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ORIGINAL ARTICLE

The impact of anesthesia and surgical provider characteristics on outcomes after spine surgery

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Abstract

Purpose Information regarding the impact of provider characteristics on perioperative outcomes in the spine surgery setting is limited. Existing studies primarily consider the impact of surgical provider volume. This analysis sought to identify the impact of anesthesiologist and surgeon volume and experience as well as anesthesia care team composition on adverse outcomes following anterior cervical discectomy and fusions (ACDF) and posterior lumbar fusions (PLF).

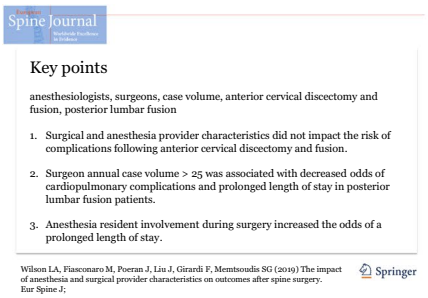
Methods We identified 5900 patients who underwent ACDF or PLF procedures at a high-volume orthopedic institution from 2005 to 2014. Provider characteristics of interest were anesthesiologist and surgeon volume and experience along with anesthesia care team composition. Multivariable logistic regression models were used to evaluate the outcomes of any complication, cardiopulmonary complication, and prolonged length of stay (> 7 days). Intraclass correlation coefficients were calculated to determine how much variation in outcomes could be explained by provider characteristics.

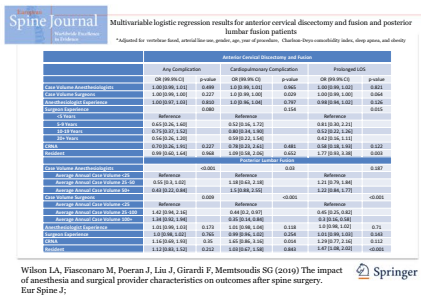
Results There were no significant relationships between provider characteristics and perioperative outcomes among ACDF patients. Within the PLF cohort, surgeon annual case volume > 25 was associated with decreased odds of prolonged length of stay, while anesthesia resident involvement was associated with increased odds of prolonged length of stay. Surgeon characteristics explained the greatest proportion of variation in outcomes while anesthesiologist characteristics explained the least.

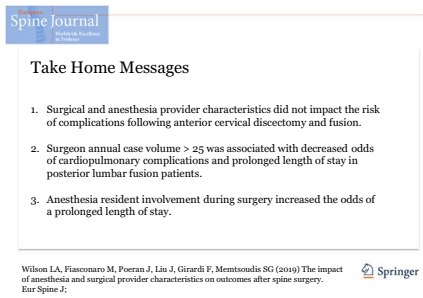
Conclusions Anesthesia provider volume and experience did not significantly impact the odds of adverse outcome for ACDF and PLF patients. Higher surgeon volume was exclusively associated with decreased odds of prolonged length of stay following PLF. Further study is necessary to determine if these relationships persist in a less-specialized setting.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Anesthesiologists · Surgeons · Case volume · Anterior cervical discectomy and fusion · Posterior lumbar fusion

Introduction

While several studies have examined the relationship between hospital or surgeon volume and outcomes following orthopedic surgery, these studies have predominantly

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focused on total joint arthroplasties. Few have investigated these relationships within the spine surgery setting [1]. Of those that have, the majority consider the role of surgical provider volume [2–4] neglecting to consider provider experience or the role of the anesthesia provider.

Research regarding the role of anesthesia care teams (consisting of an anesthesiologist alone, with a certified registered nurse anesthetist (CRNA), or anesthesia resident) is limited. Studies evaluating the impact of resident involvement on postoperative complications have primarily focused on orthopedic residents [5] rather than anesthesia residents. Studies evaluating the impact of care teams composed of anesthesiologists and CRNAs are limited to the outcome of postoperative mortality [6, 7].

Therefore, we sought to identify risk factors for postoperative complications as a function of surgeon and anesthesiologist volume and experience as well as anesthesia care team composition. We hypothesized that higher provider volume and greater experience for both surgeons and anesthesiologists would be associated with improved patient outcomes within a high volume, specialized orthopedic institution.

Materials and methods

Approval for this retrospective cohort study of spine surgery patients identified from hospital billing datasets was obtained from the Institutional Review Board of Hospital for Special Surgery (IRB #2016-436), and the study was deemed exempt from the requirement of informed consent. This study was reported according to the Strengthening the Reporting of Studies in Epidemiology (STROBE) statement. The datasets analyzed during the current study are not publicly available due to the fact that they contain protected health information, but are available from the corresponding author on reasonable request.

International Classification of Diseases 9th *revision* (ICD-9) procedure codes were used to identify patients who underwent anterior cervical discectomy and fusion (ACDF) (81.02) or posterior lumbar fusion (PLF) (81.08) procedures from 2005 to 2014. Patients were excluded if they had a type of anesthesia reported other than general ($n = 61$) or were missing gender information ($n = 3$). Procedures performed by surgeons or anesthesiologists with fewer than 20 procedures over the entire study period were excluded as well ($n = 134$).

The main provider characteristics of interest were both surgeon and anesthesiologist annual case volume and experience. Individual providers were assigned unique numeric identifiers to minimize bias. Case volume was calculated annually to account for any year-to-year fluctuations in provider volume. Experience was defined based on years since American Board of Orthopaedic Surgery certification for surgeons and years since American Board of Anesthesiology certification for anesthesiologists, adjusted to reflect their experience at the time of surgery. Anesthesia care team composition, as reflected by the presence or absence of a CRNA or anesthesiology resident, was also considered. These variables were defined based on whether or not patients were billed for having a CRNA present during surgery and/or had a resident's name listed in their billing file.

The primary outcome of any complication included cardiopulmonary, central nervous system, delirium, renal/genitourinary, or thrombosis complications at any point during the patient's postoperative stay. We also separately considered incidence of cardiopulmonary complications. Both variables were defined according to ICD-9 diagnosis codes that were not present on admission (Appendix). Prolonged length of stay was included as an additional outcome. This outcome was defined according to the 90th percentile of length of stay which was 7 days.

Additional covariates considered were age, gender, case duration, number of vertebrae fused (2–3: ICD-9 81.62; 4–7 ICD-9 81.63), procedure year, comorbidity burden as measured by Charlson–Deyo comorbidity index [8], the presence of sleep apnea, obesity, and placement of an arterial line.

Statistical analysis

Univariate analyses were conducted for the entire sample of spine patients stratified by complication status. Frequencies (%) of categorical variables were reported and analyzed using Chi-square tests. To account for non-normal distributions, continuous variables were reported as median [interquartile range (IQR)] and analyzed using Kruskal–Wallis tests.

Six separate multivariable logistic regression models were run for the ACDF and PLF cohorts for each of the three outcomes of interest: any complication, cardiopulmonary complication, and prolonged length of stay. The variables of annual case volume and experience were originally treated as continuous. If these variables were significantly associated with any of the outcomes, they were then categorized to further evaluate their relationship with the outcome of interest. Models were used to evaluate the association between both surgical and anesthesia provider characteristics and each outcome upon adjusting for patient age, gender, number of vertebrae fused, Charlson–Deyo index (categorized as 0, 1, 2, and 3+), sleep apnea, obesity, and placement of an arterial line (used an additional proxy for case invasiveness). Odds ratios (OR) and Bonferroni corrected 99.9% confidence intervals (CI) are reported as well as model c-statistics. There were 36 provider-related hypotheses of interest tested in this analysis, and therefore, after a Bonferroni correction, results with a P value less than or equal to 0.001 were considered statistically significant.

All analyses were conducted using RStudio version 1.1.45 [9] as an interface for R version 3.5.1 [10]. The package 'tableone' was used to conduct univariate analyses [11], 'pROC' was used to calculate c-statistics [12], 'lme4' was used to run multilevel models [13], and the 'sjstats' package was used to calculate ICC [14].

Results

The total cohort consisted of 2976 ACDF and 2924 PLF procedures performed by 18 individual surgeons (median annual case volume 77 and median experience 15 years) and 40 individual anesthesiologists (median annual case volume 37 and median experience 11 years). Complications were more likely to occur following posterior fusions (23.6%) compared to ACDF (7.0%). Overall incidence of complications and prolonged length of stay significantly declined throughout the study period within both surgical cohorts.

In univariate analyses, adverse outcomes were less likely to occur when surgeons or anesthesiologists had more than 20 years of experience. Greater anesthesiologist annual case volume was associated with a lower incidence of complications; however, surgeon volume did not have any apparent association with complication incidence. Complications were more likely to occur following spine procedures where a CRNA or resident was present. The same provider-related trends were observed for cardiopulmonary complications and prolonged length of stay (Table 1).

Anterior cervical discectomy and fusion

Across all three outcomes, no provider-related variables significantly impacted the odds of experiencing a complication or prolonged length of stay upon adjusting for other covariates (Table 2).

Surgeon volume explained the greatest proportion of variance in complications (3.0%), while anesthesiologist volume did not explain any, and surgeon and anesthesiologist experience each explained approximately 1.9%. Similar trends were observed for cardiopulmonary complications with surgeon volume explaining 4.5% and experience explaining 2.2% of variation, while anesthesiologist volume explained 1.0%. Anesthesiologist experience did not explain any of the variation in both cardiopulmonary complications and prolonged length of stay. Surgeon experience explained the greatest proportion of variance in prolonged length of stay (6.6%) followed by surgeon volume (5.9%) and anesthesiologist volume (2.1%).

Posterior lumbar fusion

Upon inclusion in the multivariable model, no provider-related variables were significant predictors of experiencing a postoperative complication. Surgeon annual case volume greater than 25 was associated with significantly decreased odds of a prolonged length of stay among PLF patients, while having a anesthesia resident present during surgery increased the odds of a prolonged length of stay (OR 1.47, CI 1.08, 2.02) (Table 3).

Surgeon volume and experience explained the greatest proportion of variation in complications (3.8% and 3.0%, respectively), while anesthesiologist volume and experience explained the least (1.4% and 0.8%). The same trends were observed for prolonged length of stay with 5.2% explained by surgeon volume, 3.0% by experience, 0.8% by anesthesiologist volume, and 0.2% by experience. Anesthesiologist volume explained a greater proportion of variance in cardiopulmonary complications than surgeon volume (3.1% vs 1.5%), while provider experience explained approximately 2.4%.

Discussion

Within this sample of 5900 spine surgery patients, we found that provider characteristics played a minor role in influencing postoperative complications following procedures performed at a high-volume orthopedic institution. No significant relationships were observed between provider variables and outcomes among ACDF patients. However, greater surgeon annual case volume was found to reduce the odds of a prolonged length of stay following PLF, while anesthesia resident involvement increased the odds. For both surgical cohorts, surgeon volume and experience explained the greatest variation in complications and anesthesia provider characteristics explained the least.

Our finding that greater surgeon annual case volume was associated with decreased odds of a complication among PLF patients is consistent with previous findings. A study examining the relationship between provider volume and complications following surgery for lumbar spinal stenosis observed the same trend [15]. Prior research, attempting to establish procedure volume benchmarks for lumbar spine surgery, identified 43 procedures per year as the inflection point for decreased complication risk following lumbar interbody fusions [16]. We observed a similar declining trend in cardiopulmonary complications; however, in our study this reached significance when surgeons performed greater than 25 procedures per year. This lower threshold maybe a consequence of utilizing data from a high-volume specialized institution. Further study in less-specialized

Table 1 Summary of ACDF and PLF patient characteristics, stratified by the presence or absence of any complication, cardiopulmonary complications, and prolonged length of stay

	Any complication ($n=898$)	No complication ($n=5002$)	*P* value	Cardiopulmonary complication ($n=410$)	No complication ($n=5490$)	*P* value	LOS ≥ 7 days ($n=806$)	LOS < 7 days ($n=5094$)	*P* value
	n (%)	*n* (%)		*n* (%)	*n* (%)		*n* (%)	*n* (%)	
Type of surgery			< 0.001			< 0.001			< 0.001
ACDF	207 (7.0)	2769 (93.0)		124 (4.2)	2852 (95.8)		130 (4.4)	2846 (95.6)	
Posterior fusion	691 (23.6)	2233 (76.4)		286 (9.8)	2638 (90.2)		676 (23.1)	2248 (76.9)	
Case volume anesthesiologists			< 0.001			< 0.001			< 0.001
Average annual case volume < 25	242 (13.3)	1585 (86.8)		110 (6.0)	1717 (94.0)		227 (12.4)	1600 (87.6)	
Average annual case volume 25–50	264 (13.7)	1667 (86.3)		111 (5.7)	1820 (94.3)		216 (11.2)	1715 (88.8)	
Average annual case volume 50+	392 (18.3)	1750 (81.7)		189 (8.8)	1953 (91.2)		363 (17.0)	1779 (83.1)	
Case volume surgeons			0.147			0.506			0.021
Average annual case volume < 25	72 (16.1)	374 (83.9)		37 (8.3)	409 (91.7)		80 (17.9)	366 (82.1)	
Average annual case volume 25–100	548 (14.5)	3222 (85.5)		257 (6.8)	3513 (93.2)		508 (13.5)	3262 (86.5)	
Average annual case volume 100+	278 (16.5)	1406 (83.5)		116 (6.9)	1568 (93.1)		218 (13.0)	1466 (87.1)	
Anesthesiologist experience			< 0.001			0.002			0.005
< 5 years	222 (13.8)	1391 (86.2)		97 (6.0)	1516 (94.0)		210 (13.0)	1403 (87.0)	
5–9 years	159 (14.2)	962 (85.8)		67 (6.0)	1054 (94.0)		142 (12.7)	979 (87.3)	
10–19 years	384 (18.4)	1709 (81.7)		188 (9.0)	1905 (91.0)		329 (15.7)	1764 (84.3)	
20 + years	133 (12.4)	940 (87.6)		58 (5.4)	1015 (94.6)		125 (11.7)	948 (88.4)	
Surgeon experience			< 0.001			< 0.001			< 0.001
< 5 years	143 (18.6)	625 (81.4)		80 (10.4)	688 (89.6)		134 (17.5)	634 (82.6)	
5–9 years	148 (19.1)	628 (81.0)		56 (7.2)	720 (92.8)		131 (16.9)	645 (83.1)	
10–19 years	436 (14.9)	2487 (85.1)		205 (7.0)	2718 (93.0)		367 (12.6)	2556 (87.4)	
20 + years	171 (11.9)	1262 (88.1)		69 (4.8)	1364 (95.2)		174 (12.1)	1259 (87.9)	
Vertebrae fused			< 0.001			< 0.001			< 0.001
2–3	641 (13.9)	3975 (86.1)		281 (6.1)	4335 (93.9)		512 (11.1)	4104 (88.9)	
4+	235 (22.0)	835 (78.0)		118 (11.0)	952 (89.0)		252 (23.6)	818 (76.5)	
Missing	22 (10.3)	192 (89.7)		11 (5.1)	203 (94.9)		42 (19.6)	172 (80.4)	
CRNA	94 (22.7)	321 (77.4)	< 0.001	53 (12.8)	362 (87.2)	< 0.001	93 (22.4)	322 (77.6)	< 0.001
Resident	497 (17.4)	2352 (82.6)	< 0.001	222 (7.8)	2627 (92.2)	0.016	509 (17.9)	2340 (82.1)	< 0.001
Arterial line	418 (18.2)	1877 (81.8)	< 0.001	181 (7.9)	2114 (92.1)	0.027	412 (18.0)	1883 (82.1)	< 0.001
Case duration (median [IQR])	137.33 (111.0, 167.6)	133.0 (105.0, 171.0)	0.14	137.0 (113.3, 171.8)	133.0 (105.0, 170.5)	0.1	137.0 (111.0, 170.5)	133.0 (105.0, 170.5)	0.078
Year			< 0.001			< 0.001			< 0.001
2005	180 (27.8)	468 (72.2)		73 (11.3)	575 (88.7)		108 (16.7)	540 (83.3)	
2006	164 (21.9)	585 (78.1)		81 (10.8)	668 (89.2)		148 (19.8)	601 (80.2)	

Table 1 (continued)

	Any complication ($n=898$) *n* (%)	No complication ($n=5002$) *n* (%)	*P* value	Cardiopulmonary complication ($n=410$) *n* (%)	No complication ($n=5490$) *n* (%)	*P* value	LOS ≥ 7 days ($n=806$) *n* (%)	LOS < 7 days ($n=5094$) *n* (%)	*P* value
2007	120 (17.3)	572 (82.7)		66 (9.5)	626 (90.5)		133 (19.2)	559 (80.8)	
2008	110 (16.0)	577 (84.0)		38 (5.5)	649 (94.5)		118 (17.2)	569 (82.8)	
2009	102 (14.0)	627 (86)		40 (5.5)	689 (94.5)		119 (16.3)	610 (83.7)	
2010	68 (10.7)	570 (89.3)		32 (5.0)	606 (95.0)		75 (11.8)	563 (88.2)	
2011	17 (4.7)	343 (95.3)		9 (2.5)	351 (97.5)		12 (3.3)	348 (96.7)	
2012	36 (9.7)	337 (90.4)		23 (6.2)	350 (93.8)		29 (7.8)	344 (92.2)	
2013	36 (8.5)	388 (91.5)		18 (4.3)	406 (95.8)		18 (4.5)	406 (95.6)	
2014	65 (10.8)	535 (89.2)		30 (5.0)	570 (95.0)		46 (7.7)	554 (92.3)	
Gender			< 0.001			0.064			< 0.001
Female	505 (17.4)	2393 (82.6)		220 (7.6)	2678 (92.4)		484 (16.7)	2414 (83.3)	
Male	393 (13.1)	2609 (86.9)		190 (6.3)	2812 (93.7)		322 (10.7)	2680 (89.3)	
Age (median [IQR])	64.0 (53.0, 74.0)	54.0 (45.0, 65.0)	< 0.001	63.0 (53.0, 74.0)	55.0 (45.0, 66.0)	< 0.001	64.0 (54.0, 73.0)	54.0 (45.0, 65.0)	< 0.001
Deyo index			< 0.001			< 0.001			< 0.001
0	518 (12.9)	3505 (87.1)		227 (5.6)	3796 (94.4)		470 (11.7)	3553 (88.3)	
1	137 (17.5)	648 (82.6)		75 (9.6)	710 (90.5)		131 (16.7)	654 (83.3)	
2	166 (23.3)	548 (76.8)		74 (10.4)	640 (89.6)		130 (18.2)	584 (81.8)	
3+	73 (32.4)	152 (67.6)		33 (14.7)	192 (85.3)		75 (33.3)	150 (66.7)	
Missing	4 (2.6)	149 (97.4)		1 (0.7)	152 (99.4)		0	153 (100.0)	
Sleep apnea			0.221			1			0.152
Yes	82 (17.6)	383 (82.4)		33 (7.1)	432 (92.9)		76 (16.3)	389 (83.7)	
No	812 (15.4)	4470 (84.6)		376 (7.1)	4906 (92.9)		730 (13.8)	4552 (86.2)	
Missing	4 (2.6)	149 (97.4)		1 (0.7)	152 (99.4)		0 (0.0)	153 (100.0)	
Obesity			0.006			0.005			0.011
Yes	169 (18.7)	737 (81.4)		85 (9.4)	821 (90.6)		152 (16.8)	754 (83.2)	
No	725 (15.0)	4116 (85.0)		324 (6.7)	4517 (93.3)		654 (13.5)	4187 (86.5)	
Missing	4 (2.6)	149 (97.4)		1 (0.7)	152 (99.4)		0 (0.0)	153 (100.0)	

Table 2 Multivariable logistic regression results for anterior cervical discectomy and fusion patients

	Any complication		Cardiopulmonary complication		Prolonged LOS	
	OR (99.9% CI)	*P* value	OR (99.9% CI)	*P* value	OR (99.9% CI)	*P* value
Case volume anesthesiologists	1.00 (0.99, 1.01)	0.499	1.0 (0.99, 1.01)	0.965	1.00 (0.99, 1.02)	0.821
Case volume surgeons	1.00 (0.99, 1.00)	0.227	1.0 (0.99, 1.00)	0.029	1.00 (0.99, 1.00)	0.064
Anesthesiologist experience	1.00 (0.97, 1.03)	0.810	1.0 (0.96, 1.04)	0.797	0.98 (0.94, 1.02)	0.126
Surgeon experience		0.080		0.154		0.015
< 5 years	Reference		Reference		Reference	
5–9 years	0.65 (0.26, 1.60)		0.52 (0.16, 1.72)		0.81 (0.30, 2.21)	
10–19 years	0.75 (0.37, 1.52)		0.80 (0.34, 1.90)		0.52 (0.22, 1.26)	
20 + years	0.56 (0.26, 1.20)		0.59 (0.22, 1.54)		0.42 (0.16, 1.11)	
CRNA	0.70 (0.26, 1.91)	0.227	0.78 (0.23, 2.61)	0.481	0.58 (0.18, 1.93)	0.122
Resident	0.99 (0.60, 1.64)	0.968	1.09 (0.58, 2.06)	0.652	1.77 (0.93, 3.38)	0.003
Vertebrae fused		< 0.001		< 0.001		< 0.001
2–3	Reference		Reference		Reference	
4+	2.23 (1.32, 3.77)		2.58 (1.34, 5.00)		2.98 (1.55, 5.73)	
Unknown	0.87 (0.12, 6.44)		1.65 (0.22, 12.72)		2.58 (0.40, 16.55)	
Arterial line	1.44 (0.87, 2.40)	0.018	1.44 (0.76, 2.73)	0.064	1.94 (1.02, 3.69)	< 0.001
Gender		0.721		0.883		0.682
Female	Reference		Reference		Reference	
Male	0.95 (0.57, 1.56)		1.03 (0.54, 1.95)		1.08 (0.57, 2.06)	
Age	1.04 (1.02, 1.06)	< 0.001	1.04 (1.01, 1.07)	< 0.001	1.05 (1.02, 1.08)	< 0.001
Year	0.90 (0.81, 1.00)	0.001	0.89 (0.78, 1.01)	0.004	0.93 (0.81, 1.07)	0.097
Deyo index		0.003		< 0.001		< 0.001
0	Reference		Reference		Reference	
1	1.26 (0.66, 2.42)		1.63 (0.75, 3.56)		1.87 (0.87, 4.03)	
2	3.17 (1.23, 8.16)		4.15 (1.41, 12.27)		4.38 (1.46, 13.19)	
3+	1.16 (0.09, 14.34)		2.22 (0.18, 28.28)		5.71 (0.74, 43.96)	
Unknown	0.42 (0.04, 4.56)		–		–	
Sleep apnea	1.07 (0.48, 2.41)	0.780	1.26 (0.49, 3.25)	0.428	0.84 (0.29, 2.44)	0.592
Obesity	1.25 (0.63, 2.48)	0.288	1.45 (0.63, 3.32)	0.148	1.04 (0.43, 2.55)	0.879
	c-statistic: 0.730		c-statistic: 0.756		c-statistic: 0.816	

settings is necessary to obtain a more generalizable estimate of the ideal surgical provider volume to reduce risk of complications.

The involvement of a CRNA had no significant impact on complication incidence or prolonged length of stay within either patient population. While cardiopulmonary complications seemed to be more frequent in patients having PLF surgery when CRNAs were involved, this association was not significant in the multivariable regression analysis using our stringent significance cutoff. Given the observed trend and significant interest in the topic, future research may be warranted to more closely study a potential link between outcomes and CRNA involvement including questions of causality, particularly since these results conflict with a recent study which found that anesthesia care teams resulted in better patient outcomes relative to those performed by anesthesiologists alone [6]. Among PLF patients, we found that anesthesia resident involvement significantly increased the odds of prolonged length of stay. However, it is not possible to conclude a causal relationship, especially given the increased likelihood of confounding by extraneous factors as time from surgery increases. Therefore, it is possible that residents were assigned to more involved cases for educational purposes.

Of note is the decline in the incidence of complications and prolonged length of stay throughout the study period. This may be a consequence of advances in perioperative care resulting in decreased length of stay and improved patient outcomes. Regardless of the cause, the relationships identified in this analysis arose independently of these trends.

We did not observe significant trends associated with anesthesiologist volume or experience within both the ACDF and PLF cohorts. This is in line with a study that found no relationship between patient outcomes following pancreatic resections and anesthesia provider volume [17]. Given this finding, it is not surprising that anesthesiologist

Table 3 Multivariable logistic regression results for posterior lumbar fusion patients

	Any complication		Cardiopulmonary complication		Prolonged LOS	
	OR (99.9% CI)	*P* value	OR (99.9% CI)	*P* value	OR (99.9% CI)	*P* value
Case volume anesthesiologists		< 0.001		0.03		0.187
Average annual case volume < 25	Reference		Reference		Reference	
Average annual case volume 25–50	0.55 (0.3, 1.02)		1.18 (0.63, 2.18)		1.21 (0.79, 1.84)	
Average annual case volume 50+	0.43 (0.22, 0.84)		1.5 (0.88, 2.55)		1.22 (0.84, 1.77)	
Case volume surgeons		0.009		< 0.001		< 0.001
Average annual case volume < 25	Reference		Reference		Reference	
Average annual case volume 25–100	1.42 (0.94, 2.16)		0.44 (0.2, 0.97)		0.45 (0.25, 0.82)	
Average annual case volume 100+	1.34 (0.92, 1.94)		0.35 (0.14, 0.84)		0.3 (0.16, 0.58)	
Anesthesiologist experience	1.01 (0.99, 1.03)	0.173	1.01 (0.98, 1.04)	0.118	1.0 (0.98, 1.02)	0.71
Surgeon experience	1.0 (0.98, 1.02)	0.765	0.99 (0.96, 1.02)	0.254	1.01 (0.99, 1.03)	0.143
CRNA	1.16 (0.69, 1.93)	0.35	1.65 (0.86, 3.16)	0.014	1.29 (0.77, 2.16)	0.112
Resident	1.12 (0.83, 1.52)	0.212	1.03 (0.67, 1.58)	0.843	1.47 (1.08, 2.02)	< 0.001
Vertebrae fused		< 0.001		0.036		< 0.001
2–3	Reference		Reference		Reference	
4+	1.46 (0.99, 2.16)		1.28 (0.75, 2.18)		2.59 (1.77, 3.79)	
Unknown	0.47 (0.2, 1.1)		0.51 (0.15, 1.77)		1.34 (0.69, 2.6)	
Arterial line	1.17 (0.86, 1.59)	0.085	0.95 (0.61, 1.47)	0.699	1.31 (0.96, 1.78)	0.005
Gender		0.124		0.743		< 0.001
Female	Reference		Reference		Reference	
Male	0.87 (0.64, 1.18)		1.04 (0.68, 1.6)		0.68 (0.5, 0.93)	
Age	1.02 (1.01, 1.03)	< 0.001	1.02 (1.0, 1.04)	< 0.001	1.01 (1.0, 1.03)	< 0.001
Year	0.88 (0.82, 0.95)	< 0.001	0.86 (0.77, 0.96)	< 0.001	0.91 (0.85, 0.98)	< 0.001
Deyo index		0.012		0.036		< 0.001
0	Reference		Reference		Reference	
1	1.26 (0.8, 1.97)		1.52 (0.83, 2.78)		1.16 (0.74, 1.82)	
2	1.03 (0.67, 1.58)		1.06 (0.58, 1.96)		0.83 (0.53, 1.31)	
3+	1.67 (0.94, 2.97)		1.65 (0.76, 3.59)		1.88 (1.05, 3.36)	
Unknown	0.82 (0.07, 9.71)		1.09 (0.04, 33.55)		–	
Sleep apnea	1.26 (0.72, 2.2)	0.187	0.66 (0.26, 1.67)	0.127	1.43 (0.81, 2.53)	0.04
Obesity	1.58 (1.05, 2.39)	< 0.001	1.79 (1.03, 3.1)	< 0.001	1.54 (1.01, 2.35)	< 0.001
	c-statistic: 0.664		c-statistic: 0.676		c-statistic: 0.695	

experience and volume explained limited proportions of the variation in complications and prolonged length of stay.

Although surgeon characteristics explained a greater proportion of the variability in complications relative to anesthesiologists, these proportions were still marginal. The most substantial relationship was between surgeon volume and prolonged length of stay following PLF, and this ICC barely exceeded 5%. This indicates that risk of complications is largely attributable to other factors such as patient demographics and comorbidity burden.

There are a number of limitations to this study. As with any observational study, confounding is a concern, particularly in regards to our prolonged length of stay definition of seven days. There are likely a number of unmeasured factors that accumulate a week into a patient's stay that are unrelated to their surgical team. As previously mentioned, our use of data from a high-volume specialized orthopedic institution limits the generalizability of our findings. Results are also subject to information bias due to dependence on ICD-9 codes to define complications. Any errors in data entry may have influenced the relationships we observed.

In conclusion, surgical and anesthesia provider characteristics did not impact the risk of complications following ACDF in this study. Surgeon annual case volume greater than 25 cases was associated with decreased odds of cardiopulmonary complications and prolonged length of stay among PLF patients. Anesthesia care team composition did not appear to have a significant impact on spine patient outcomes, aside from an association between anesthesia resident involvement during surgery and increased odds of prolonged length of stay. Further study in a less-specialized

setting is necessary to determine if these relationships persist.

Compliance with ethical standards

Conflict of interest Lauren A. Wilson, Megan Fiasconaro, Jashvant Poeran, Jiabin Liu, and Federico Girardi have no conflict of interest. Stavros G. Memtsoudis is a director on the boards of the American Society of Regional Anesthesia and Pain Medicine (ASRA) and the Society of Anesthesia and Sleep Medicine (SASM). He is a one-time consultant for Sandoz Inc. and Teikoku and the holder of US Patent ulticatheter Infusion System. US-2017-0361063. He is the owner of SGM Consulting, LLC and co-owner of FC Monmouth, LLC. None of the above relations influenced the conduct of the present study.

Appendix

See Table 4.

Table 4 Variable definitions based on ICD-9 diagnosis codes

Variable	Complication	ICD-9 code	Description
Any complication	Cardiopulmonary	410.XX	Acute myocardial infarction
		426.0	Atrioventricular block, complete
		427.XX	Cardiac dysrhythmias
		466.XX	Acute bronchitis and bronchiolitis
		512.1	Iatrogenic pneumothorax
		514.0	Pulmonary congestion and hypostasis
		518.0	Pulmonary collapse
		518.4	Acute edema of lung, unspecified
		518.5X	Pulmonary insufficiency following trauma and surgery
		518.81	Acute respiratory failure
		518.82	Other pulmonary insufficiency, not elsewhere classified
		785.51	Cardiogenic shock
		786.09	Other respiratory distress, insufficiency
		799.02	Hypoxemia
		799.01	Asphyxia
		799.1	Respiratory arrest
		997.1	Cardiac complications
		997.3X	Respiratory complications
	Gastrointestinal	560.1	Paralytic ileus
		560.9	Unspecified intestinal obstruction
		997.4X	Digestive system complications
	Renal/genitourinary acute renal failure	584.XX	Acute kidney failure
		591	Hydronephrosis
		595.0	Acute cystitis
		595.9	Cystitis, unspecified
		599.0	Urinary tract infection, site not specified
		599.6	Urinary obstruction, unspecified
		788.2X	Retention of urine
		997.5	Urinary complications
	Thrombosis	415.11	Iatrogenic pulmonary embolism and infarction
		415.19	Other pulmonary embolism and infarction
		451.8X	Phlebitis and thrombophlebitis of other sites
		453.4X	Acute venous embolism and thrombosis of unspecified deep vessels of lower extremity
		453.8X	Acute venous embolism and thrombosis of other specified veins
		997.2	Peripheral vascular complications
		999.2	Other vascular complications
	CNS	433.11	Carotid artery with cerebral infarction
		433.31	Multiple and bilateral with cerebral infarction

Table 4 (continued)

Variable	Complication	ICD-9 code	Description
		434.01	Cerebral thrombosis with cerebral infarction
		434.11	Cerebral embolism with cerebral infarction
		434.91	Cerebral artery occlusion unspecified with cerebral infarction
		435.8X	Other specified transient cerebral ischemia
		435.9X	Unspecified transient cerebral ischemia
		997.0X	Nervous system complications
	Delirium	292.81	Drug-induced delirium
		293.0	Delirium due to conditions classified elsewhere
		293.1	Subacute delirium
		293.9	Unspecified transient mental disorder in conditions classified elsewhere
		780.09	Other alteration of consciousness
		780.97	Altered mental status
	Obesity	278.00	Obesity, unspecified
		278.01	Morbid obesity
		278.03	Obesity hypoventilation syndrome
		649.1X	Obesity complicating pregnancy, childbirth, or the puerperium
		V85.3X	Body mass index between 30 and 39, adult
		V85.4X	Body mass index 40 and over, adult
		V85.54	Body mass index, pediatric, greater than or equal to 95th percentile for age
	Sleep apnea	327.2X	Organic sleep apnea
		780.53	Hypersomnia with sleep apnea, unspecified
		780.51	Insomnia with sleep apnea, unspecified
		780.57	Unspecified sleep apnea
		786.03	Apnea

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