysis due to missing data for American Society of Anesthesiologists (ASA) Class 4 or 5 (10 data points missing) and operation time (1 data point missing). In the defect repair category, 1 case was excluded out of 242 cases in the multivariable model due to missing data for ASA Class 4 or 5. In the laminectomy category, no data were missing, and all 1811 cases were included in the multivariable model. In the shunts and implants category, no data were missing, and all 4560 cases were included in the multivariable model.

Results

Demographics

Data for a total of 9996 children who underwent an NSQIP-Peds targeted neurosurgical procedure between 2012 and 2014 were included in the analysis (Table 1). Among children who underwent a craniotomy/craniectomy procedure ($n = 3383$), the median patient age was 5.8 years (IQR 1.3–12.4 years), 55.2% were male, 76.5% were Caucasian, 9.7% were preterm, and 2.8% had ASA Class 4 or 5. The predominant admission source was from home with 85.5% of patients, and 8.2% were urgent or emergency cases. Among children who underwent a defect repair procedure, the median patient age was 1 day (IQR 1–1 day), 54.5% were male, 74.0% were Caucasian, 18.2% were preterm, and 9.9% were ASA Class 4 or 5. More than half were outside hospital transfers (newborn intensive care unit [NICU], pediatric intensive care unit [PICU], inpatient), and urgent and emergency cases accounted for nearly 60% of all cases. Among children who underwent a laminectomy procedure, the median patient age was 5.5 years (IQR 1.4–10.3 years), 46.5% were male, 78.4% were Caucasian, 16.9% were preterm, and 0.7% had ASA Class 4 or 5. The predominant admission source was from home (97.6%), and urgent and emergency cases accounted for 1.5%. Among children who underwent shunt and implant procedures, the median age was 6.8 years (IQR 0.9–12.3 years), 56.8% were male, and 69.8% were Caucasian, with African American children representing a larger proportion than in other procedure categories with 18.7%. Only 5.3% were preterm, and ASA Class 4 or 5 was noted in 6% of patients. A significant source of admission in this procedure category came from emergency rooms (40.1%) and home (48.2%). Urgent and emergency cases also represented a higher proportion than in other categories (46.7%).

Patient Risk Factors

For all categories, more than 85% of patients had no

TABLE 1. Demographic information by NSQIP-Peds neurosurgical procedure categories

Demographics	Craniotomy/Craniectomy (%)	Defect Repairs (%)	Laminectomy (%)	Shunts & Implants (%)
Total cases	3383 (100)	242 (100)	1811 (100)	4560 (100)
Male sex	1867 (55.2)	132 (54.5)	842 (46.5)	2588 (56.8)
Hispanic ethnicity	388 (11.5)	31 (12.8)	217 (12)	462 (10.1)
Race				
Caucasian	2589 (76.5)	179 (74.0)	1420 (78.4)	3184 (69.8)
African American	319 (9.4)	26 (10.7)	128 (7.1)	852 (18.7)
Asian	65 (1.9)	1 (0.4)	81 (4.5)	69 (1.5)
Pacific Islander	7 (0.2)	1 (0.4)	4 (0.2)	11 (0.2)
Native American	23 (0.7)	1 (0.4)	9 (0.5)	27 (0.6)
Other	380 (11.2)	34 (14.1)	169 (9.3)	417 (9.1)
Age				
<29 days	11 (0.3)	220 (90.9)	19 (1)	280 (6.1)
29–364 days	936 (27.7)	12 (5)	346 (19.1)	939 (20.6)
1–5 yrs	936 (27.7)	5 (2.1)	598 (33)	1117 (24.5)
6–12 yrs	930 (27.5)	4 (1.7)	612 (33.8)	1242 (27.2)
13–18 yrs	738 (21.8)	1 (0.4)	236 (13)	982 (21.5)
Preterm birth*	327 (9.7)	44 (18.2)	306 (16.9)	241 (5.3)
ASA class				
1	240 (7.1)	7 (2.9)	164 (9.1)	57 (1.3)
2	1487 (44)	70 (28.9)	1042 (57.5)	1304 (28.6)
3	1550 (45.8)	140 (57.9)	592 (32.7)	2917 (64)
4 or 5	96 (2.8)	24 (9.9)	12 (0.7)	272 (6.0)
Wound classification				
Clean	3330 (98.4)	153 (63.2)	187 (10.3)	4340 (95.2)
Clean/contaminated	43 (1.3)	48 (19.8)	22 (1.2)	128 (2.8)
Contaminated	5 (0.1)	37 (15.3)	0 (0)	20 (0.4)
Dirty/infected	5 (0.1)	4 (1.7)	2 (0.1)	72 (1.6)
Origin of admission				
Home	2891 (85.5)	62 (25.6)	1767 (97.6)	2199 (48.2)
Emergency department	395 (11.7)	5 (2.1)	25 (1.4)	1827 (40.1)
Chronic care facility	1 (0)	1 (0)	0 (0)	14 (0.3)
Outside hospital†	7 (0.2)	127 (52.5)	2 (0.1)	82 (1.8)
Other	89 (2.6)	48 (19.8)	17 (0.9)	438 (9.6)
Inpatient	3225 (95.3)	236 (97.5)	1767 (97.6)	4184 (91.8)
Case status				
Elective	3105 (91.8)	101 (41.7)	1785 (98.6)	2432 (53.3)
Emergency	121 (3.6)	79 (32.6)	10 (0.6)	1241 (27.2)
Urgent	157 (4.6)	62 (25.6)	16 (0.9)	887 (19.5)

Data summarize a number of cases within a subgroup of each category (with percentages).

* Preterm was defined as any infant who was born at less than 37 weeks' gestation.

† Outside hospital includes NICU, PICU, and inpatient.

cardiac risk factors (Table 2). Nutritional support was predominantly found in defect repairs (17.4%) and shunt and implant (17.6%) categories. Pulmonary conditions varied across categories, with the craniotomy/craniectomy and laminectomy categories having the largest proportion of patients with asthma, the defect repair category having the greatest proportion of patients needing oxygen and ventilator support, and the shunts and implants category having the largest proportion of patients with chronic lung

disease. The two most prevalent hematological and immunological conditions, cancer and preoperative steroid use, were the same for craniotomy/craniectomy, laminectomy, and shunt and implant categories, whereas for the defect repair category it was hematological disorder. Esophageal gastrointestinal disease was a common risk factor for laminectomy (16.7%) and shunts and implants (19.4%). More than 99.8% of patients did not have any renal conditions for all categories. Previous operation was among the top

TABLE 2. Patient risk factors and measures of system efficiency and procedure complexity by NSQIP-Peds neurosurgical procedure categories

Patient Risk Factors	Craniotomy/ Craniectomy (%)	Defect Repairs (%)	Laminectomy (%)	Shunts & Implants (%)
Total cases	3383 (100)	242 (100)	1811 (100)	4560 (100)
Cardiovascular conditions				
Congenital cardiac RF				
No cardiac RF	3226 (95.4)	208 (86)	1577 (87.1)	3932 (86.2)
Minor cardiac RF	106 (3.1)	14 (5.8)	159 (8.8)	458 (10)
Major cardiac RF	45 (1.3)	18 (7.4)	66 (3.6)	142 (3.1)
Severe cardiac RF	6 (0.2)	2 (0.8)	9 (0.5)	28 (0.6)
Previous cardiac surgery	56 (1.7)	2 (0.8)	73 (4)	255 (5.6)
Metabolic & nutritional conditions				
Diabetes	10 (0.3)	0 (0)	3 (0.2)	13 (0.3)
Preop 10% weight loss	50 (1.5)	0 (0)	37 (2)	141 (3.1)
Nutritional support	88 (2.6)	42 (17.4)	79 (4.4)	804 (17.6)
Pulmonary conditions				
Asthma	184 (5.4)	0 (0)	115 (6.4)	301 (6.6)
Structural pulmonary abnormality	122 (3.6)	5 (2.1)	87 (4.8)	276 (6.1)
Preop oxygen support	75 (2.2)	29 (12)	26 (1.4)	375 (8.2)
Preop ventilator dependence	71 (2.1)	23 (9.5)	13 (0.7)	262 (5.7)
Preop tracheostomy	24 (0.7)	0 (0)	21 (1.2)	142 (3.1)
History of chronic lung disease	36 (1.1)	2 (0.8)	40 (2.2)	520 (11.4)
Cystic fibrosis	1 (0)	0 (0)	0 (0)	6 (0.1)
Preop pneumonia	3 (0.1)	1 (0.4)	0 (0)	18 (0.4)
Hematological & immunological conditions				
Bleeding disorder	19 (0.6)	0 (0)	8 (0.4)	38 (0.8)
Hematological disorder	55 (1.6)	2 (0.8)	21 (1.2)	198 (4.3)
Preop transfusion	33 (1)	1 (0.4)	1 (0.1)	58 (1.3)
Immune disorder	37 (1.1)	0 (0)	9 (0.5)	40 (0.9)
Preop steroid use	484 (14.3)	1 (0.4)	36 (2)	295 (6.5)
Current cancer	791 (23.4)	0 (0)	46 (2.5)	248 (5.4)
Chemotherapy	54 (1.6)	0 (0)	5 (0.3)	82 (1.8)
Radiotherapy	12 (0.4)	0 (0)	0 (0)	25 (0.5)
Bone marrow transplant	20 (0.6)	0 (0)	0 (0)	1 (0)
Organ transplant	3 (0.1)	0 (0)	0 (0)	2 (0)
Neurological conditions				
CNS structural abnormality	1850 (54.7)	222 (91.7)	1427 (78.8)	3861 (84.7)
Cerebral palsy	24 (0.7)	2 (0.8)	48 (2.7)	781 (17.1)
CNS tumor	1116 (33)	0 (0)	88 (4.9)	373 (8.2)
Preop coma	3 (0.1)	0 (0)	0 (0)	2 (0)
Neuromuscular disease	165 (4.9)	24 (9.9)	205 (11.3)	570 (12.5)
Developmental delay	515 (15.2)	4 (1.7)	399 (22)	1789 (39.2)
Preop seizure history	381 (11.3)	3 (1.2)	78 (4.3)	1133 (24.8)
IVH Grade 3 or 4	38 (1.1)	6 (2.5)	13 (0.7)	979 (21.5)
Preop CVA	90 (2.7)	1 (0.4)	27 (1.5)	517 (11.3)
Gastrointestinal conditions				
ESOVAR	282 (8.3)	9 (3.7)	302 (16.7)	883 (19.4)
Hepatobiliary pancreatic disease	9 (0.3)	0 (0)	11 (0.6)	43 (0.9)
Renal conditions				
Preop renal failure	0 (0)	0 (0)	1 (0.1)	2 (0)
Preop dialysis	1 (0)	0 (0)	0 (0)	3 (0.1)

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TABLE 2. Patient risk factors and measures of system efficiency and procedure complexity by NSQIP-Peds neurosurgical procedure categories

Patient Risk Factors	Craniotomy/ Craniectomy (%)	Defect Repairs (%)	Laminectomy (%)	Shunts & Implants (%)
Acuity of condition				
Preop open wound	5 (0.1)	134 (55.4)	9 (0.5)	80 (1.8)
Previous op 30 days	89 (2.6)	2 (0.8)	8 (0.4)	320 (7)
Preop sepsis 48 hrs	14 (0.4)	1 (0.4)	1 (0.1)	132 (2.9)
Periop inotropic support	34 (1)	2 (0.8)	9 (0.5)	39 (0.9)
Preop CPR	7 (0.2)	1 (0.4)	0 (0)	14 (0.3)
Do not resuscitate	1 (0)	0 (0)	0 (0)	9 (0.2)

CPR = cardiopulmonary resuscitation; CVA = cerebrovascular accident; ESOVAR = esophageal gastric intestinal disease; IVH = intraventricular hemorrhage; RF = risk factor.

two most common acuity conditions for craniotomy/craniectomy, laminectomy, and shunts and implants, whereas for defect repair it was preoperative open wound (55.4%).

The most common patient risk factor, CNS structural abnormality, was similar for all 4 procedure categories, with more than half of the patients having this comorbidity (Table 2). For all categories, at least 2 of the most common patient risk factors were neurological. Following a CNS

structural abnormality, developmental delay was a common risk factor for all categories, except defect repair.

System Efficiency and Procedural Complexity Measures

For analysis of measures of system efficiency, we found that a longer duration from admission to operation was associated with any AE for craniotomy/craniectomy (mean duration 0.6 days for no AE vs 1.1 days for any AE, $p <$

TABLE 3. Efficiency and procedure complexity by NSQIP-Peds neurosurgical procedure categories

Clinical Factors†	AE		p Value*	
	None	Any	Unadjusted	Adjusted
Craniotomy/craniectomy				
Admission to op (days)	0.6 ± 2.3	1.1 ± 4.3	<0.001	0.049
Length of hospital stay (days)	4.5 ± 4.7	8.3 ± 11.3	—	—
wRVU	32.2 ± 5.3	31.8 ± 6.8	0.046	0.503
Op time (mins)	185.8 ± 105.7	246.4 ± 146.3	<0.001	<0.001
Defect repair				
Admission to op (days)	1.1 ± 1.7	3.2 ± 17.7	0.207	NS
Length of hospital stay (days)	11.8 ± 8.2	18.5 ± 14.3	—	—
wRVU	23.8 ± 1.5	24.0 ± 1.5	0.319	NS
Op time (mins)	108.9 ± 67.4	115.1 ± 70.0	0.489	NS
Laminectomy				
Admission to op (days)	0.1 ± 1.9	0.8 ± 5.3	0.007	0.605
Length of hospital stay (days)	2.9 ± 3.1	6.3 ± 7.1	—	—
wRVU	22.7 ± 4.0	24.1 ± 5.8	<0.001	0.174
Op time (mins)	117.8 ± 89.8	188.3 ± 129.1	<0.001	<0.001
Shunts and implants				
Admission to op (days)	2.5 ± 13.3	9.1 ± 23.2	<0.001	0.001
Length of hospital stay (days)	5.3 ± 11.2	16.8 ± 25.1	—	—
wRVU	10.7 ± 3.5	10.4 ± 3.7	0.049	0.001
Op time (mins)	58.0 ± 39.4	61.2 ± 56.5	0.032	0.001

NS = variable did not meet the $p < 0.05$ criterion for entry into the multivariable model; hence, no adjusted OR was computed.

Continuous variables expressed as mean ± SD. Boldface type indicates statistical significance.

* Unadjusted p value generated from Student t-test analysis to identify significant differences in variable means between groups with no AE versus groups with any AE. Adjusted p value generated by backward stepwise multivariable logistic regression analysis for any AE with variable entry level $p < 0.05$. This adjustment accounts for other covariate risk factors that may affect the relationship between AEs and the variable of interest.

† Length of hospital stay is represented as a descriptive statistic, because it is partially an outcome measure.

0.001) and shunts and implants (mean duration 2.5 days for no AE vs 9.1 days for any AE, $p < 0.001$) (Table 3). The mean length of hospital stay for craniotomy/craniectomy was 4.5 days for no AE versus 8.3 days for any AE. For defect repair, the mean duration was 11.8 days for no AE versus 18.5 days for any AE, for laminectomy it was 2.9 days for no AE versus 6.3 days for any AE, and for shunts and implants it was 5.3 days for no AE versus 16.8 days for any AE (Table 3). For procedural complexity, a longer total operation time was associated with any AE based on multivariable analysis for craniotomy/craniectomy (mean 185.8 minutes for no AE vs 246.4 minutes for any AE, $p < 0.001$), laminectomy (mean 117.8 minutes for no AE vs 188.3 minutes for any AE, $p < 0.001$), and shunts and implants (mean 58.0 minutes for no AE vs 61.2 minutes for any AE, $p = 0.032$; Table 3). Work RVU was associated with any AE on multivariable analysis for the shunts and implants category (mean 10.7 for no AE vs 10.4 for any AE, $p = 0.049$; Table 3).

Adverse Events

Defect repair category had the highest occurrence of

AEs, with 52.9% suffering at least 1 AE (Table 4). Laminectomy category had the lowest occurrence of AEs, with 11.1% of patients experiencing any AE. Mortality rates were under 1% in all categories, with the exception of defect repair, which had a mortality rate of 1.2%. For all procedure categories except laminectomy, unplanned reoperation represented a significant portion of AEs. The highest rate of unplanned reoperation was seen in defect repairs (29.8%) followed by shunts and implants (13.2%) and craniotomy/craniectomy (6.2%). The most common AE for craniotomy/craniectomy was bleeding requiring transfusion (24.2%), which was relatively less common for the other procedure categories. In both defect repair and shunts and implants, ventilator dependence greater than 24 hours represented the most common AE at 24.4% and 5.8%, respectively. For laminectomy, SSI and wound dehiscence were the most common AEs.

Predictors of AEs

Using findings from univariate analysis, we identified risk factors that were associated with any AE by multivariable analysis (Table 5). For craniotomy, 10 risk fac-

TABLE 4. Adverse events by NSQIP-Peds neurosurgical procedure categories

Clinical Outcomes	Craniotomy/Craniectomy (%)	Defect Repairs (%)	Laminectomy (%)	Shunts & Implants (%)
Total cases	3383	242	1811	4560
Any adverse event	1091 (32.2)	128 (52.9)	201 (11.1)	889 (19.5)
Mortality	13 (0.4)	3 (1.2)	1 (0.1)	18 (0.4)
Unplanned reop	209 (6.2)	72 (29.8)	73 (4)	602 (13.2)
SSI	62 (1.8)	12 (5)	67 (3.7)	114 (2.5)
Superficial	28 (0.8)	6 (2.5)	47 (2.6)	21 (0.5)
Deep	5 (0.1)	2 (0.8)	14 (0.8)	7 (0.2)
Organ-space infection	29 (0.9)	4 (1.7)	6 (0.3)	89 (2)
Composite morbidity	1022 (30.2)	94 (38.8)	185 (10.2)	489 (10.7)
Superficial SSI	28 (0.8)	6 (2.5)	47 (2.6)	21 (0.5)
Deep SSI	5 (0.1)	2 (0.8)	14 (0.8)	7 (0.2)
Organ-space infection	29 (0.9)	4 (1.7)	6 (0.3)	89 (2)
Superficial wound dehiscence	33 (1)	13 (5.4)	37 (2)	26 (0.6)
Deep wound dehiscence	33 (1)	18 (7.4)	43 (2.4)	25 (0.5)
SIRS/sepsis/septic shock	25 (0.7)	1 (0.4)	10 (0.6)	37 (0.8)
Unplanned reintubation	32 (0.9)	10 (4.1)	4 (0.2)	37 (0.8)
Pneumonia	10 (0.3)	0 (0)	1 (0.1)	21 (0.5)
Ventilator dependence >24 hrs	177 (5.2)	59 (24.4)	24 (1.3)	265 (5.8)
Pulmonary embolism	0 (0)	0 (0)	0 (0)	0 (0)
Cardiac arrest	1 (0)	0 (0)	0 (0)	5 (0.1)
Urinary tract infection	22 (0.7)	5 (2.1)	34 (1.9)	33 (0.7)
Progressive renal insufficiency	0 (0)	0 (0)	0 (0)	2 (0)
Acute renal failure	0 (0)	0 (0)	0 (0)	0 (0)
Cerebrovascular accident	25 (0.7)	0 (0)	0 (0)	13 (0.3)
Coma for >24 hrs	2 (0.1)	0 (0)	0 (0)	1 (0)
Seizure	33 (1)	3 (1.2)	1 (0.1)	33 (0.7)
Nerve injury	7 (0.2)	0 (0)	1 (0.1)	1 (0)
Venous thromboembolism	6 (0.2)	0 (0)	0 (0)	7 (0.2)
Intra/postop blood transfusion	820 (24.2)	10 (4.1)	21 (1.2)	53 (1.2)

SIRS = systemic inflammatory response syndrome.

TABLE 5. Multivariable analysis of predictors of any adverse event by NSQIP-Peds neurosurgical procedure categories

Risk Factor	Craniotomy/Craniectomy			Defect Repair			Laminectomy			Shunts/Implants		
	AOR	95% CI	p Value	AOR	95% CI	p Value	AOR	95% CI	p Value	AOR	95% CI	p Value
Male							0.7	0.5–0.9	0.012			
Age												
<29 days	9.0	1.9–42.3	0.005									
29–364 days	26.3	19.1–36.1	<0.001									
1–5 yrs	5.0	3.7–6.8	<0.001									
6–12 yrs	1.5	1.1–2.1	0.014									
13–18 yrs	1.0		Ref									
ASA Class 4 or 5	2.3	1.3–4.1	0.004	3.8	1.3–11.0	0.014						
Admission origin												
Home				1.0		Ref	1.0		Ref	1.0		Ref
Emergency department				0.4	0.0–3.9	0.408	2.5	1.0–6.4	0.049	1.3	1.1–1.6	0.01
Chronic care				2.2	1.1–4.3	0.018	11.7	4.1–33.2	<0.001	1.9	0.6–6.2	0.271
Hospital*				2.3	1.0–5.1	0.048	14.3	0.9–230.9	0.062	1.8	1.4–2.4	<0.001
Inpatient										1.6	1.2–2.2	0.005
Case status												
Elective	1.0		Ref							1.0		Ref
Emergency	1.7	1.1–2.7	0.027							1.3	1.1–1.6	0.005
Urgent	1.8	1.2–2.6	0.0006							1.1	0.9–1.3	0.476
Congenital CRF												
None										1.0		Ref
Minor										1.3	1.0–1.6	0.041
Major										1.4	0.9–2.1	0.115
Severe										1.5	0.6–3.6	0.385
Preop 10% weight loss	2.2	1.1–4.5	0.035									
Nutritional support										2.0	1.6–2.4	<0.001
Preop oxygen support										1.5	1.1–2.0	0.005
Preop ventilator dependence	6.9	3.5–13.5	<0.001	4.3	1.3–13.8	0.016	69.8	8.7–562.6	<0.001	6.4	4.5–9.0	<0.001
Preop tracheostomy	4.9	1.4–17.3	0.015									
Preop transfusion										3.4	1.7–6.9	0.001
Chemotherapy	3.0	1.5–5.7	0.001									
CNS structural abnormality				0.3	0.1–0.9	0.032						
Cerebral palsy										0.8	0.6–0.9	0.009
CNS tumor										1.5	1.1–1.9	0.003
Development delay	1.5	1.2–2.0	0.001				1.9	1.3–2.7				
Preop seizure history	0.5	1.2–2.0	<0.001									
IVH Grade 3 or 4	2.8	1.3–6.2	0.01									
Preop sepsis 48 hr										1.9	1.3–2.7	0.02
Do not resuscitate										5.0	1.1–22.3	0.037
Admit to op (days)	1.04†		0.049							1.01†		0.001
wRVU										0.96†		0.001
Total op time (min)	1.01†		<0.001				1.01†		<0.001	1.01†		0.001

CRF = cardiac risk factor; Ref = reference.

Adjusted OR, 95% CI, and p value generated from multivariable logistic regression of 30-day postoperative any AEs with stepwise elimination of variables not significant at the $p < 0.05$ level. Multivariable models were controlled for demographic, patient risk factor, and continuous variable covariates listed in Tables 1 and 2. Empty cells represent risk factors that were not significant at the $p < 0.05$ level on stepwise multivariable analysis.

* Outside hospital.

† System efficiency and procedure complexity measures are continuous variables. This explains the nature of the marginal increase in odds of incurring any AE for each variable unit increase (i.e., days, wRVU, and minutes).

tors (in decreasing order of adjusted OR [AOR]) were associated with any AE: age (29–364 days, AOR 26.3; < 29 days, AOR 9.0; 1–5 years, AOR 5.0; 6–12 years, AOR 1.5; reference 13–18 years), ventilator dependence (AOR 6.9), preoperative tracheostomy (AOR 4.9), chemotherapy (AOR 3.0), intraventricular hemorrhage Grade 3 or 4 (AOR 2.8), ASA Class 4 or 5 (AOR 2.3; reference ASA Class 1–3), preoperative weight loss (AOR 2.2), case status (urgent, AOR 1.8; emergency, AOR 1.7; reference, elective), developmental delay (AOR 1.5), and seizure history (AOR 0.5). Four patient risk factors (in decreasing order of AOR) were associated with any AE for defect repair: ventilator dependence (AOR 4.3), ASA Class 4 or 5 (AOR, 3.8; reference ASA Class 1–3), origin of admission (outside hospital, AOR 2.3; chronic care facility, AOR 2.2; reference, home), and CNS structural abnormality (AOR 0.3). Four patient risk factors (in decreasing order of AOR) were associated with any AE for laminectomy: ventilator dependence (AOR 69.8), origin of admission (outside hospital, AOR 14.3; chronic care facility, AOR 11.7; emergency department, AOR 2.5; reference, home), developmental delay (AOR 1.9), and female sex (AOR 1.3). Eleven patient risk factors (in decreasing order of AOR) were associated with any AE for shunts and implants: ventilator dependence (AOR 6.4), do not resuscitate status (AOR 5.0), preoperative transfusion (AOR 3.4), nutritional support (AOR 2.0), sepsis (AOR 1.9), origin of admission (chronic care facility, AOR 1.9; outside hospital, AOR 1.8; emergency department, AOR 1.3; reference, home), CNS tumor (AOR 1.5), oxygen supplementation (AOR 1.5), cardiac risk factors (severe, AOR 1.5; major, AOR 1.4; minor, AOR 1.3; reference, no cardiac risk factors), inpatient (AOR 1.6), and case status (emergency, AOR 1.3; urgent, AOR 1.1; reference, elective). With regards to system efficiency, after accounting for all covariates, admission to operation time was retained as a significant predictor of AEs for the following procedure categories: craniotomy/craniectomy and shunts/implants. Use of this adjustment demonstrates that independent of the patient's risk factor level, a longer admission to operation time significantly correlated with any AE. For procedure complexity, operation time significantly correlated with any AE for craniotomy/craniectomy, laminectomy, and shunts/implants procedure category, independent of the patient's risk factor (Table 3).

Laboratory Data

For all procedure categories, except laminectomy, only select laboratory variables (hematocrit, platelets, and WBC) had fewer than 33% missing data and were included in our analysis. Hematocrit (mean $\pm$ SD gm/dl) was associated with any AE by univariate analysis for craniotomy/craniectomy (37.6 ± 4.1 for no AE vs 35.3 ± 4.1 for any AE, $p < 0.001$) and shunts and implants (37.7 ± 5.3 for no AE vs 36.4 ± 6.3 for any AE, $p < 0.001$). Platelet (mean $\pm$ SD $\times 10^3/\mu\text{l}$), was associated with any AE on univariate analysis for craniectomy (301.3 ± 96.4 for no AE vs 345.8 ± 113.6 for any AE, $p < 0.001$) and defect repair (270.9 ± 110 for no AE vs 232.6 ± 72.8 for any AE, $p = 0.004$). WBC count (mean $\pm$ SD $\times 10^3/\mu\text{l}$) was associated with any AE on univariate analysis for craniotomy/craniectomy

(8.0 ± 3.2 for no AE vs 9.7 ± 4.0 for any AE, $p < 0.001$) and shunts and implants (9.4 ± 4.0 for no AE vs 10.5 ± 5.1 for any AE, $p < 0.001$).

Discussion

To our knowledge, studies using the ACS NSQIP-Peds platform to describe perioperative mortality and morbidity for various pediatric neurosurgical procedure categories have been limited. We presented a broad national landscape of patients who underwent an NSQIP-Peds targeted pediatric neurosurgical procedure between 2012 and 2014. Our analysis should help neurosurgeons, intensivists, and hospital administrative staff guide clinical care and QI initiatives.

We found that the rate of AEs varied widely by procedure category, with the highest rates following defect repair followed by craniotomy/craniectomy, shunts and implants, and laminectomy. These rates are higher than previously reported by Saito et al. in their overview of all NSQIP-Peds procedures,¹⁵ although their analyses did not include the occurrences of unplanned reoperation. There is an increased emphasis to include unplanned reoperation measures into surgical quality assessments, which is especially pertinent in pediatric and adult neurosurgery where high rates of reoperation often are required to address important complications, such as postoperative intracranial bleeding and shunt failures.^{9,10,19} In addition, we found the composite morbidity for craniotomy/craniectomy and defect repairs higher than previously reported.¹⁵ These 2 procedures had high rates of bleeding, requiring transfusion and ventilator dependence > 24 hours. Although the overall rate of AEs following laminectomy was relatively low, the major contributors to composite morbidity were SSI and wound dehiscence, which represented a greater proportion than in other procedure categories. For the shunts and implants, the major contributor to its postoperative complications was unplanned reoperation.

We found the frequency of unplanned reoperations highest in the defect repair (29.8%) and shunt and implant (13.2%) categories, suggesting that these procedures may carry significant risks of neurosurgical complications. Our results are consistent with a similar high rate of unplanned reoperation following other types of adult and pediatric neurosurgical procedures.⁸ In a study looking at risk factors for unplanned readmission in pediatric neurosurgery, Sherrod et al. found shunts and implants (16.8%) and myelomeningocele repair (14.4%) to have the 2 highest rates.¹⁷ Although only looking at unplanned readmission may fail to capture patients having AEs needing reoperation during their initial stay, this finding supports our conclusion that these 2 procedure categories are associated with a significantly higher risk of subsequent unplanned interventions. In their study, SSIs were found to be the most significant risk factor for unplanned readmission. Interpreting our results in this context allows the identification of the specific risk factors for SSIs and other AEs across varying procedure categories, which provides health care teams to better anticipate and manage the risk of these AEs and unplanned readmission and reoperation.

A comparison of mortality and morbidity with that in

other pediatric surgical subspecialties would be helpful to guide multidisciplinary QI initiatives and quality benchmarking. However, to date the most comprehensive assessment using NSQIP-Peds has been limited to the specialty level of analysis, and more granular assessment (by procedures) or procedure class is needed to guide QI efforts. Saito et al. found that pediatric neurosurgery had the highest rate of morbidity, not accounting for unplanned reoperation, across all pediatric subspecialties: general surgery (7.0%), neurosurgery (13.6%), orthopedic surgery (2.4%), otolaryngology (2.0%), plastic surgery (10.0%), and urological surgery (3.1%).¹⁵

There are several notable differences in the AE types between pediatric and adult neurosurgical patients. For adult neurosurgical patients, common AEs include postoperative pneumonia, ventilator dependence > 48 hours, urinary tract infections, deep venous thrombosis, and reoperation within 30 days.¹⁴ In contrast, children have a different profile of complication types as well as risk factors. Mortality is generally a rare occurrence in the pediatric neurosurgical setting, similar to other pediatric surgical subspecialties.^{2,3,13} Our mortality findings are consistent with previously reported figures of 0.8% for pediatric neurosurgery.¹⁵ The higher rate (1.2%) noted in defect repair, as compared with below 1.0% noted in the other 3 procedure categories, is likely due to the low occurrence ($n = 3$) and low case volume ($n = 242$).

Efficiency measures such as delays in care are increasingly recognized as important attributes of health care quality. We found that patients who suffered AEs following craniotomy/craniectomy as well as shunt and implant procedures were more likely to have had a delay in surgery. Although this association does not confirm causation, this is not a trivial finding, because the presence of any AE is also associated with a longer length of hospitalization. Further analysis may help identify whether these differences result from the patient's risk profile, clinical management, or operational efficiencies of a hospital system. Some of these outcomes may be related to procedure complexity, as we noted a longer total operation time in patients who had an AE compared with those who did not experience any AE for most categories. An association between AEs and wRVU was only observed in shunts and implants, suggesting that wRVU may not serve as an accurate predictor of postoperative complication for most procedures. Measures such as wRVU values themselves have too many confounders to use for prediction of complications, because wRVUs are not only based on a physician's time and effort, but also incorporate input from procedure expense and professional liability insurance. In most studies, the use of wRVU alone for surgical risk prediction has not shown consistency, because it often does not account for anatomical or procedural variations among operations with similar RVUs.¹ Similar to most studies, our study demonstrated that despite the use of wRVU within a distinct CPT procedure range, the case mix complexity was not accurately captured in risk prediction.^{3,11}

Many of the predictors of AEs were expected, such as ASA Class 4 or 5 and preoperative ventilator dependence, because they are considered high-risk comorbidities as noted in other surgical specialties.¹⁵ However, many neu-

rological risk factors (such as neuromuscular disease) that were associated with AEs by univariate analysis did not retain their significance on multivariable analysis. Future modeling that accounts for procedure-specific risk factors, efficiency measures, and procedural complexities may serve to be a more holistic risk prediction model that has better clinical value. Many of the predictors of AEs are reflective of underlying patient characteristics and are not readily remediable, although they may serve to delineate the risk profile within a specific patient population. In addition, having a full understanding of the patient's risk profile preoperatively may allow medical teams to better anticipate and prepare for specific postoperative AEs.

Several limitations exist in this study, many of which are inherent to analysis of a large surgical outcome data set. A major strength of NSQIP-Peds is its protocolized sampling and use of standardized outcome definitions. However, several limitations exist to these processes as they pertain to pediatric neurosurgical patients. First, epilepsy CPT codes were only recently added to NSQIP-Peds collection protocols, and future studies should investigate the outcomes in this increasingly common category. Second, many important AEs experienced by neurosurgical patients are not directly captured within NSQIP-Peds, such as shunt infections, meningitis, CSF leakage, intracranial bleeding, and seizures. Similarly, certain AEs, such as postoperative ventilator dependence > 24 hours, may be normal clinical practice for some children undergoing neurosurgical procedures, and are therefore not an appropriate measure of quality. For example, some neonates have brain swelling or brainstem abnormality as part of their defect repair and are commonly kept intubated longer than 24 hours. Third, many of the perioperative complications often observed in neurosurgical patients, such as neurological impairment, may be either permanent or transient, resulting in dramatically different long-term outcomes. Because NSQIP-Peds only collects outcomes to 30 days following surgery, there are no means to delineate whether a neurological deficit is permanent or resolves over time. Fourth, although unplanned reoperations are increasingly being incorporated into measures of hospital and surgical quality, concerns have been raised in regards to the usefulness of this outcome in the NSQIP program. Unplanned reoperation (as defined by NSQIP) is the absence of any preoperative or intraoperative documentation that specifies the need for a patient to return to the operating room. Auditing of NSQIP vascular surgery cases has shown that more than 50% of operations coded as unplanned are related to errors in documentation, rather than complications such as bleeding or infection.⁸ Therefore, interpretation of our unplanned reoperation rate should be consistent with these constraints. Finally, because all AEs were aggregated together as the composite outcome measure for our multivariable models, this approach does not delineate associations between risk factors and complications of varying severity. Future studies could explore these associations through varying complication severity weights for each AE.

Conclusions

NSQIP-Peds offers a broad national overview of cur-

rent expected perioperative outcomes following neurosurgical procedures in children. Although we found that the overall rates of mortality following pediatric neurosurgical procedures are low, there is a relatively high rate of AEs for some procedure categories, offering several areas for targeted QI interventions, such as the use of care bundles to decrease the rate of SSIs as has been described in several surgical specialties. In particular, significant delays to operation are associated with increased rates of AEs, suggesting a potential role for system level improvements. Although there are several limitations to our current use of NSQIP-Peds, the use of this data set has transformed our understanding of the outcomes and quality of neurosurgical care for children.

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Disclosures

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

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Conception and design: Rice, Kuo, Haglund. Acquisition of data: Rice, Kuo. Analysis and interpretation of data: Rice, Kuo, Vissoci, Smith. Drafting the article: Kuo. Critically revising the article: Rice, Kuo, Egger, Smith, Grant, Haglund. Reviewed submitted version of manuscript: Rice, Kuo, Vissoci, Smith, Grant, Haglund. Approved the final version of the manuscript on behalf of all authors: Rice. Statistical analysis: Kuo, Egger. Study supervision: Rice.

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