Journal of Clinical Neuroscience 56 (2018) 131–136

Contents lists available at ScienceDirect

Journal of Clinical Neuroscience

journal homepage: www.elsevier.com/locate/jocn

Clinical study

Impact of resident participation on outcomes following lumbar fusion: An analysis of 5655 patients from the ACS-NSQIP database

Jonathan T. Yamaguchi, Roxanna M. Garcia, Michael B. Cloney, Nader S. Dahdaleh *

Department of Neurological Surgery, Northwestern University, Feinberg School of Medicine, Chicago, USA

ARTICLE INFO

Article history:
Received 5 August 2017
Accepted 19 June 2018

Keywords:
Arthrodesis
Lumbar spine
Propensity score matching
Resident involvement
Surgical outcomes
Neurological surgery
Orthopedic surgery

ABSTRACT

The role of resident involvement on patient safety, morbidity, and mortality in lumbar spinal surgery has been poorly defined in the literature. The objective of this study is to investigate the relationship between resident involvement in the operating room and 30-day complication rates in patients undergoing lumbar spinal fusion procedures. We used the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database to retrospectively identify all patients who underwent a lumbar spinal fusion from 2006 to 2013. A propensity score matching algorithm was employed to minimize baseline differences. Multivariate logistic regression analysis of unadjusted and propensity-matched groups was performed to examine the effect of resident participation on operative details and 30-day complication rates. A total of 5655 patients met the inclusion criteria and propensity score matching yielded 1965 well-matched pairs. Resident involvement in lumbar fusion procedures was not found to be a significant predictor for mortality or reoperation. It was found to be a significant predictor for increased hospital stay (matched non-resident 4.0 ± 5.8 days vs. resident 4.6 ± 4.3 days, $p < 0.001$), operative time (matched non-resident 198 ± 102 min vs. resident 243 ± 118 min, $p < 0.001$), sepsis (matched OR 4.36, 95% CI 2.10–9.05, $p < 0.001$), development of DVT/PE (matched OR 2.02, 95% CI 1.10–3.70, $p = 0.023$), and superficial surgical site infections (matched OR 1.78, 95% CI 1.04–3.06, $p = 0.037$). In conclusion, this large-scale, population-based study found that resident participation in the operating room was safe but increased the risk of 30-day complications and increased operative duration and length of hospital stay.

1. Introduction

Arthrodesis of the lumbar spine is one of the most common procedures used for treatment of traumatic, neoplastic, infectious, and degenerative disorders [1,2]. This popularity could be due to the myriad of surgical approaches that have recently evolved such as the addition of minimally invasive techniques. With the aging population, the use of these surgeries is steadily increasing [3,4]. Yoshihara et al. determined that surgical treatment for lumbar disc degenerative disease has increased 2.4-fold from 2000 to 2009 in the United States [5]. This increase in spinal fusion utilization provides a greater opportunity for resident trainee involvement but the role of resident involvement on patient outcomes has not been well defined in the literature.

The effect of resident training on patient safety remains controversial especially after the adoption of resident duty hour regulations by the Accreditation Committee on Graduate Medical Education (ACGME) in 2003 and the refusal of some patients to be treated by residents [6–11]. The surgical techniques for lumbar fusion vary by difficulty and require experience to be performed safely [12]. The impact of resident involvement on clinical outcomes remains controversial [13–17]. Within spine literature, studies relate predominantly to cervical spine surgery and shows no change in mortality with resident involvement [18–22]. However, there are other studies that show increased operative times and post-operative complications when residents are involved [15,23,24].

At the lumbar level, however, there is currently lack of data denoting the relationship between resident training in spine surgery and perioperative outcomes in patients that undergo lumbar spinal fusion. In the present study, we investigated the role of resident involvement on lumbar fusions using the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP), a nationally validated multi-institutional database,

* Corresponding author at: Department of Neurological Surgery, Northwestern University, Feinberg School of Medicine, 676 N. St Clair Street, Suite 2210, Chicago, IL 60611, USA.

E-mail address: nader.dahdaleh@northwestern.edu (N.S. Dahdaleh).

https://doi.org/10.1016/j.jocn.2018.06.030
0967-5868/

to determine if there were associations between resident involvement and patient outcomes. The purpose of this study is to isolate lumbar fusions as a procedure and to analyze how resident involvement impacts these common operations.

2. Materials and methods

2.1. Data source and population

The ACS-NSQIP database is a nationwide program that collects data on major surgical procedures in both the inpatient and outpatient settings. Patients are selected by a billable Current Procedural Terminology (CPT) code. Trained surgical clinical reviewers extract variables from the preoperative period and up to 30 days after the procedure in systematic sampling process described elsewhere. Every case is assigned an International Classification of Diseases Version 9 (ICD-9) code corresponding to the post-operative diagnosis extracted from a brief operative note, surgical, or pathology report. In 2008, the definitions of ethnicity and race were revised to comply with the Centers for Medicare and Medicaid Services and other federal agencies. Data from national participant use files from 2006 to 2013 were compiled and all patients undergoing single and multilevel arthrodesis of lumbar spine were identified. The ACS-NSQIP data is a publicly available, de-identified database, and as such Institutional Review Board approval or informed consent was waived.

2.2. Patient selection

We used five primary CPT codes 22533, 22558, 22612, 22630, and 22,633 to retrospectively review the 2006–2013 ACS-NSQIP database and identify all patients who underwent single and multilevel lumbar arthrodesis. Cases undergoing revision or fusion extending to the cervical, thoracic or pelvis were excluded. Additionally, cases were excluded because they were emergent since lumbar spinal fusions are generally elective; did not provide information on resident involvement; did not provide pertinent demographic information including sex, height, or weight; lacked co-morbidity profile; or length of hospital stay was greater than 365 days. The final dataset was subdivided into non-resident and resident groups.

2.3. Study demographics and outcomes

Patient demographics, co-morbidities, and operative characteristics were tracked to analyze baseline differences between the groups and to identify potential confounders. Demographics included age, body mass index (BMI), sex, and race. Analyzed medical co-morbidities included diabetes mellitus, dyspnea, dependent functional status, history of chronic obstructive pulmonary disease (COPD), current pneumonia, history of congestive heart failure (CHF) within 30 days of operation, history of myocardial infarction (MI), previous percutaneous coronary intervention (PCI) and/or cardiac surgery, hypertension requiring medication, hemiplegia and/or paraplegia and/or quadraplegia, history of transient ischemic attack (TIA) and/or stroke, pre-operative open wound and/or wound infection, chronic steroid use, bleeding disorders, >10% body weight loss within 6 months of operation, chemotherapy within 30 days of operation, radiotherapy within 90 days of operation, and previous operation within 30 days of the index operation. Alcohol use (>2 drinks/day for 2 weeks preceding the index procedure) and smoking history (within 1 year of operation) were included as lifestyle variables. Operative characteristics included length of hospital stay (LOS), relative value units (RVU), operative time, specialty, inpatient status, and American Society of Anesthesiologists (ASA) Physical Status class. The ASA classification system uses a scale from 1 to 6 that evaluates a patient's physical state prior to anesthesia or an operation with 1 being a normal healthy patient and 3 and beyond with severe systemic illness.

Thirty-day post-operative complications were categorized as overall, surgical, and medical complications. Overall complications were defined as having any surgical and/or medical complications. Surgical complications included surgical site wound infection (SSI) by location (superficial, deep, and/or organ/space), and wound dehiscence. Medical complications were defined as complications related to medical conditions that developed from non-surgical causes and included: 1) cardiovascular (cardiac arrest, myocardial infarction, stroke, or transfusions); 2) pulmonary (pneumonia, unplanned re-intubation, or ventilator-assisted respiration for over 48 h); 3) coma or peripheral nerve damage; 4) renal (progressive renal insufficiency or acute renal failure); 5) thromboembolic (deep vein thrombosis (DVT) or pulmonary embolism (PE)); 6) septic (sepsis or septic shock); and 7) urinary tract infection (UTI). Re-operation is defined by ACS-NSQIP as a return to the operating room within 30 days of the index procedure for intervention of any kind. Major outcomes of interest in this study included overall/surgical/medical complications, re-operations, mortality, and total LOS.

2.4. Statistical analysis

IBM SPSS Statistics version 20 (IBM Corp, Armonk, NY) was utilized to perform all descriptive and comparative statistics. We first compared unadjusted variables between the non-resident and resident groups. Categorical variables were analyzed by using Pearson χ^2 test or Fisher's exact test where appropriate. Continuous variables were analyzed by using Student's *t*-test or the Mann-Whitney *U* test when needed.

To account for the nonrandom assignment of patients between the two groups, a propensity score matching analysis was employed. The propensity score matching allows for an improved estimate of the treatment effect by balancing observed covariates simultaneously between groups. The details and description of propensity score matching in its applied context are published elsewhere [25–27]. Briefly, we created a non-parsimonious logistic regression model in which to derive the propensity scores. The matching algorithm used for this study was 1:1, nearest neighbor matching without replacement, in which each non-resident case was matched to unique resident case based on nearest propensity scores. Units outside of common support were discarded from both groups for improved balance of covariates. The optimal caliper width was determined by calculating 0.2 of the standard deviation of the logit of the propensity score [28]. This procedure yielded 1965 well-matched non-resident and resident pairs. Model adequacy was validated by comparing the significance and standardized mean difference of propensity scores between the pre- and post-matched sample. A total of 29 patient clinical and operative variables were balanced which included all of aforementioned perioperative variables except operative duration and LOS. Operative duration was not included because it was deemed as a function of resident proficiency. We then performed two independent series of multivariate logistic regression analyses using both the unadjusted and propensity score matched dataset. For each regression model, candidate variables were identified via univariate screening, from which pre-, and intra-operative variables with $p < 0.2$, and 10 or more occurrences were selected. To assess the effect of resident involvement on outcomes, the final regression models were constructed by including the candidate variables. Hosmer-Lemeshow statistics and c-indices were calculated for each regression model to measure its goodness of fit and discriminative ability, respectively. For all tests, significance was defined at p < 0.05.

3. Results

3.1. Unmatched unadjusted patient population

There were a total of 5655 patients from the 2006–2013 ACS-NSQIP database that were identified and met our inclusion criteria. There were 3659 patients in the non-resident subgroup and 2006 patients in the resident subgroup. The clinical characteristics were relatively similar between the two subgroups with several exceptions shown in Table 1. Patients in the non-resident subgroup had lower age at the time of surgery (p = 0.003), a greater mean BMI (p = 0.002), and with a predominant number of patients identified as White race (p < 0.001). The baseline comorbidity characteristics of patients in the resident group differed from the non-resident group per the following factors: diabetes mellitus (p = 0.001), current smoking status (p = 0.001), dyspnea (p = 0.044), paralysis (p = 0.001), and prior operation within 30 days (p < 0.001). The operative characteristics differed significantly between the two subgroups. Patients belonging to the resident subgroup had a longer mean LOS (p < 0.001), higher total RVU (p < 0.001), longer total operative time (p < 0.001), and a higher proportion of patients in ASA Classes 3 and 4 (p = 0.014).

3.2. Propensity score matched population

Propensity score matching resulted in 1965 well-matched non-resident and resident pairs. The mean standard differences of propensity scores before and after the matching procedure were 0.361 and 0.014, respectively. After propensity score matching the hospital LOS and total operative time were found to be significantly different between the two subgroups with the propensity matched resident subgroups having a longer mean LOS (matched non-resident 4.0 ± 5.8 days vs. resident 4.6 ± 4.3 days, p < 0.001) and a longer total operative time (matched non-resident 198 ± 10 2 min vs. resident 243 ± 118 min, p < 0.001).

3.3. 30-Day outcomes

Thirty-day complication rates for the non-resident and resident subgroups for both unadjusted and propensity score matched patients are shown in Table 3. Univariate analysis of the unadjusted population showed statistically significant differences in all outcome complications categories between the non-resident and the resident subgroups, respectively with the biggest differences observed between overall medical complications (13.1% vs. 20.6%) and transfusions (9.5% vs. 14.9%). Similarly, univariate analysis of the propensity matched subgroups demonstrated resident

Table 1
Patient clinical characteristics.

		Unadjusted			Propensity Matched		
		No Resident	Resident	P-value	No Resident	Resident	P-value
		N (%)			N (%)		
		3649 (64.5)	2006 (35.5)		1965 (50.0)	1965 (50.0)	
Demographics	Age (years, mean ± SD)	58 ± 14	59 ± 14	0.003*	59 ± 14	59 ± 14	0.835
	BMI (kg/m^2, mean ± SD)	30.33 ± 6.51	29.78 ± 6.11	0.002*	29.74 ± 6.35	29.82 ± 6.14	0.715
	Sex			0.550			0.522
	Male	1660 (45.5)	896 (44.7)		900 (45.8)	880 (44.8)	
	Female	1989 (54.5)	1110 (55.3)		1065 (54.2)	1085 (55.2)	
	Race			<0.001*			0.552
	White	3098 (84.9)	1542 (76.9)		1565 (79.6)	1528 (77.8)	
	Black	231 (6.3)	144 (7.2)		133 (6.8)	144 (7.3)	
	Asian	24 (0.7)	20 (1.0)		18 (0.9)	19 (1.0)	
	Other/Unspecified	296 (8.1)	300 (15.0)		249 (12.7)	274 (13.9)	
Comorbidities	Diabetes mellitus	613 (16.8)	270 (13.5)	0.001*	253 (12.9)	266 (13.5)	0.540
	Current smoker	937 (25.7)	434 (21.6)	0.001*	410 (20.9)	431 (21.9)	0.414
	EtOH > 2 drinks/day	115 (3.2)	77 (3.8)	0.172	83 (4.2)	73 (3.7)	0.414
	Dyspnea	278 (7.6)	124 (6.2)	0.044*	116 (5.9)	122 (6.2)	0.688
	Dependent status	166 (4.5)	86 (4.3)	0.648	69 (3.5)	81 (4.1)	0.318
	History of COPD	152 (4.2)	73 (3.6)	0.333	74 (3.8)	70 (3.6)	0.734
	Current pneumonia	1 (0.0)	1 (0.0)	1.000	1 (0.1)	1 (0.1)	1.000
	CHF<30 days	6 (0.2)	2 (0.1)	0.720	2 (0.1)	2 (0.1)	1.000
	History of MI	5 (0.1)	3 (0.1)	1.000	3 (0.2)	3 (0.2)	1.000
	Previous PCI/CS	321 (8.8)	164 (8.2)	0.425	158 (8.0)	162 (8.2)	0.816
	Hypertension	1931 (52.9)	1060 (52.8)	0.956	1052 (53.5)	1037 (52.8)	0.632
	Paralysis	214 (5.9)	77 (3.8)	0.001*	76 (3.9)	67 (3.4)	0.443
	History of TIA/stroke	152 (4.2)	67 (3.3)	0.125	84 (4.3)	76 (3.9)	0.518
	Open wound/wound infection	18 (0.5)	14 (0.7)	0.326	11 (0.6)	11 (0.6)	1.000
	Chronic steroid use	97 (2.7)	67 (3.3)	0.144	68 (3.5)	64 (3.3)	0.723
	>10% weight loss in 6 mos	15 (0.4)	11 (0.5)	0.465	6 (0.3)	9 (0.5)	0.438
	Bleeding disorders	52 (1.4)	32 (1.6)	0.613	28 (1.4)	31 (1.6)	0.694
	Chemotherapy <30 days	2 (0.1)	5 (0.2)	0.105	1 (0.1)	2 (0.1)	1.000
	Radiotherapy <90 days	3 (0.1)	3 (0.1)	0.673	2 (0.1)	3 (0.2)	0.687
	Sepsis	45 (1.2)	22 (1.1)	0.650	21 (1.1)	22 (1.1)	0.878
	Prior operation <30 days	39 (1.1)	46 (2.3)	<0.001*	32 (1.6)	37 (1.9)	0.544

BMI indicates body mass index; EtOH, alcohol; COPD, chronic obstructive pulmonary disease; CHF, congestive heart failure; MI, myocardial infarction; PCI, percutaneous coronary intervention; CS, cardiac surgery; TIA, transient ischemic attack.

* Denotes significant value, p < 0.05.

involvement significantly increased the rates of overall/medical complication, bleeding transfusion, and sepsis/septic shock.

3.4. Multivariate analysis

Table 4 shows the multivariate logistic regression among the unadjusted and propensity matched subgroup. The overall odds of complications was 1.33 times greater (95% CI 1.11–1.58, p = 0.002) in the resident subgroup compared to the non-resident subgroup after statistical matching of baseline covariates. The odds of sepsis had the strongest magnitude of association among the covariate post-operative outcome risk factors (matched OR 4.36, 95% CI 2.10–9.05, p < 0.001) with development of DVT/PE (matched OR 2.02, 95% CI 1.10–3.70, p = 0.023) and superficial surgical site infections (matched OR 1.78, 95% CI 1.04–3.06, p = 0.037) serving as the next most strongly associated risk factors.

4. Discussion

In this study, we investigated the impact of resident involvement on 30-day morbidity and mortality among patients undergoing lumbar spinal fusion. We found that cases with resident participants had higher mean LOS (p < 0.001) and operative time (p < 0.001) than cases without residents; the only patient clinical or operative characteristics to remain statistically significant after propensity score matching (Table 2). After propensity score matching, the multivariate analysis demonstrated that resident involvement was not associated with a change in mortality. In addition, there were slight increases in the risk for complications classified as "overall" and "medical" but they were small. We hypothesize that the increased operative duration in the resident subgroup may have contributed to the increased post-operative risk of sepsis, development of DVT/PE, and potentially, superficial SSI, which can prolong the LOS. Unplanned reoperation and return to OR was not found to be statistically significant under multivariate analysis. This could be attributed to more evenly balanced patient morbidities and preoperative risk factors that are accounted for in multivariate analysis.

The mean operative time in the resident subgroup was 45 min longer than the attending alone (Table 2). The longer operative times are inherent in teaching cases, as training environments require additional time. There are numerous studies demonstrating that longer operative times during teaching cases can lead to further risk for post-operative complications, especially thromboembolic events and infections [29–33]. Daley et al. showed that longer cases had increased risk of sepsis, DVT, and superficial site infections among general and vascular surgical procedures from member hospitals in the Tennessee Surgical Quality Collaborative [34]. In lumbar fusion, Kim et al. examined 4500 cases and found that increasing operative duration was a step-wise increase in risk for overall, medical, and surgical complications, superficial SSI, and post-operative transfusion [35]. Kiran et al. similarly attributed the increase in surgical complications with resident involvement to the longer operative times [36]. Kothari et al., examining elective orthopedic spinal fusions, noted that there was an increase in overall morbidity, wound complication, blood transfusion, and LOS with longer operation times, increasing morbidity rates, but not affecting mortality [23]. Furthermore, Lee et al. investigated posterior cervical fusion in the NSQIP database and found that resident involvement was associated with increased rates of transfusions (matched OR 3.6, 95% CI 1.7–7.4, p = 0.0007), operative time >4 h (matched OR 1.7, 95% CI 1.1–2.6, p = 0.010), and LOS >5 days (matched OR 1.6, 95% CI 1.0–2.6, p = 0.040) [24]. However, it is still unclear how long is too long for lumbar spinal fusions.

Other studies have found increased rates of venous thromboembolism with increased operative durations [34,35,37,38]. Interestingly, our analysis showed that resident involvement was associated with increased rates of DVT/PE in our multivariate analysis after propensity score matching (Table 3). We attempted to adjust statistically for differences in confounders and baseline covariates by using propensity score matching and continued to observe highly statistically significant differences among cases with resident involvement. It is logical that cases involving residents result in longer procedural time, thus increasing the risk for possible adverse outcomes. These risks must be balanced with the necessity of training future generations and creating safe practice environments for resident education.

The ACS-NSQIP database does not provide the granular data needed to determine the degree of resident participation. For example, the database does not include who the first assistant is and only incorporates the highest level of training of any of the residents in the procedure. There are reports that the learning curve for more difficult procedures can lead to higher incidence of post-operative complications, longer operative times, and increase hospital stay during the initial cases without changes in long-term outcomes [39]. A study done by Saliba et al. found resident involvement across surgical specialties was associated with a slightly higher risk of cardiac and respiratory morbidities in resident cases [16]. Other studies showed that the resident year and level of expertise can positively impact the surgical outcomes. Ferraris et al. found surgical outcomes in high-complexity procedures were correlated with improved surgical outcomes when resident participation involvement included more senior residents [17].

Table 2
Patient operative characteristics.

		Unadjusted			Propensity Matched		
		No Resident	Resident	P-value	No Resident	Resident	P-value
		N (%)			N (%)		
		3649 (64.5)	2006 (35.5)		1965 (50.0)	1965 (50.0)	
Operative Details	Length of hospital stay (days)						
	Mean ± SD	4.0 ± 5.0	4.6 ± 4.9	<0.001*	4.0 ± 5.8	4.6 ± 4.3	<0.001*
	Median (IQR)	3 (3)	4 (2)		3 (3)	4 (2)	
	Total RVU	45.30 ± 26.14	48.61 ± 24.70	<0.001*	49.20 ± 27.71	48.41 ± 24.61	0.342
	Total operative time	196 ± 100	244 ± 118	<0.001*	198 ± 102	243 ± 118	<0.001*
	Specialty (Neurosurgery)	1826 (50.0)	1032 (51.4)	0.312	1019 (51.9)	1013 (51.6)	0.848
	Inpatient	3574 (97.9)	1962 (97.8)	0.729	1916 (97.5)	1923 (97.9)	0.458
	ASA Class			0.014*			0.847
	Class 1/2	2157 (59.1)	1118 (55.7)		1116 (56.8)	1110 (56.5)	
	Class 3/4	1492 (40.9)	888 (44.3)		849 (43.2)	855 (43.5)	

SD indicates standard deviation; IQR, interquartile range; RVU, relative value unit; ASA, American Society of Anesthesiologists.
* Denotes significant value, p < 0.05.

Table 3
Comparison of 30-day outcomes.

	Unadjusted			Propensity Matched		
	No Resident	Resident	P-value	No Resident	Resident	P-value
	N (%)			N (%)		
30-day Post-operative Variables	3649 (64.5)	2006 (35.5)		1965 (50.0)	1965 (50.0)	
Overall complications	534 (14.6)	447 (22.3)	<0.001*	306 (15.6)	432 (22.0)	<0.001*
Surgical complications	76 (2.1)	67 (3.3)	0.004*	41 (2.1)	65 (3.3)	0.018*
Superficial SSI	41 (1.1)	44 (2.2)	0.002*	21 (1.1)	42 (2.1)	0.008*
Deep incisional SSI	17 (0.5)	16 (0.8)	0.117	9 (0.5)	16 (0.8)	0.160
Organ/space SSI	8 (0.2)	4 (0.2)	1.000	4 (0.2)	4 (0.2)	1.000
Wound disruption	13 (0.4)	5 (0.2)	0.494	9 (0.5)	5 (0.3)	0.284
Graft failure	3 (0.1)	1 (0.0)	1.000	2 (0.1)	1 (0.1)	1.000
Medical complications	479 (13.1)	413 (20.6)	<0.001*	276 (14.0)	399 (20.3)	<0.001*
Pneumonia	27 (0.7)	16 (0.8)	0.811	14 (0.7)	15 (0.8)	0.852
Unplanned re-intubation	13 (0.4)	11 (0.5)	0.288	11 (0.6)	11 (0.6)	1.000
DVT/PE	37 (1.0)	38 (1.9)	0.006*	16 (0.8)	37 (1.9)	0.004*
Mechanical ventilation > 48 h	16 (0.4)	11 (0.5)	0.566	11 (0.6)	11 (0.6)	1.000
Renal insufficiency	5 (0.1)	4 (0.2)	0.729	2 (0.1)	4 (0.2)	0.687
Acute renal failure	7 (0.2)	0 (0.0)	0.056	5 (0.3)	0 (0.0)	0.062
UTI	76 (2.1)	57 (2.8)	0.072	44 (2.2)	55 (2.8)	0.263
Stroke	7 (0.2)	6 (0.3)	0.403	4 (0.2)	5 (0.3)	1.000
Coma > 24 h	2 (0.1)	0 (0.0)	0.542	2 (0.1)	0 (0.0)	0.500
Peripheral nerve injury	11 (0.3)	8 (0.4)	0.545	8 (0.4)	8 (0.4)	1.000
Cardiac arrest	7 (0.2)	2 (0.1)	0.506	5 (0.3)	2 (0.1)	0.453
Myocardial infarction	9 (0.2)	6 (0.3)	0.714	7 (0.4)	6 (0.3)	0.781
Transfusions	347 (9.5)	298 (14.9)	<0.001*	200 (10.2)	287 (14.6)	<0.001*
Sepsis/septic shock	15 (0.4)	45 (2.2)	<0.001*	9 (0.5)	44 (2.2)	<0.001*
Death	11 (0.3)	6 (0.3)	0.988	8 (0.4)	6 (0.3)	0.592
Reoperation	129 (3.5)	106 (5.3)	0.002*	77 (3.9)	102 (5.2)	0.056

SSI indicates surgical site infection; DVT, deep vein thrombosis; PE, pulmonary embolism; UTI, urinary tract infection.
* Denotes significant value, $p < 0.05$.

Table 4
Risk-adjusted Multivariate Analysis of Major Outcomes.

	Unadjusted			Propensity Matched		
	OR	95% CI Lower-Upper	P-value	OR	95% CI Lower-Upper	P-value
Overall complications	1.33	1.14–1.55	<0.001*	1.33	1.11–1.58	0.002*
Medical complications	1.36	1.15–1.59	<0.001*	1.36	1.13–1.64	0.001*
Surgical complications	1.52	1.08–2.16	0.017*	1.44	0.96–2.16	0.081
Superficial SSI	1.76	1.13–2.74	0.013*	1.78	1.04–3.06	0.037*
DVT/PE	1.54	0.96–2.46	0.074	2.02	1.10–3.70	0.023*
Transfusion	1.25	1.04–1.51	0.016*	1.34	1.08–1.67	0.008*
Sepsis	5.07	2.77–9.26	<0.001*	4.36	2.10–9.05	<0.001*
Return to OR	1.49	1.13–1.95	0.005*	1.25	0.91–1.70	0.165

OR indicates odds ratio; CI, confidence interval; SSI, surgical site infection; DVT, deep vein thrombosis; PE, pulmonary embolism; return to OR, operating room.
* Denotes significant value, $p < 0.05$.

Meanwhile, Fischer et al. found that resident participation was associated with increased risk of surgical morbidity and the post-graduate year was inversely related to risk of surgical complications following breast surgery [40]. It is possible that more senior level residents may positively impact patient outcomes but this was not purpose of the present analysis. Furthermore, each residency program is unique and offers its own faculty, patient population, and mandates. As mentioned previously, it is difficult to discern the optimal time to increase the operative experience in spinal fusion among surgical trainees. In addition, with the advancement of software and virtual reality technology, the current graduate education landscape is poised for improvement, especially for junior residents. For example, a pilot study by Sundar et al. utilized software technology allowing residents to practice on models and cadavers leading to a reduction in overall complications [41].

This study has several limitations that are inherent in the use of the ACS-NSQIP database. Although we attempted to reduce confounding with propensity score matching and multivariate logistic regression, they cannot be eliminated. This study is also limited by our inability to completely adjust for variables that are not captured (i.e. number of residents in the OR, degree of resident participation). Degree of resident and attending participation could provide means of improved risk stratification. In addition, the database only captures 30-day post-operative outcomes limiting our ability to assess long-term patient outcomes related to care provided by residents. Lastly, specific clinical endpoints that are pertinent to spine surgeons, such as functional outcomes, are not available in ACS-NSQIP.

5. Conclusion

Resident education continues to play an extensive role in academic medical centers with conflicting results about its impact on clinical measurements. Through this ACS-NSQIP database study of 5655 patients, we determined that resident participation in lumbar spinal fusions was relatively safe with no increase in mortality or reoperation. However, it is associated with longer operative times and longer hospital stays. In addition, there is an increased risk of post-operative complications such as sepsis, thromboembolic events such as DVT and PE, and superficial surgical site infections. As the surgical techniques continue to expand in spine surgery, there needs to be a corresponding evolution in resident education in order to maximize the learning experience and to ensure proficiency and patient safety.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jocn.2018.06.030.

References

[1] Mobbs RJ, Phan K, Malham G, et al. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015;1:2–18.
[2] Eck JC, Sharan A, Ghogawala Z, et al. Guideline update for the performance of fusion procedures for degenerative disease of the lumbar spine. Part 7: lumbar fusion for intractable low-back pain without stenosis or spondylolisthesis. J Neurosurg Spine 2014;21:42–7.
[3] Pannell WC, Savin DD, Scott TP, et al. Trends in the surgical treatment of lumbar spine disease in the United States. Spine J 2015;15:1719–27.
[4] Weinstein JN, Lurie JD, Olson PR, et al. United States' trends and regional variations in lumbar spine surgery: 1992–2003. Spine 2006;31:2707–14.
[5] Yoshihara H, Yoneoka D. National trends in the surgical treatment for lumbar degenerative disc disease: United States, 2000 to 2009. Spine J 2015;15:265–71.
[6] Dutta S, Dunnington G, Blanchard MC, et al. And doctor, no residents please! J Am Coll Surg 2003;197:1012–7.
[7] Norby K, Siddiq F, Adil MM, et al. The effect of duty hour regulations on outcomes of neurological surgery in training hospitals in the United States: duty hour regulations and patient outcomes. J Neurosurg 2014;121:247–61.
[8] Rajaram R, Chung JW, Jones AT, et al. Association of the 2011 ACGME resident duty hour reform with general surgery patient outcomes and with resident examination performance. JAMA 2014;312:2374–84.
[9] Babu R, Thomas S, Hazzard MA, et al. Morbidity, mortality, and health care costs for patients undergoing spine surgery following the ACGME resident duty-hour reform: clinical article. J Neurosurg Spine 2014;21:502–15.
[10] Ahmed N, Devitt KS, Keshet I, et al. A systematic review of the effects of resident duty hour restrictions in surgery: impact on resident wellness, training, and patient outcomes. Ann Surg 2014;259:1041–53.
[11] Durkin ET, McDonald R, Munoz A, et al. The impact of work hour restrictions on surgical resident education. J Surg Edu 2008;65:54–60.
[12] Neal CJ, Rosner MK. Resident learning curve for minimal-access transforaminal lumbar interbody fusion in a military training program. Neurosurg Focus 2010;28:E21.
[13] Moore DB, Slabaugh MA. Surgical outcomes and cost basis for resident-performed cataract surgery in an uninsured patient population. JAMA Ophthalmol 2013;131:891–7.
[14] Jordan SW, Mioton LM, Smetona J, et al. Resident involvement and plastic surgery outcomes: an analysis of 10,356 patients from the American College of Surgeons National Surgical Quality Improvement Program database. Plastic Reconstruct Surg 2013;131:763–73.
[15] Castleberry AW, Clary BM, Migaly J, et al. Resident education in the era of patient safety: a nationwide analysis of outcomes and complications in resident-assisted oncologic surgery. Ann Surg Oncol 2013;20:3715–24.
[16] Saliba AN, Taher AT, Tamim H, et al. Impact of Resident Involvement in Surgery (IRIS-NSQIP): Looking at the Bigger Picture Based on the American College of Surgeons-NSQIP Database. J Am Coll Surg 2016;222:30–40.
[17] Ferraris VA, Harris JW, Martin JT, et al. Impact of residents on surgical outcomes in high-complexity procedures. J Am Coll Surg 2016;222:545–55.
[18] Stienen MN, Joswig H, Jucker D, et al. Anterior cervical discectomy and fusion: is surgical education safe? Acta Neurochirurgica 2015;157:1395–404.
[19] Joswig H, Hock C, Hildebrandt G, et al. Microscopic lumbar spinal stenosis decompression: is surgical education safe? Acta Neurochirurgica 2016;158:357–66.
[20] Kim RB, Garcia RM, Smith ZA, et al. Impact of resident participation on outcomes after single-level anterior cervical diskectomy and fusion: an analysis of 3265 patients from the American College Of Surgeons National Surgical Quality Improvement Program Database. Spine 2016;41:E289–96.
[21] Lim S, Parsa AT, Kim BD, et al. Impact of resident involvement in neurosurgery: an analysis of 8748 patients from the 2011 American College of Surgeons National Surgical Quality Improvement Program database. J Neurosurg 2015;122:962–70.
[22] Edelstein AI, Lovecchio FC, Saha S, et al. Impact of resident involvement on orthopaedic surgery outcomes: an analysis of 30,628 patients from the American College of Surgeons National Surgical Quality Improvement Program Database. Journal Bone Joint Surg Am 2014;96:e131.
[23] Kothari P, Lee NJ, Lakomkin N, et al. Impact of resident involvement on morbidity in adult patients undergoing fusion for spinal deformity. Spine 2016;41:1296–302.
[24] Lee NJ, Kothari P, Kim C, et al. The impact of resident involvement in elective posterior cervical fusion. Spine 2016.
[25] Rosenbaum PRRD. Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. Am Statist 1985;39:33–9.
[26] Thoemmes FJ, Kim ES. A systematic review of propensity score methods in the social sciences. Multivariate Behav Res 2011;46:90–118.
[27] Stukel TA, Fisher ES, Wennberg DE, et al. Analysis of observational studies in the presence of treatment selection bias: Effects of invasive cardiac management on ami survival using propensity score and instrumental variable methods. JAMA 2007;297:278–85.
[28] Austin PC. Optimal caliper widths for propensity-score matching when estimating differences in means and differences in proportions in observational studies. Pharm Stat 2011;10:150–61.
[29] Campbell Jr DA, Henderson WG, Englesbe MJ, et al. Surgical site infection prevention: the importance of operative duration and blood transfusion–results of the first American College of Surgeons-National Surgical Quality Improvement Program Best Practices Initiative. J Am Coll Surg 2008;207:810–20.
[30] Jackson TD, Wannares JJ, Lancaster RT, et al. Does speed matter? The impact of operative time on outcome in laparoscopic surgery. Surg Endoscopy 2011;25:2288–95.
[31] Tan TW, Kalish JA, Hamburg NM, et al. Shorter duration of femoral-popliteal bypass is associated with decreased surgical site infection and shorter hospital length of stay. J Am Coll Surg 2012;215:512–8.
[32] Davis GB, Peric M, Chan LS, et al. Identifying risk factors for surgical site infections in mastectomy patients using the National Surgical Quality Improvement Program database. Am J Surg 2013;205:194–9.
[33] Khuri SF, Najjar SF, Daley J, et al. Comparison of surgical outcomes between teaching and nonteaching hospitals in the Department of Veterans Affairs. Ann Surg 2001;234:370–82. discussion 82-3.
[34] Daley BJ, Cecil W, Clarke PC, et al. How slow is too slow? Correlation of operative time to complications: an analysis from the Tennessee Surgical Quality Collaborative. J Am Coll Surg 2015;220:550–8.
[35] Kim BD, Hsu WK, De Oliveira GS, Jr,, et al. Operative duration as an independent risk factor for postoperative complications in single-level lumbar fusion: an analysis of 4588 surgical cases. Spine 2014;39:510–20.
[36] Kiran RP, Ahmed Ali U, Coffey JC, et al. Impact of resident participation in surgical operations on postoperative outcomes: National Surgical Quality Improvement Program. Ann Surg 2012;256:469–75.
[37] Hernandez AJ, Almeida AM, Favaro E, et al. The influence of tourniquet use and operative time on the incidence of deep vein thrombosis in total knee arthroplasty. Clinics (Sao Paulo, Brazil) 2012;67:1053–7.
[38] Abel EJ, Wong K, Sado M, et al. Surgical operative time increases the risk of deep venous thrombosis and pulmonary embolism in robotic prostatectomy. JSLS 2014;18:282–7.
[39] Eck JC, Hodges S, Humphreys SC. Minimally invasive lumbar spinal fusion. J Am Acad Orthopaedic Surg 2007;15:321–9.
[40] Fischer JP, Wes AM, Kovach SJ. The impact of surgical resident participation in breast reduction surgery–outcome analysis from the 2005–2011 ACS-NSQIP datasets. J Plastic Surg Hand Surg 2014;48:315–21.
[41] Sundar SJ, Healy AT, Kshettry VR, et al. A pilot study of the utility of a laboratory-based spinal fixation training program for neurosurgical residents. J Neurosurg Spine 2016;24:850–6.