



Original Article

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Impact of Resident Involvement in Neurosurgery: An American College of Surgeons' National Surgical Quality Improvement Program Database Analysis of 33,977 Patients

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Objective: There is conflicting and limited literature on the effect of intraoperative resident involvement on surgical outcomes. Our study assessed effects of resident involvement on outcomes in patients undergoing neurosurgery.

Methods: We identified 33,977 adult neurosurgical cases from 374 hospitals in the 2006–2012 National Surgical Quality Improvement Program, a prospectively collected national database with established reproducibility and validity. Outcomes were compared according to resident involvement before and after 1:1 matching on procedure and perioperative risk factors.

Results: Resident involvement was documented in 13,654 cases. We matched 10,170 resident-involved cases with 10,170 attending-alone. In the matched sample, resident involvement was associated with increased surgery duration (average, 34 minutes) and slight increases in odds for prolonged hospital stay (odds ratio, 1.2; 95% confidence interval [CI], 1.2–1.3) and complications (odds ratio, 1.2; 95% CI, 1.1–1.3) including infections (odds ratio, 1.4; 95% CI, 1.2–1.7). Increased risk for infections persisted after controlling for surgery duration (odds ratio, 1.3; 95% CI, 1.1–1.5). The majority of cases were spine surgeries, and resident involvement was not associated with morbidity or mortality for malignant tumor and aneurysm patients. Training level of residents was not associated with differences in outcomes.

Conclusion: Resident involvement was more common in sicker patients undergoing complex procedures, consistent with academic centers undertaking more complex cases. After controlling for patient and intraoperative characteristics, resident involvement in neurosurgical cases continued to be associated with longer surgical duration and slightly higher infection rates. Longer surgery duration did not account for differences in infection rates.

Keywords: Complications, Outcomes, Resident training, Surgical wound infection



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INTRODUCTION

Hands-on participation in the operating room (OR) is a vital component of surgical graduate medical education. However,

there is ample disagreement on the effect that resident involvement has on patient outcomes. The majority of studies have focused on general, vascular, and orthopedic surgery patients.¹⁻⁵ Studies investigating effect of resident involvement on morbidity

ty and mortality in neurosurgery patients are limited.⁶⁻¹⁰ We used the National Surgical Quality Improvement Program, a prospectively collected, clinical database, with proven validity and reproducibility,¹¹ to conduct a comparative effectiveness study of early (≤ 30 days) perioperative complications after neurosurgery when performed by a sole attending or with resident involvement. We also assessed the effect that resident training level has on outcomes.

MATERIALS AND METHODS

1. Database

We used the American College of Surgeons' National Surgical Quality Improvement Program database (NSQIP) to identify patients who underwent spine and cranial surgeries between 2006 and 2012. This database consisted of prospectively collected, clinical data from nearly 400 community and academic hospitals in the United States. Data consisted of 252 variables that include demographic variables, preoperative laboratory values, pre-existing comorbidities, intraoperative variables, and 30-day postoperative morbidity and mortality. NSQIP also reported data distinguishing resident participation in surgeries; however, this data collection was discontinued after 2012. Sites that contribute data to NSQIP undergo annual interrater reliability audits to ensure accurate data collection, making NSQIP a high quality and reliable database.¹¹⁻¹³ This study was approved by the Cleveland Clinic and University of Illinois at Chicago Institutional Review Boards.

2. Subjects and Surgical Specialty

We originally identified 34,155 patients who underwent neurosurgery between 2006 and 2012 with data available on resident surgical involvement (Fig. 1). We excluded patients that received preoperative transfusion ($n = 122$) and those with septic shock ($n = 56$), features that dictate a distinct postoperative course.¹⁴ Our final study sample consists of 33,977 patients who underwent neurological surgery. We stratified patients according to resident involvement in surgery, with 20,323 patients (59.8%) operated on by an attending alone and 13,654 involving resident participation during the surgery. We classified residents as junior if they were in years 1 through 5 of training ($n = 7,745$) or senior if in their 6th or 7th years ($n = 4,491$).

In order to assess the generalizability of our findings from the entire neurosurgery population to different subgroups of patients, we used current procedure terminology (CPT) procedure codes and Ninth Revision of International Classification of Disease (ICD-9) diagnostic codes to identify: all spine surgery patients ($n = 25,181$), patients that underwent laminectomy, fusion or both procedures ($n = 18,189$), patients who underwent craniotomy for definitive resection of a malignant brain tumor ($n = 2,000$), and patients who underwent open surgery for intracranial aneurysms ($n = 587$).

3. Covariates

We analyzed all available pre- and intraoperative factors in NSQIP that might have an effect on postoperative outcomes (Table 1). Age, body mass index, and surgical time were includ-

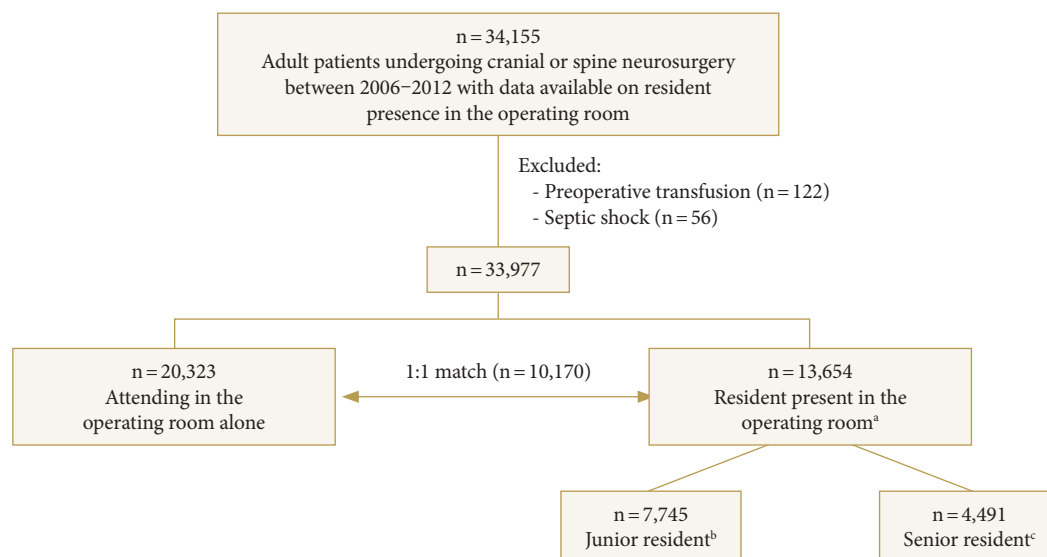


Fig. 1. Patient selection criteria. ^aPostgraduate year (PGY) level was not known for all residents. ^bResidents PGY 1–5. ^cResidents PGY 6–7. Some patients had missing data for the level of the resident.

Table 1. Baseline characteristics in the general and matched cohort^a, stratified by resident involvement

Variable	General cohort (n = 33,977)			Matched cohort (n = 20,340)		
	Resident present n = 13,654 (40.2%)	Attending alone n = 20,323 (59.8%)	Absolute standardized difference	Resident present n = 10,170 (50%)	Attending alone n = 10,170 (50%)	Absolute standardized difference
Age (yr), mean ± SD	56 ± 15	57 ± 15	0.07	56 ± 14	57 ± 15	0.07
Female sex	49.2	48.7	0	47.4	49.0	0.03
Caucasian	77.1	78.7	0.04	78.0	77.6	0.01
Admitted from home	91.4	96.3	0.20 ^b	93.1	94.7	0.07
Smoking status						
Never	61.4	63.3	0.13	60.4	63.9	0.12
Current	22.8	25.3		23.3	23.8	
Previous	15.8	11.4		16.3	12.3	
> 2 Alcoholic drinks per day	3.9	3.8	0	4.0	4.0	0
Partially or fully dependent functional status	9.7	7.5	0.08	9.2	9.4	0.01
ASA PS classification						
I & II	42.6	53.0	0.21 ^b	45.7	47.5	0.04
III & IV	56.8	46.8		53.7	52.0	
Body mass index (kg/m ²), mean ± SD	29.2 ± 6.6	29.6 ± 6.6	0.07	29.3 ± 6.6	29.5 ± 6.7	0.03
Diabetes mellitus	13.0	15.1	0.06	13.8	15.7	0.05
Cerebrovascular comorbidities	4.1	3.6	0.03	3.5	3.9	0.02
Cardiopulmonary comorbidities	16.8	18.2	0.04	17.4	19.5	0.06
Hypertension requiring medication	44.6	47.9	0.07	46.5	48.6	0.04
Renal comorbidities	23.2	23.1	0	23.2	24.6	0.03
Cancer comorbidities	7.0	3.5	0.16	5.6	5.2	0.02
Steroid use for chronic condition	7.3	4.7	0.11	6.6	5.7	0.03
Sepsis or SIRS	4.4	2.0	0.14	4.0	2.7	0.08
Prior operation within 30 days	3.3	1.9	0.09	3.2	2.4	0.05
Bleeding risk factors	8.9	7.8	0.04	8.9	9.0	0
Anemia	20.8	18.1	0.07	28.7	27.7	0.06
Abnormal LFT	13.5	11.8	0.05	13.2	13.2	0
Abnormal Na	21.5	20.6	0.05	21.8	20.6	0.05
Abnormal WBC count	21.5	16.7	0.12	20.2	18.8	0.04
Perioperative transfusion	9.0	4.7	0.17	8.0	5.3	0.11
Emergency	7.5	5.1	0.10	7.1	6.9	0.01
Cranial surgery	41.0	15.7	0.59 ^b	28.2	28.3	0
Number of procedures undergone						
1	51.7	62.4	0.25 ^b	58.2	58.2	0
2	19.1	12.7		15.8	15.8	
3	10.2	6.9		7.1	7.1	
4	5.3	5.9		5.4	5.4	
5	4.6	4.3		4.7	4.7	
6	3.8	3.3		3.8	3.8	
7	2.4	2.0		2.3	2.3	
8	1.5	1.4		1.6	1.6	
9	1.1	0.7		0.8	0.8	
10	0.4	0.4		0.3	0.3	
Multiple CPT codes	48.4	37.6	0.22 ^b	41.8	41.8	0
Length of surgery (min), mean ± SD	198 ± 122	140 ± 96	0.53 ^b	181 ± 111	147 ± 100	0.32 ^b

Values are presented as percentage (%) unless otherwise indicated.

SD, standard deviation; ASA PS, American Association of Anesthesiologists physical status; SIRS, systemic inflammatory response syndrome; LFT, liver function test; Na, sodium; WBC, white blood cell; CPT, current procedural terminology; ICD-9, Ninth Revision of the International Classification of Diseases; OR, operating room.

^aPropensity score consists of diagnostic and procedure codes, defined according to CPT and ICD-9 codes. ^bSignificant standardized differences (>0.20).

ed as continuous variables. We merged race categories into Caucasian versus all other. We dichotomized both transfer and functional status, respectively, as admitted from home versus transferred from any facility and as independent versus partially or totally dependent. Patients that presented with acute mental status changes and/or delirium at the time of surgery were considered to have altered mental status. We classified patients that had a history of transient ischemic attacks or cerebrovascular accident with or without residual neurological deficits as having cerebrovascular comorbidities. Patients with the following characteristics were considered to have cardiopulmonary comorbidities: required ventilator-assisted respiration during the 48 hours prior to surgery, had congestive heart failure that was diagnosed or was symptomatic within 30 days prior to surgery, had self-reported angina in the month leading up to surgery, had myocardial infarction within the 6 months prior to surgery, had any history of percutaneous coronary intervention, prior cardiac surgery, angioplasty or revascularization procedure for atherosclerotic peripheral vascular disease, or were experiencing rest pain or gangrene. Preoperative hemostatic screening lab values were recorded in the NSQIP database if drawn within 90 days prior to the surgical procedure, and were considered abnormal according to commonly accepted guidelines.¹⁵ Patients were defined as having renal comorbidities if they had renal disease, abnormal blood urea nitrogen or creatinine lab values. We defined cancer comorbidities as presenting with disseminated cancer, unintentional weight loss greater than 10% of body weight in the 6 months preceding surgery, or receiving chemotherapy or radiotherapy within 90 days prior to surgery. Self-reported patient history of abnormal bleeding, self-reported family history of bleeding disorders, vitamin K deficiency, and a comprehensive list of medications that pose a risk for bleeding abnormalities were captured through the NSQIP variable "bleeding disorders." Patients with bleeding disorders or abnormal preoperative international normalized ratio or platelet count were considered to have bleeding risk factors. Anemia was defined as hematocrit less than 36% in women or less than 39% in men.^{16,17} Abnormal liver function tests were defined as abnormal bilirubin, alkaline phosphatase, aspartate transaminase, or albumin. Perioperative transfusion was defined as transfusion of greater than or equal to 1 unit of whole blood or packed red blood cells any time from the start of surgery to 72 hours after surgery. We used CPT codes to quantify the number of procedures each patient underwent and created a summative variable, "multiple CPT codes," to capture all patients who underwent more than one procedure. We used CPT codes

to identify patients that underwent cranial surgery.

4. Outcomes

Outcomes of interest (Table 2) were: (1) total length of hospital stay (LOS), assessed as a continuous variable; (2) prolonged LOS, which we arbitrarily chose to define as postoperative hospitalization longer than the third-quartile of the entire study population, or here, greater than 4 days; (3) minor postoperative complications defined as one or more of: superficial surgical site infection, urinary tract infection, deep venous thrombosis or thrombophlebitis; (4) major postoperative complications defined as deep incision surgical site infection, organ or space surgical site infection, wound disruption, pneumonia, unplanned intubation, pulmonary embolism, greater than 48-hour postoperative ventilator-assisted respiration, progressive renal insufficiency, acute renal failure, cardiovascular accident with neurological deficit, coma of greater than 24 hours, peripheral nerve injury, cardiac arrest requiring cardiopulmonary resuscitation, myocardial infarction, graft, prosthesis or flap failure, sepsis, septic shock, and/or 30-day return to the OR; (5) any infection, defined as at least one superficial surgical site infection, deep incision surgical site infection, organ or space surgical site infection, and/or sepsis or septic shock; (6) postoperative complication, defined as having at least one minor or major complications or unplanned return to the OR; (7) discharged with continued care, defined as patients who were discharged to home with continued care or to a facility with skilled or unskilled care but who had not initially been admitted from such a facility; (8) 30-day readmission, defined as unplanned readmission to any hospital within 30 days of discharge; (9) 30-day unplanned return to the OR, defined as any unplanned return to the OR within 30 days of surgery; (10) 30-day readmission, defined as readmission to hospital within 30 days of index surgery after initial discharge, and (11) 30-day mortality, which constitutes death within 30 days after index surgery regardless of hospitalization status. NSQIP data on discharge destination and readmission were only available for the years 2011 and 2012.

5. Statistical Analyses

We compared pre- and intraoperative factors according to residence presence in the OR using standardized differences (Table 1). This statistical measure is the ideal tool to assess intragroup differences in covariate balance because, unlike significance tests such as Pearson chi-square or Fisher test, which generate p-values, standardized differences are not affected by

sample size. This is important in matched analyses, where the invariably smaller sample size of the matched cohort may result in statistically insignificant p-values that is falsely interpreted as improved covariate balance. An absolute standardized difference of greater than 0.20 was considered statistically significant.¹⁸ We found that several baseline characteristics were significantly different between resident involvement and attending only surgeries (Table 1). Given the nonrandomized design of this study,

our best option to control for imbalance with regard to these covariates was to generate a propensity score that included all unbalanced baseline characteristics and type of surgery undergone.^{19,20} Prior studies have suggested that the length of surgery observed between cases done with and without resident participation is the result of the resident participation; thus, including length of surgery into the propensity score would not be appropriate.⁴ We used the 1:1 greedy matching technique to match

Table 2. Thirty-day perioperative complications in the general and matched cohort^a, stratified by resident involvement

Outcome	General cohort (n = 33,977)		Matched cohort (n = 20,340)	
	Resident present n = 13,654 (40.2%)	Attending alone n = 20,323 (59.8%)	Resident present n = 10,170 (50%)	Attending alone n = 10,170 (50%)
Total length of hospital stay (day), mean ± SD	6 ± 10	4 ± 10	6 ± 10	5 ± 12
Median	3	2	3	3
Prolonged LOS (> 4 days)	34.6	21.9	30.3	27.5
Minor postoperative complications	5.0	3.5	4.8	4.2
Superficial surgical site infection	1.0	0.9	1.1	1.0
Urinary tract infection	2.6	1.8	2.4	2.2
DVT or thrombophlebitis	1.7	0.8	1.6	1.1
Major postoperative complications	11.8	6.9	10.2	8.7
Deep incision surgical site infection	0.7	0.5	0.7	0.4
Organ or space surgical site infection	0.7	0.3	0.6	0.3
Wound disruption	0.2	0.3	0.2	0.2
Pneumonia	2.1	1.1	1.8	1.5
Unplanned intubation	1.9	0.8	1.6	1.1
> 48-Hour postoperative ventilator-assisted respiration	3.8	1.6	2.9	2.5
Pulmonary embolism	0.8	0.5	0.7	0.7
Renal insufficiency or failure	0.3	0.2	0.3	0.2
Cerebrovascular accident with neurological deficit	1.2	0.4	0.6	0.7
Coma of > 24 hours	0.5	0.3	0.4	0.5
Peripheral nerve injury	0.2	0.1	0.1	0.2
Cardiac arrest or MI	0.6	0.4	0.6	0.5
Graft, prosthesis, or flap failure	0	0	0	0
Sepsis or septic shock	3.1	1.2	2.5	1.6
Any infection ^b	4.8	2.6	4.2	3.0
Any postoperative complication ^c	5.4	3.7	12.7	11.2
Discharged with continued care ^d	19.5	12.7	17.7	14.9
30-Day readmission ^d	7.3	5.5	6.5	5.8
30-Day return to the OR	5.4	3.7	4.7	4.2
30-Day mortality	2.1	1.3	2.0	2.1

SD, standard deviation; LOS, length of stay; DVT, deep venous thrombosis; MI, myocardial infarction; OR, operating room; ICD-9, Ninth Revision of the International Classification of Diseases.

^aPropensity score consists of diagnostic and procedure codes, defined according to CPT and ICD-9 codes. ^bAny > 1 of: superficial surgical site infection, deep incision surgical site infection, organ or space surgical site infection, and/or sepsis or septic shock. ^c> 1 minor or major complications. ^dData only available for 2011 and 2012.

patients operated on with resident involvement with patients that were operated on by the attending alone according to their respective propensity score and to their CPT codes.²⁰⁻²² In greedy matching, a patient operated on with resident involvement is selected at random and matched to a patient operated on by the attending alone whose propensity score is closest to that of the resident involvement patient and whose CPT code is an identical match.²² This process was then repeated until all patients operated on with resident involvement are matched to those operated on by the attending alone. We successfully matched 10,170 patients operated on with resident involvement with 10,170 patients operated on by the attending alone to create our matched cohort. To ensure covariate balance was achieved with propensity score matching, we compared baseline characteristics of patients in the matched cohort using standardized difference. Only length of surgery continued to be significantly different according to resident involvement (Table 1).

We used logistic regression analysis to determine whether resident involvement was independently associated with adverse outcomes in the unmatched cohort (Table 2). Due to the matched nature of the data, we used conditional logistic regression analysis to model the relationship between resident involvement and adverse outcomes in the matched cohort.^{18,23} To assess whether length of surgery could account for the differences in outcomes in our matched sample, we used multivariate logistic regression including both resident involvement and length

of surgery to predict each adverse outcome of interest (Table 3).

In order to assess the generalizability of our findings from the entire neurosurgery population to different subgroups of patients, we repeated all analyses in patient subgroups of interest: all spine surgery patients (data not shown), patients that under-

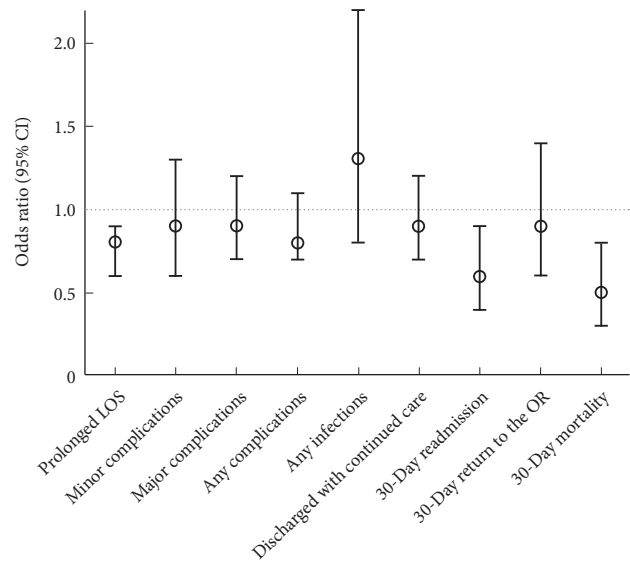


Fig. 2. Association between resident involvement and perioperative complications in patients that underwent craniotomy for definitive resection of a malignant brain tumor (n = 2,000). CI, confidence interval; LOS, length of hospital stay; OR, operating room.

Table 3. Association between resident involvement and perioperative complications in neurosurgery patients in the general and matched cohorts

Outcome	Logistic regression in the full study sample ^b	Conditional logistic regression in the propensity score-matched sample ^c	Multivariate conditional logistic regression in the propensity score-matched sample, including length of surgery ^c
Prolonged LOS	1.9 (1.8-2.0) ^a	1.2 (1.1-1.3) ^a	1.0 (1.0-1.1)
Minor complications	1.5 (1.3-1.7) ^a	1.2 (1.0-1.3)	1.1 (1.0-1.3)
Major complications	1.8 (1.7-1.9) ^a	1.2 (1.1-1.3) ^a	1.1 (1.0-1.2)
Any infection ^b	1.9 (1.7-2.1) ^a	1.4 (1.2-1.7) ^a	1.3 (1.1-1.6) ^a
Any complications	1.6 (1.5-1.8) ^a	1.2 (1.1-1.3) ^a	1.1 (1.0-1.2)
Discharged with continued care ^d	1.7 (1.5-1.8) ^a	1.1 (1.0-1.3)	1.0 (0.9-1.2)
30-Day readmission ^d	1.4 (1.2-1.6) ^a	1.1 (0.8-1.4)	1.0 (0.8-1.3)
30-Day return to OR	1.5 (1.3-1.6) ^a	1.1 (1.0-1.3)	1.0 (0.9-1.2)
30-Day mortality	1.6 (1.4-1.9) ^a	0.9 (0.8-1.2)	0.9 (0.8-1.2)

Values are presented as odds ratio (95% confidence interval).

CPT, current procedural terminology; LOS, length of hospital stay; OR, operating room.

^aOdds ratios that are significant are bolded. ^bLogistic regression in total sample described in Tables 1 and 2 (n_{resident present} = 13,654; n_{attending alone} = 20,323). ^cConditional logistic regression in the propensity-score matched sample described in Table 1 (n_{resident present} = 10,170; n_{attending alone} = 10,170). Propensity score was determined based on primary CPT, number of procedures undergone, and all baseline characteristics significantly different between resident alone and attending alone in Table 1 except for time in the OR. ^dData only available for 2011 and 2012.

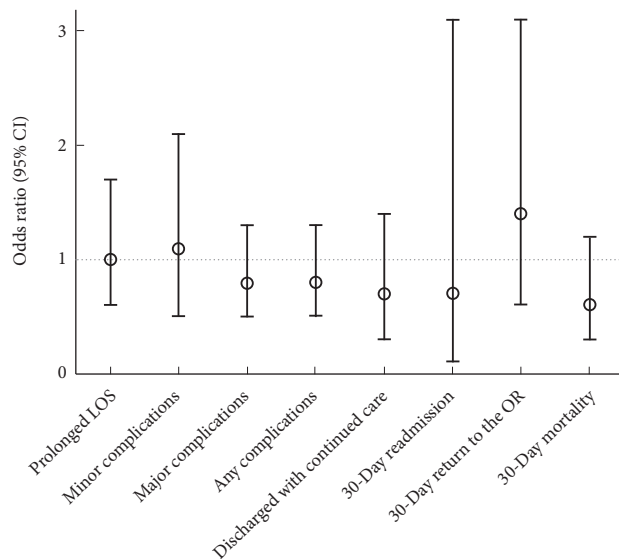


Fig. 3. Association between resident involvement and perioperative complications in patients that underwent open surgery for intracranial aneurysms ($n = 587$). LOS, length of hospital stay; OR, operating room.

went laminectomy, patients that underwent fusion, patients that underwent laminectomy and fusion (data not shown), patients who underwent definitive resection of a malignant brain tumor (Fig. 2), and patients who underwent craniotomy for treatment of an aneurysm (Fig. 3).

We used the same methodology to assess the effect of resident seniority on outcomes; comparing senior and junior residents in the same manner that we compared resident surgical participation with that of the attending alone (Fig. 4). SAS ver. 9.2 (SAS Institute Inc., Cary, NC, USA) was used.

RESULTS

Pre- and intraoperative characteristics according to resident involvement are listed in Table 1. Patients operated on with resident involvement were less likely to be admitted from home and had higher American Association of Anesthesiologists physical status classification. They were far more likely to undergo cranial surgery, with 41% of resident cases consisting of cranial surgery compared to only 15.7% of sole attending cases, and these patients were more likely to require multiple procedures. We provide additional information on the most frequent CPT procedure codes and ICD-9 diagnostic codes according to resident involvement in the Supplementary Figs. 1–4 and Supplementary Tables 1, 2. Length of surgery was on average almost an hour longer in procedures with resident participation.

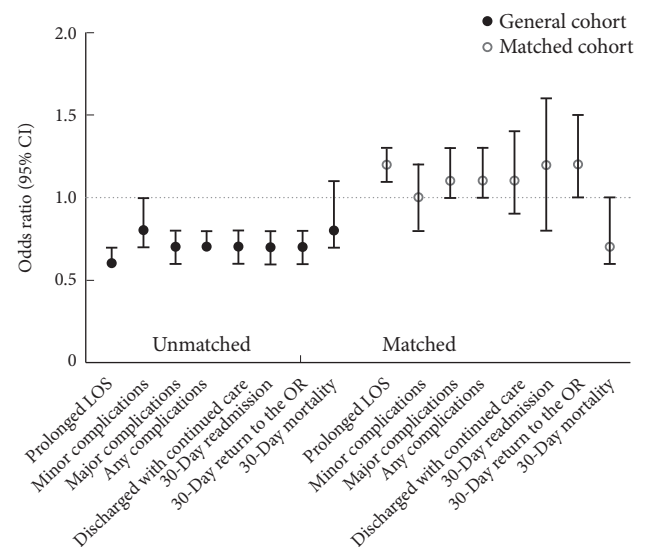


Fig. 4. Association between resident level of training and perioperative complications in neurosurgery patients in the general and matched cohorts. LOS, length of hospital stay; OR, operating room.

Frequency of outcomes was compared according to resident involvement (Table 2). Both the mean and median length of hospitalization in resident cases were longer by 2 days and 1 day respectively, and resident cases appeared to have higher incidence of morbidity and mortality in the general cohort.

We matched 10,170 resident-assisted cases to 10,170 attending-only cases on propensity scores consisting of primary CPT and number of procedures undergone. Once matched, no covariate imbalance with regard to baseline characteristics or operative procedures undergone remained between resident-assisted and attending-alone cases, with the exception of length of surgery which was on average 30 minutes longer in cases with resident involvement (Table 1).

Using logistic regression in the general cohort of 33,977 patients (Table 3), we found that in comparison to attending-alone cases, resident-assisted cases were nearly twice as likely to experience prolonged length of stay (LOS); they had 1.6 (95% confidence interval [CI], 1.5–1.8) times the odds for postoperative complications; and they were about 50% more likely to undergo discharge with continued care, 30-day readmission with return to the OR, and 30-day mortality.

In the matched cohort, we used conditional logistic regression to assess the relationship between resident involvement and each outcome of interest (Table 3). We found that resident involvement had only slightly higher odds for prolonged LOS and for complications including infection as compared to at-

tending-alone cases. This finding is supported by the outcomes in the matched cohort seen in Table 2. While the median LOS with and without resident involvement is the same—3 days—the mean length of stay continues to be on average one day longer with resident surgeries (Table 2). Differences in incidence of morbidity and mortality according to resident involvement are far less apparent here.

To assess whether length of surgery was the reason for slightly increased odds for prolonged LOS and complications in resident cases, we used conditional multivariate logistic regression, including both length of surgery and resident involvement as predictor variables (Table 3). No significant differences were present in prolonged LOS or complications aside from infections after taking into account length of surgery. This suggests that while longer surgery times do play a role in length of hospitalization and most complications in resident cases, length of surgery alone cannot account for the slightly higher odds for infection that is associated with resident surgical involvement.

Our full study sample results were similar when conducting subgroup sensitivity analyses limiting our sample to each of all spine patients and then to only patients that underwent laminectomy, fusion, or both (data not shown). Seeing that the majority of our study population is comprised of spine surgery patients, who make up 72% of the matched cohort (Table 1), this is a logical finding. Interestingly, when limiting our sample to patients that underwent definitive resection of a malignant brain tumor, resident involvement was associated with reduced LOS, 30-day readmission, and mortality (Fig. 2). No association was found between resident involvement and outcomes in patients that underwent craniotomy for aneurysm treatment (Fig. 3).

When comparing outcomes between junior and senior level resident involvement in all neurosurgery patients, we found that junior level resident involvement was associated with lower odds (between 0.6 and 0.8) for prolonged LOS, morbidity and mortality in the general cohort (Fig. 4). However, after matching on surgical procedure undergone, all differences in outcomes were eliminated.

DISCUSSION

We used a large, prospectively collected, clinical database, reported from hospitals nationwide, to conduct a comparative effectiveness analysis of neurosurgery patients. In this analysis of over 30,000 patients, the odds for morbidity and mortality were higher with resident surgical involvement in the general neurosurgical population. There were no significant differences in

the pre- or intraoperative characteristics of patients operated on with and without resident involvement after matching surgical procedure performed, with the exception of length of surgery, which was on average 30 minutes longer with resident involvement. Resident participation continued to have slightly higher odds for prolonged LOS and complications in the matched sample. Length of surgery mediated the relationship between resident involvement and prolonged LOS, but did not account for the slight increase in infection associated with resident involvement. Study findings were similar when limiting the study population to spine surgery patients and subgroups of laminectomy and fusion patients. Resident involvement was not associated with morbidity or mortality in patients who underwent definitive resection of a malignant brain tumor or those who underwent craniotomy for treatment of an aneurysm. Training level of residency did not appear to affect outcomes in the general neurosurgical patient population.

1. Interpretations of Results

Since the majority of our sample—72% of the matched cohort (Table 1)—is comprised of spine surgery patients, it was important to assess whether there were differences in resident involvement on outcomes in subgroups of neurosurgery patients. Thus, we chose to assess separately the effect of resident involvement on patients that underwent craniotomy for definitive resection of a malignant brain tumor and those that underwent craniotomy for treatment of aneurysm. The baseline characteristics of these patient populations are rather different from non-traumatic spine surgery patients—as are the skills required to operate. These subgroup analyses produced interesting and perhaps unexpected results with resident involvement failing to increase morbidity or mortality in aneurysm patients (Fig. 3) and in fact being associated with reduced LOS and mortality in malignant brain tumor patients (Fig. 2).

Resident-assisted surgeries were found to take 30 minutes longer on average compared to cases done by the attending alone. A prior orthopedic surgery study in lumbar discectomy patients identified length of surgery as a risk factor for infections.²⁴ In order to see if lengthy surgery was the reason for higher odds of infection in resident-assisted cases, we included length of surgery into our final model (Table 3). Even so, resident-assisted cases continued to be associated with higher odds for infection, thus suggesting that there must be some other mechanism behind the association aside from longer surgery duration.

The differences seen in the general cohort indicating fewer complications with junior level residents were eliminated in the

matched cohort (Fig. 4). This is consistent with the theory that senior level residents tend to participate in more complicated surgeries on sicker patients: matching cases on surgery type and baseline patient characteristics eliminated differences in 30-day outcomes between junior and senior level residents.

2. Interpretations in the Context of the Literature

While a number of prior studies have assessed the effect of resident involvement on general, vascular, and orthopedic surgery outcomes,¹⁻⁵ only a few have investigated the effect of resident involvement on morbidity and mortality in neurosurgery patients, and these have been limited in design or scope.⁶⁻⁹

Among the studies investigating patients of neurosurgeons, two analyzed subsets of spinal fusion cases^{7,8} and 2 analyzed most neurosurgical procedures in the NSQIP database with particular limitations.^{6,9}

The spinal fusion studies found significant associations between resident involvement and increased lengths of surgical time and hospital stay, and also noted associations between resident participation and increases in wound complications and transfusion rates. The authors did not conduct statistical analyses to determine whether these complications may be attributed to increased surgery times, although one author did suggest the prospect. By using conditional regression analysis accounting for length of surgery, our study indicated that longer surgery times in resident-assisted cases do indeed play a role in length of hospitalization and all complications besides infection.

The 2 papers that included all neurosurgical procedures in NSQIP reported associations between resident involvement and increased lengths of surgical time and hospital stay, but demonstrated that no differences remained after particular statistical balancing of perioperative patient characteristics. Despite these encouraging results, these papers have limitations that are overcome by our statistical analyses. One study used data from 2006 to 2012 but only included 16,098 patients and used t-tests and rank-sum tests followed by step-wise multivariate regression as opposed to propensity score matching and methods that are more appropriate for NSQIP analyses (see Materials and Methods section above).⁶ The other study did include appropriate propensity score matching, however, their data was limited to 8,747 cases from only a single year in the NSQIP database.⁹ Our data set included 33,997 cases from 2006 to 2012, and unlike previous studies, we performed several different and additional statistical analyses as reported in previous sections: baseline characteristic comparison using standardized differences rather than the less ideal Pearson chi-square or Fisher tests, mat-

ching by CPT code (type of surgery) in addition to baseline propensity scores, conditional regression analysis accounting for length of surgery, subgroup sensitivity analyses for types of surgery, and comparison of junior and senior resident level involvement. On top of our subgroup analyses, our findings confirmed that resident involvement was not a significant factor for post-operative complications but additionally noted an association with infection that was not accounted for by longer surgery times. Consistent with our report, Morgan et al.¹⁰ found no association between neurosurgery resident involvement and aneurysm surgery outcomes in 355 cases.

To our knowledge, no studies other than those above have assessed resident involvement in neurosurgery patients. A large breadth of studies has looked at orthopedic resident involvement in cases such as spine surgeries, which made up the majority of cases analyzed in the present study. Hence, next we compare our findings with these studies. It is important to remember, however, that while orthopedic surgeons and neurosurgeons overlap in performing spine surgery that does not involve the dura, the patient populations covered by these specialties and the training that each specialty undergoes are different. Furthermore, a study comparing the effect of surgical specialty on spine outcomes demonstrated minor differences associated with surgical specialty in and of itself.²⁵ Thus, we must keep in mind that the effect of orthopedic residents on orthopedic spine surgery outcomes may be different than that of neurosurgical residents on spine surgery outcomes.

Several of the studies assessing the effect of orthopedic surgery residents on outcomes include spine surgery patients, though only a few are limited to spine surgery patients.^{1,4,5,25} Three of the studies done in mixed groups of orthopedic surgery patients use the ACS NSQIP database, but each arrive at different conclusions. Edelstein et al.³ found that resident involvement is associated with lower morbidity and mortality. Pugely et al.⁴ conclude that resident involvement is not associated with increased mortality but has higher odds for postoperative complications in spine surgery patients before and after matching on propensity scores, with odd ratios very similar to those in our Table 3. A third study of mixed orthopedic surgery patients using the NSQIP database shows mild to moderate risk for complications in joint arthroplasty cases with resident involvement but not in spine surgery cases.⁵ However, the low prevalence of complications in the author's spine surgery subsample makes the null finding prone to type II error—erroneously rejecting the null hypothesis when there was in fact an association between resident involvement and morbidity. One single-institution study

of 303 consecutive scoliosis surgery cases found resident involvement to be associated with longer surgery duration, just as we did in our study.¹ However, the authors concluded that resident involvement was not associated with morbidity or mortality. It is not possible to ascertain whether the lack of association between resident involvement and adverse outcomes was the result of type II error, as the prevalence of complications was fairly low in an already limited sample size.

With regards to neurosurgery patients, a number of studies have shown that case volume and years of experience operating are predictive factors for outcomes.²⁶⁻²⁸ None, however, have assessed the effect that level of resident training has on outcomes. In our study, we found no differences between junior and senior residents after adjusting for all baseline characteristics and for type of surgery undergone. Only one of the orthopedic surgery studies assessed the effect of residency level of training on outcomes, and also found there to be none.⁴

3. Clinical Implications

We identified slight differences in 30-day outcomes with resident surgical involvement in neurosurgical patients overall, and we showed that resident involvement in malignant brain tumor and aneurysm cases is generally safe. There was a slight increase in infection rate that was seen with resident involvement, which was not mediated by the length of surgery. It is important to note that it may be difficult to be sure that resident involvement is the sole reason for slightly higher morbidity and operative times seen in our study. Residents only participate in surgery at academic centers, the same environments where other healthcare students train as well.⁴ This includes anesthesiology residents and nurse anesthetists, circulating and scrub nurses and techs and floor nurses that care for the patients postoperatively. With the NSQIP database, we are unable to determine the level of training of patient care providers aside from surgeons, and this could be an important confounder partially contributing to longer surgery durations and increased postoperative morbidity seen in resident cases.

4. Limitations

This study has limitations. While NSQIP collects clinical data prospectively from nearly 400 institutions across the United States, this is a retrospective analysis, so that it is not possible to confirm definitively a cause-and-effect relationship between resident surgical involvement and the outcomes measured. In spite of matching on propensity scores, this is not a randomized study, which means that we cannot rule out that the possibility

that patients that were operated on with the assistance of a resident are different from those operated on by attending alone with regard to preoperative factors for which we are unaware such as disease burden. While CPT codes quantifying the general nature of the procedures performed, we recognize that they are an imperfect way to capture the exact nature of what occurs in the OR. The same is true for ICD-9 diagnostic codes, which are an inadequate way to quantify burden of disease which can be very different between 2 patients with the same diagnosis seemingly undergoing the same procedure. Since residents only participate in care at academic institutions and academic centers generally treat patients with greater disease burden, there may be some inherent bias in patient populations between residents and private practice attendings that we cannot account for.^{4,29} Furthermore, we cannot ascertain from the NSQIP database the training experiences of healthcare providers besides that of the surgeons. Since residents only provide care at academic centers, the outcomes for resident-assisted neurosurgery cases may be biased by the participation of anesthesiology residents and nurses in training.⁴ Lastly, we were unable to assess the effect of hospital and surgeon volume on outcomes in our study because this data is not available in the NSQIP database.

CONCLUSION

We compared early (≤ 30 -day) perioperative outcomes of neurosurgical operations that were resident-assisted or conducted by an attending alone. In the unmatched cohort, the odds for morbidity and mortality were higher with resident surgical involvement. After matching type of surgery performed and baseline covariates, resident participation continued to result in surgical times that were about 30 minutes longer than surgeries performed by attendings alone, and resident participation continued to have slightly higher odds for prolonged LOS and complications. Length of surgery mediated the relationship between resident involvement and prolonged LOS but did not account for the slight increase in infection associated with resident involvement. Therefore, resident involvement in neurosurgical cases may slightly increase odds for prolonged LOS and some complications. Study findings were similar when limiting the study population to spine surgery patients and subgroups of laminectomy and fusion patients, but we found no difference in outcomes with resident involvement in malignant brain tumor and aneurysm patients. Training level of residency did not appear to affect outcomes in the general neurosurgical patient population. Using a large, multi-institutional sample of pro-

spectively collected data, our analysis suggests that resident surgical involvement is generally safe in neurosurgical patients but associated with minor increases in morbidity.

CONFLICT OF INTEREST

The authors have nothing to disclose.

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SUPPLEMENTARY MATERIALS

Supplementary Tables 1–2 and Figs. 1–4 can be found via <https://doi.org/10.14245/ns.1836008.004>.

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