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Clinical Study

Treatment of adult deformity surgery by orthopedic and neurological surgeons: trends in treatment, techniques, and costs by specialty

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Abstract

BACKGROUND CONTEXT: Surgery to correct adult spinal deformity (ASD) is performed by both neurological surgeons and orthopedic surgeons. Despite well-documented high costs and complication rates following ASD surgery, there is a dearth of research investigating trends in treatment according to surgeon subspeciality.

PURPOSE: The purpose of this investigation was to perform an analysis of surgical trends, costs and complications of ASD operations by physician specialty using a large, nationwide sample.

STUDY DESIGN/SETTING: Retrospective cohort study using an administrative claims database.

PATIENT SAMPLE: A total of 12,929 patients were identified with ASD that underwent deformity surgery performed by neurological or orthopedic surgeons.

OUTCOME MEASURES: The primary outcome was surgical case volume by surgeon specialty. Secondary outcomes included costs, medical complications, surgical complications, and reoperation rates (30-day, 1-year, 5-year, and total).

METHODS: The PearlDiver Mariner database was queried to identify patients who underwent ASD correction from 2010 to 2019. The cohort was stratified to identify patients who were treated by either orthopedic or neurological surgeons. Surgical volume, baseline characteristics, and surgical techniques were examined between cohorts. Multivariable logistic regression was employed to assess the cost, rate of reoperation and complication according to each subspecialty while

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controlling for number of levels fused, rate of pelvic fixation, age, gender, region and Charlson Comorbidity Index (CCI). Alpha was set to 0.05 and a Bonferroni correction for multiple comparisons was utilized to set the significance threshold at $p \leq .000521$.

RESULTS: A total of 12,929 ASD patients underwent deformity surgery performed by neurological or orthopedic surgeons. Orthopedic surgeons performed most deformity procedures accounting for 64.57% (8,866/12,929) of all ASD operations, while the proportion treated by neurological surgeons increased 44.2% over the decade (2010: 24.39% vs. 2019: 35.16%; p<.0005). Neurological surgeons more frequently operated on older patients (60.52 vs. 55.18 years, p<.0005) with more medical comorbidities (CCI scores: 2.01 vs. 1.47, p<.0005). Neurological surgeons also performed higher rates of arthrodesis between one and six levels (OR: 1.86, p<.0005), three column osteotomies (OR: 1.35, p<.0005) and navigated or robotic procedures (OR: 3.30, p<.0005). Procedures performed by orthopedic surgeons had significantly lower average costs as compared to neurological surgeons (Orthopedic Surgeons: $17,971.66 vs. Neurological Surgeons: $22,322.64, p=.253). Adjusted logistic regression controlling for number of levels fused, pelvic fixation, age, sex, region, and comorbidities revealed that patients within neurosurgical care had similar odds of complications to orthopaedic surgery.

CONCLUSIONS: This investigation of over 12,000 ASD patients demonstrates orthopedic surgeons continue to perform the majority of ASD correction surgery, although neurological surgeons are performing an increasingly larger percentage over time with a 44% increase in the proportion of surgeries performed in the decade. In this cohort, neurological surgeons more frequently operated on older and more comorbid patients, utilizing shorter-segment fixation with greater use of navigation and robotic assistance.

Keywords: Adult spinal deformity; Neurological surgery; Orthopedic surgery; Complications; Cost effectiveness; Surgical education

Introduction

Spine surgery is performed by both neurological and orthopedic surgeons alike. However, there remain substantial differences in the training pathways between the two specialties including number of spinal deformity procedures performed during their training, variety and breadth of spine procedures performed, and percentage who pursue fellowship training. [1−4] Exposure to spine surgical procedures during residency and fellowship are integral towards developing skills in the diagnosis and management of both pediatric and adult spine cases. [1,3,5,6]

Several studies have investigated the relationship between residency training and surgical outcomes within spine surgery. [7−13] Early investigations that focused on the outcomes of procedures for degenerative spinal pathology generally reported that orthopedic surgeons had higher rates of reoperation [11−13] and other surgical complications. [7,10,12,13] However, these studies had limitations regarding generalizability, and a recent meta-analysis demonstrated no differences in reoperations, readmissions, or any other complications. [14]

Adult spinal deformity (ASD) represents some of the most challenging cases in spine surgery, leading to high revision rates, costs, and complications. [15] It is currently unknown if surgeon specialty affects outcomes of ASD surgery in a similar manner to degenerative conditions.

The primary goal of this investigation was to perform an analysis of trends in case volume between orthopedic and neurological surgeons. Secondary investigations were conducted to examine operative techniques, costs, and postoperative complications between orthopedic and neurological surgeons using a large, nationwide sample of patients. We hypothesized that orthopedic surgeons would perform more adult spinal deformity operations than their neurological surgery colleagues. Additionally, we hypothesized that neurological surgeons would perform more short-segment fusions with more frequent use of robotic and navigated technology, likely due to their baseline familiarity with robotics and navigation utilized in cranial surgical procedures.

Methods

Data source

This investigation is a retrospective cohort study that identified patients undergoing spinal deformity procedures by utilizing the PearlDiver Mariner database (PearlDiver Inc., Colorado Springs, CO). The PearlDiver Mariner database encompasses records of over 144 million patients from 2010 to 2019. The multi-institution database is derived from provider claims across various payer types including Medicare, Medicaid, private plans and out of pocket expenditures. Patients with spinal deformity were identified by *International Classification of Disease, Tenth Edition, Clinical Modification* ICD-10, and ICD-9 diagnosis codes depicting deformity of the thoracolumbar spine. Spinal deformity procedures were identified using the Current Procedural Terminology (CPT) codes 22206, 22207, 22212, 22214, 22800, 22802, and 22804 as these codes relate most specifically to spinal deformity operations. Patients with ICD- 9 or ICD-10 deformity diagnostic codes present in their medical record before the incidence of one of the procedural codes, and patients aged 18 and above were retained for primary analysis (Appendix A).

Exclusion criteria included a history of malignancy or metastasis within a patient's record as well as emergent procedures, defined as a deformity procedure performed within 7 days of an emergency room visit with moderate or high severity. Physician specialty that treated each patient was recorded, and only patients with either orthopedic surgery, orthopedic spine surgery, or neurosurgery in their record were selected for inclusion. Patients were categorized based on undergoing operative intervention by either orthopedic or neurological surgeons.

Variables

The primary independent variable considered for this study was the specialty of the attending physician performing the operation. The dataset was stratified to patients who were operated on by orthopedic surgeons (Ortho) compared to a cohort of patients who were operated on by neurological surgeons (NSGY). Reoperation rates within 30 days, 1 year, 5 years, and overall, in addition to surgical and medical complications, comprised the dependent variables of interest. Surgical volume and cost were also compared between the two cohorts. ICD-9, ICD-10, and CPT codes were used to define surgical and medical complications that occurred within 30 days of the original procedure. Surgical complications included dural tears, postoperative hematoma, postoperative infection, postprocedural fever, sepsis, transfusions, and wound dehiscence. Medical complications included acute kidney injury, cardiac complications, deep venous thrombosis, pulmonary embolism, pneumonia, and urinary tract infection. All medical and surgical complications were measured within 30 days postoperatively. CPT codes were additionally used to define varying surgical techniques including 1 to 6 levels fused, 7 to 12 levels fused, more than 12 levels fused, use of pelvic fixation, use of 3-column osteotomies, use of navigation or robotic assisted procedures and the use of anterior or posterior interbody devices of 1 level, 2 to 3 levels or 4+ levels. The incidence of each variable, either complication, comorbidity or technique utilized, is reported as a parentage of the overall cohort, either orthopedic or neurological surgery.

The cost associated with spinal deformity procedures was defined as the total amount reimbursed to the provider between one day before and 90 days after the procedure was performed excluding the bottom 10% and top 10% to avoid outliers due to bundled or denied claims.

Statistical analyses

The statistical analyses in this study were all conducted using the R statistical package on the PearlDiver Bellwether research query interface. Alpha was set to 0.05 and a Bonferroni correction for multiple comparisons was utilized to set the significance threshold at $p \leq .000521$, *a priori.* Bivariable analysis of spine surgeon specialty and outcomes, as well as specialty and cost, were investigated using Pearson χ^2 tests of association and Welsh T test. Multivariable analysis included logistic regression utilized to assess the rate of reoperation and complications while accounting for age, gender, region, Charlson Comorbidity Index (CCI) score, 1 to 6 levels fused, 7 to 12 levels fused, 13 or more levels fused and rate of pelvic fixation. The Mariner database contains exclusively deidentified patient records in compliance with the Health Insurance Portability and Accountability Act (HIPAA) allowing this study to be exempt from International Review Board (IRB) approval.

Results

Demographics

In total, 12,929 patients with a diagnosis of adult spinal deformity met the inclusion criteria for primary analysis (Table 1). A total of 68.57% of patients (8,866 persons) underwent spinal deformity surgery by an orthopedic surgeon, while 31.43% of patients (4,063 persons) underwent deformity surgery performed by a neurological surgeon. The 30-day, 1-year, 5-year, and total reoperation rates of patients in both cohorts were 11.27%, 26.71%, 41.16%, and 43.37%, respectively. The majority of patients were female (67.78%). The regions with the greatest number of patients were the South (39.28%) and Midwest (26.81%) (Table 1).

Patients undergoing surgery by neurological surgeons were older ($\bar{x}$ = 60.52 vs. 55.18, p<.0001) and had higher Charlson Comorbidity Index (CCI) scores ($\bar{x}$=2.01 vs. 1.47, p<.0001). Patients under neurological surgery care also had higher rates of various comorbidities including COPD (OR: 1.20, p<.0001), CHF (OR: 1.49, p<.0001), hypertension (OR: 1.97, p<.0001), morbid obesity (OR: 1.41, p<.0001),

Table 1
Summary of total patients, reoperations, and demographics for ASD

	n	%
Total patients undergoing deformity surgery (all specialties)	12,929	
Total patients undergoing deformity surgery (Orthopedic)	8,866	68.57%
Total patients undergoing deformity surgery (Neurosurgery)	4,063	31.43%
Total reoperations	5,607	43.37%
Total reoperations within 30 days	1,457	11.27%
Total reoperations within 1 year	3,453	26.71%
Total reoperations within 5 years	5,321	41.16%
Female	8,763	67.78%
Male	4,166	32.22%
Midwest	3,466	26.81%
Northeast	2,136	16.52%
South	5,078	39.28%
Unknown	68	0.53%
West	2,181	16.87%

Table 2
Summary of patient demographics by physician subspecialty

	Orthopedic surgery	Orthopedic surgery %	Neurosurgery	Neurosurgery %	p value
Age	55.18		60.52		**p < .0001**
CCI	1.47		2.01		**p < .0001**
Alcohol abuse	638	7.20%	345	8.49%	OR = 1.20 p = .01097
COPD	3,128	35.28%	1608	39.58%	OR = 1.20 **p < .0001**
CHF	673	7.59%	443	10.90%	OR = 1.49 **p < .0001**
Hypertension	6,060	68.35%	3291	81.00%	OR = 1.97 **p < .0001**
Liver disease	1,329	14.99%	805	19.81%	OR = 1.40 **p < .0001**
Morbidly obese	681	7.68%	426	10.48%	OR = 1.41 **p < .0001**
Obesity	1,758	19.83%	1126	27.71%	OR = 1.55 **p < .0001**
Osteoarthritis	4,563	51.47%	2465	60.67%	OR = 1.45 **p < .0001**
Osteoporosis	2,449	27.62%	1206	29.68%	OR = 1.11 p = .017
Tobacco use	3,259	36.76%	1972	48.54%	OR = 1.62 **p < .0001**

Significance: p ≤.000521.

obesity (OR: 1.55, p<.0001), osteoarthritis (OR: 1.45, p<.0001), and tobacco use (OR: 1.62, p<.0001) (Table 2).

Economic analysis

Over 2010 to 2019, procedures performed by orthopedic surgeons had lower average 90-day postoperative costs compared to neurological surgeons after controlling for age, gender, region and CCI (Orthopedic Surgeons: $17,108.01 vs. Neurosurgeons: $22,023.41, p<.001) (Table 3).

Table 3
Average amount reimbursed to providers for deformity correction by year

	Orthopedic Surgery Cost	Neurosurgery Cost	p value
Year			
2010	$16,907.08	$22,923.76	.054
2011	$27,772.71	$28,263.28	.895
2012	$28,327.04	$32,630.40	.259
2013	$24,504.82	$24,504.82	.038
2014	$22,643.50	$35,451.56	<.0001
2015	$15,228.70	$25,305.43	<.0001
2016	$14,544.71	$19,028.10	.003
2017	$9,278.31	$12,884.34	<.0001
2018	$8,903.99	$10,811.93	<.001
2019	$10,605.69	$11,422.81	.078
Average	$17,871.66	$22,322.64	.235

Total cost is the average total amount reimbursed for claims paid to providers in for deformity correction and the subsequent 90 days following.

Surgical trends

Orthopedic surgeons performed the majority of procedures each year from 2010 to 2019 with the largest discrepancy observed in 2011 where orthopedic surgeons performed 76.69% of cases compared to 23.31% by neurological surgeons. The proportion of cases performed by neurological surgeons compared to orthopedic surgeons increased by 44.2% over the study period (2010: 24.39% to 2019: 35.16%) (p<.0001). While the proportions of cases performed by neurological surgeons have increased in the last decade, orthopedic surgeons still operated on a statistically significantly higher proportion of cases over this period (p<.0001) (Table 4) (Fig. 1).

Surgical techniques

Neurological surgeons performed statistically significant higher rates of arthrodesis where 1 to 6 levels were fused (75.09% vs. 51.87%; OR: 1.86, p<.0001) while orthopedic surgeons performed significantly higher rates of fusion between 7 to 12 levels (24.97% vs. 14.94%; OR: 0.53, p<.0001) and 13 or more levels (11.99% vs. 4.63%; OR: 0.36, p<.0001). Neurological surgeons utilized significantly greater increased rates of 3 column osteotomies within their deformity procedures (15.48% vs. 11.90%; OR: 1.35, p<.0001) compared to orthopedic surgeons. Furthermore, neurological surgeons had higher rates of 1 level posterior lumbar interbody fusion (PLIF) (OR: 1.51, p<.0001) and 2 to 3 level PLIF (OR: 1.95, p<.001). There were no statistically significant differences in anteriorly based interbody fusions between neurological and orthopedic surgeons

Table 4
Analysis of surgical trends and techniques utilized

	Orthopedic surgery	Orthopedic surgery %	Neurosurgery	Neurosurgery %	
Year					
2010	778	75.61%	251	24.39%	
2011	793	76.69%	241	23.31%	
2012	828	76.60%	253	23.40%	
2013	826	68.32%	383	31.68%	
2014	932	70.66%	387	29.34%	
2015	881	68.14%	412	31.86%	
2016	858	66.41%	434	33.59%	
2017	957	64.23%	533	35.77%	
2018	927	61.51%	580	38.49%	
2019	1,086	64.84%	589	35.16%	
Surgical techniques					**OR** **p value**
Arthrodesis, 1 to 6 segments	5,485	61.87%	3,051	75.09%	OR = 1.86 **p < .0001**
Arthrodesis, 7 to 12 segments	2,214	24.97%	607	14.94%	OR = 0.53 **p < .0001**
Arthrodesis, greater than 12 segments	1,063	11.99%	188	4.63%	OR = 0.36 **p < .0001**
Pelvic fixation	2,991	33.74%	1,350	33.23%	OR = 0.98 p = .569
3 column osteotomy	1,055	11.90%	629	15.48%	OR = 1.35 **p < .0001**
PLIF, 1 level	1,463	16.50%	932	22.94%	OR = 1.51 **p < .0001**
PLIF, 2 to 3 levels	979	11.04%	791	19.47%	OR = 1.95 **p < .0001**
PLIF, greater than 4 levels	50	0.56%	37	0.91%	OR = 1.62 p = .034
ALIF, 1 level	637	7.18%	281	6.92%	OR = 0.96 p = .61
ALIF, 2 to 3 levels	1,129	12.73%	427	10.51%	OR = 0.84 p = .0003
ALIF, greater than 4 levels	87	0.98%	28	0.69%	OR = 0.70 p = .123
Navigated or robotic surgery	1,062	11.99%	1,258	30.96%	OR = 3.30 **p < .0001**

Significance: p ≤.000521.

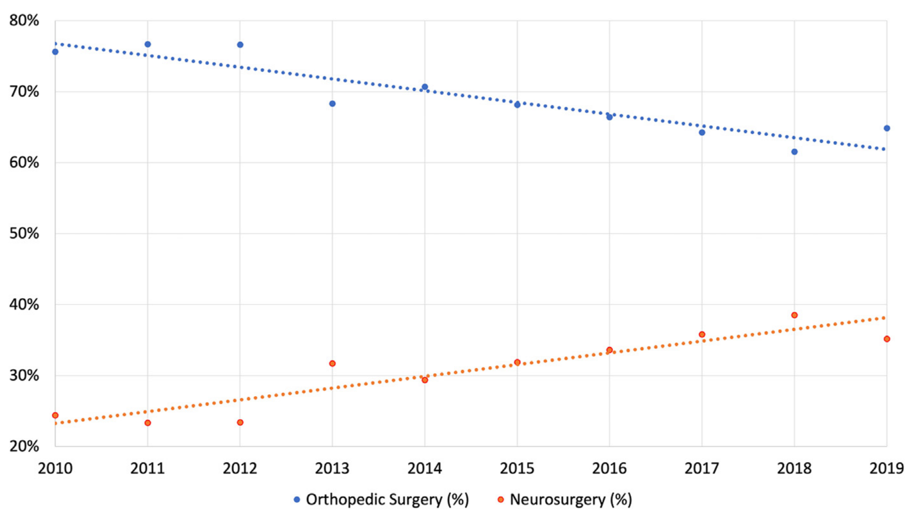

Fig. 1. Trends of surgical case volume in ASD.

Table 5
Unadjusted and adjusted logistic regression analysis of reoperations and complications for ASD by specialty

	Ortho	NSGY	OR NSGY vs. Ortho (Unadjusted)	p value	OR NSGY vs. Ortho (Adjusted)	p value
Total patients	8,866	4,063				
Total reoperations	3,003 (33.75%)	1,499 (36.89%)	1.14	0.0008	1.066	.125
Total reoperations within 30 days	766 (8.61%)	360 (8.86%)	1.03	0.68	1.024	.730
Total reoperations within 1 year	1,754 (19.71%)	916 (22.54%)	1.11	< 0.0001	1.12	.016
Total reoperations within 5 years	2,824 (31.73%)	1,435 (35.32%)	1.17	< 0.0001	1.09	.044
Surgical complications						
Dural tears	299 (3.36%)	184 (4.53%)	1.36	0.001	1.19	.078
Postoperative hematoma	164 (1.84%)	72 (1.77%)	0.96	0.759	0.95	.752
Postoperative infection	302 (3.39%)	178 (4.38%)	1.30	0.007	1.25	.027
Postprocedural fever	101 (1.13%)	66 (1.62%)	1.43	0.024	1.57	.008
Sepsis	145 (1.63%)	109 (2.68%)	1.66	< 0.0001	1.53	.001
Transfusion	243 (2.73%)	145 (3.57%)	1.31	0.011	1.32	.012
Wound dehiscence	287 (3.23%)	157 (3.86%)	1.20	0.070	1.20	.084
Medical complications						
Acute kidney injury	252 (2.83%)	182 (4.48%)	1.60	< 0.0001	1.24	.036
Cardiac complications	192 (2.16%)	146 (3.59%)	1.68	< 0.0001	1.32	.019
Deep venous thrombosis	155 (1.74%)	108 (2.66%)	1.53	0.0007	1.41	.009
Pulmonary embolism	142 (1.60%)	75 (1.85%)	1.56	0.316	1.60	.236
Pneumonia	244 (2.74%)	126 (3.10%)	1.13	0.269	1.11	.363
Urinary tract infection	462 (5.19%)	288 (7.09%)	1.39	< 0.0001	1.29	.002

(p >.000521). Additionally, neurological surgeons performed navigated or robotic-assisted deformity procedures at a significantly higher rate compared to orthopedic surgeons (30.96% vs. 11.99%; OR: 3.30, p<.0001) (Table 4).

Reoperation rate by specialty

On unadjusted analysis, reoperation rate within 30 days did not differ by specialty. However, neurological surgeons had higher rates of reoperation across other time points including within 1-year (22.54% vs. 19.71%, OR: 1.11, p<.0001), 5-years (35.32% vs. 31.73%, OR: 1.17, p<.0001), and overall (36.89% vs. 33.75%, OR: 1.14, p=.0008). After adjusting for levels fused, rate of pelvic fixation, age, gender, region and CCI, differences in the rate of reoperation by specialty failed to meet statistical significance across each time interval (p>.01 for all) (Table 5).

Surgical and medical complications by specialty

On unadjusted analysis, patients undergoing surgery by neurological surgeons had increased rates of sepsis (OR: 1.66, p<.0001), acute kidney injury (OR: 1.60, p<.0001), cardiac complications (OR: 1.68, p<.0001), deep venous thrombosis (OR: 1.53, p=.0005) and urinary tract infections (OR: 1.39, p<.0001).

After adjusting for levels fused, rate of pelvic fixation, age, gender, region and CCI, procedures performed by neurological surgeons had similar odds of medical and surgical complications compared to their orthopedic counterparts (p>.001 for all) (Table 5).

When analyzing the reoperation and complication rate across regions, there was no significant differences between orthopaedic and neurological surgery *(Appendix Tables B-E).*

Column osteotomy sub analysis

On further analysis of patients undergoing 3-column osteotomies, patients under neurosurgical care had no significant differences in any medical or surgical complications, nor in reoperation rate at any time point (Table 6).

Discussion

This study demonstrates that orthopedic surgeons currently perform the majority of ASD surgeries in the United States, while neurological surgeons are operating on an increasingly larger proportion of ASD cases accounting for 24.39% of procedures in 2010 increasing to 35.16% in 2019. Neurological surgeons, on average, operated on older patients with more medical comorbidities including higher CCI, and higher rates of COPD, CHF, liver disease, obesity and morbid obesity, and tobacco use compared to their orthopedic surgery counterparts, and also utilized more short-segment fixation with higher rates of posterior interbody use. Furthermore, neurological surgeons had significantly greater use of navigated and robotic procedures compared to orthopedic surgeons.

Although these findings may provide important data regarding current surgical care of ASD in the United States, there are inherent limitations of a retrospective database study, including both billing coding limitations as well as limitations regarding the inability to assess severity of the deformities. Additionally, due to the large variability in cost data due to interhospital differences in pay structure, cost data was not matched based on comorbidity.

This investigation revealed an increase in ASD treatment by neurosurgeons over time. The reason for the increase in deformity cases being performed by neurological surgeons

Table 6
Unadjusted and adjusted logistic regression analysis of reoperations and complications for 3 column osteotomy by specialty

	Ortho	Neuro	OR NSGY vs. ortho (unadjusted)	p value	OR NSGY vs. ortho (adjusted)	p value
Total patients	1,014	609				
Total reoperations	448 (44.18%)	264 (43.35%)	0.97	0.783	0.93	.485
Total reoperations within 30 days	134 (13.21%)	46 (7.55%)	0.67	0.018	0.66	.018
Total reoperations within 1 year	261 (25.74%)	156 (25.62%)	0.99	0.996	0.96	.759
Total reoperations within 5 years	416 (41.03%)	250 (41.05%)	1.00	0.992	0.95	.641
Surgical complications						
Dural tears	63 (6.21%)	67 (11.00%)	1.87	0.001	1.61	.014
Postoperative hematoma	35 (3.45%)	*	0.42	0.027	0.37	.01
Postoperative infection	58 (5.72%)	33 (5.42%)	0.81	0.886	0.88	.587
Postprocedural fever	11 (1.08%)	*	1.06	0.987	0.97	.956
Sepsis	30 (2.96%)	29 (4.76%)	1.64	0.081	1.65	.073
Transfusion	26 (2.56%)	16 (2.63%)	1.03	0.93	0.8	.501
Wound dehiscence	49 (4.38%)	23 (3.78%)	0.77	0.381	0.7	.186
Medical complications						
Acute kidney injury	39 (3.85%)	35 (5.75%)	1.52	0.081	1.32	.27
Cardiac complications	43 (4.24%)	32 (5.25%)	1.25	0.412	1.17	.541
Deep venous thrombosis	25 (2.47%)	17 (2.79%)	1.14	0.811	1.2	.578
Pulmonary embolism	29 (2.86%)	16 (2.63%)	0.92	0.904	0.97	.932
Pneumonia	51 (5.03%)	35 (5.75%)	1.15	0.61	1.18	.491
Urinary tract infection	90 (8.88%)	64 (10.51%)	1.21	0.318	1.23	.245

Significance: $p \leq .000521$.

is multifactorial, but likely due to both the increasing availability of information about managing deformity patients through institutions such as the Scoliosis Research Society as well as research groups that focus on presenting management strategies for deformity patients. Additionally, there has been an increase in collaboration in training pathways between orthopedic and neurological surgeons, especially for fellowship training. It is likely that this collaboration has led to neurological surgeons being more adept at treating spinal deformity. This study also revealed that neurological surgeons operated on older patients with more comorbidities, and also utilized more short-segment fixation with navigated/robotic technologies compared to orthopaedic surgeons. These findings may be due to differing patient populations presenting to the treating surgeon, and due to training differences with neurosurgery utilizing more navigation and minimally invasive approaches in cranial procedures.

The economic analysis in this investigation reveals further differences between the specialties. A greater cost of care was found for neurological surgeons compared to orthopedic surgeons, with an average cost of $20,023.41 compared to $17,108.01 (p<.0001). Of note, due to limitations associated with claims databases, these cost values represent the total amount reimbursed to providers for deformity correction and the subsequent 90 days following as opposed to total cost incurred by the provider. However, it is plausible to argue discrepancies in cost may be due to greater use of advanced technology such as navigation, robotics, and interbody cages. These results warrant further investigation, and not only differences in the procedures, but also the patient population may influence these differences.

The overall revision rate for these patients was 30.54% within 5-years. While unadjusted analysis demonstrated that neurological surgeons had higher reoperation rates at both 1 and 5-years, adjusted analysis failed to show any difference between surgeon specialty and reoperation rate. Finally, after adjusted analysis, neurological surgeons were found to have similar medical and surgical complication rates as orthopedic surgeons, highlighting the fact that both specialties provide excellent care to ASD patients.

Two of the more notable findings in this study are the differences in baseline patient characteristics (with neurological surgeons operating on older patients with significantly more comorbidities), and the increased use of short-segment fusion with increased use of interbody support and robotics/navigation within the neurological surgery cohort. While patients within the neurologic surgery cohort had higher rates of comorbidities overall, they also expressed statistically significant higher rates of individual comorbidities known to drastically increase the likelihood of complications such as CHF, [16] COPD, [17] liver dysfunction, [18−20] obesity, [18,21] morbid obesity, [18,21] and tobacco use. [18,22] A systematic review of complications in adult spinal deformity surgery found that preoperative albumin levels of 3.5 g/dL or less were associated with up to a threefold increase in the risk of complications, increased propensity for wound infections, significant rates of readmission within 30 days and longer length of stay across various studies. [18−20] This may partly explain why neurological surgeons choose more short-segment fixation and use of navigated and robotic surgery- to try to minimize complications in this difficult cohort of patients. These findings indicate that preoperative optimization is critical to obtaining the best outcomes possible, and our data may help inform efforts to screen and optimize patients prior to intervention.

The high reoperation rate in this study is consistent with previously reported literature. [15] Diebo et. al showed adult spinal deformity surgery revision rates are reported between 16.7% at 90 days, to 40% at 11 years. [23] Importantly, one study examined the high reoperation rate in deformity surgery, and suggested that there is a large variability within surgeons that may be due to differences in individual surgeon skill level and experience. [24]

Due to high complication rates, outcomes of ASD operations have been investigated extensively in terms of patient risk factors for perioperative complications and rates of reoperation. [25−29] Patients over 65-years old with longer fusion constructs has previously been associated with increased morbidity. [20] Despite a profound interest in this growing area of spine practice, there is a lack of consensus assessing whether surgical subspecialty and residency training influence outcomes. Our study is the largest to our knowledge to assess ASD patient outcomes by specialty, utilizing data from over 10,000 patients. This investigation's data corroborates recent studies for degenerative pathology that have suggested no difference in complications between orthopedic and neurological surgeons. [14] It is likely that this is due to an increased collaboration and a lack of hegemony in training pathways between neurological and orthopedic surgeons which ultimately benefits patients and allows the strengths of each subspecialty to be taught within residency or fellowship training.

Two studies using questionnaires to evaluate ASD competence of orthopedic and neurological surgeons alike both concluded that the completion of spine fellowship was associated with improved performance and ASD expertise overall. [3,30] Additionally, orthopedic and neurological surgery program directors are in agreement that trainees should complete a spine fellowship if they intend to practice in adult spine deformity. [5] Having this dedicated year may cultivate a better understanding of the care for deformity patients, with surgeons learning how to anticipate and avoid deformity surgery-specific complications.

Moreover, the core principles taught amongst each residency may result in cultural differences in the management of spinal deformity patients. Previous literature reports that residency training has shown to affect surgical opinion in spine practice. [31−33] Bone biology, biomechanics, and healing are also central to all orthopedic trainees, whereas these concepts may not be as commonly taught during neurological surgery residency. [2] Neurological surgery residency has traditionally had a greater emphasis on more minimally invasive techniques and use of technology such as robotics and navigation, which was corroborated with our study.

Ultimately, based on this data it is plausible that neurological surgeons more frequently utilize short segment and minimally invasive approaches utilizing navigated and robotic surgery as well as interbody arthrodesis on more debilitated patients. This may account for, in part, the higher costs found in this investigation. However, the impact on health outcomes and cost utility in quality adjusted life years over the greater spectrum of care necessitates further investigation.

The data presented in this study may be of interest to surgeons, training programs, academic clinical departments, as well as healthcare administrators, yet this investigation has several potential limitations. While utilizing a database of insurance claims allowed us to analyze a uniquely large and encompassing dataset, it also has its associated disadvantages. Primarily, insurance claims data is used for billing and reimbursements and typically does not contain all the relevant conditions and outcomes depicted in medical records. [34] Because PearlDiver is encompassed of private insurance claims, there are concerns regarding the external validity of our study considering the dataset may overrepresent parts of the country, particularly the Southern United States. [35] The cost data of insurance databases are known to contain incomplete and bundled claims leading to limitations when conducting cost analysis. We sought to address this by excluding the bottom and top 10% of cost values to exclude incomplete or bundled claims that may misrepresent the cost of deformity correction. Furthermore, the use of billing codes can lead to miscoding errors by the misclassification of conditions or omissions of diagnoses. [35] While we were able to delineate between procedures conducted by specialty, relevant provider characteristics, such as years spent in clinical practice or the completion of a fellowship, were not included in the dataset but may have an influence on patient outcomes. Ultimately, there remains a substantial learning curve with deformity surgery, and it is possible that without being able to evaluate experience of each surgeon, one cohort may have less experience than the other cohort, skewing results. Other factors including the setting of the practice - whether academic or private - and the case volume of an individual surgeon, are not accounted for and may play an additional role in postoperative complications. Additionally, due to the limitations of this database, we were unable to examine preoperative or postoperative spinopelvic parameters, rates of proximal junctional kyphosis, or other changes in global spinal alignment. In examining cost data, due to database limitations we were also only able to examine physician reimbursements and not the cost paid to the hospital, although this may significantly differ from procedure to procedure given differences in cost per procedure between hospitals. Finally, analyzing rates of reoperation 5 years and beyond limits our study to potential loss of follow up due to factors that may change the insurance status of the patients included within our cohort.

Conclusion

Adult spinal deformity surgery is performed by both orthopedic and neurological surgeons with differing patient demographics and complication profiles between the specialties. This study represents the largest investigation yet performed examining rates of complications and surgical outcomes of spinal deformity procedures between these two specialties. While orthopedic surgeons continue to perform most ASD surgery, neurological surgeons are performing greater percentages of surgeries in ASD patients. Patients undergoing correction by neurological surgeons were older and had more medical comorbidities at baseline. Neurological surgeons more frequently utilized short-segment fusion utilizing robotics and navigation, as well as performing more 3-column osteotomies. Cases performed by neurological surgeons were associated with higher costs compared to orthopedic surgeons, however both medical and surgical complications were similar between the two cohorts. The implication for these differences may be related to training pathway and different approaches to deformity correction. Further robust studies are needed to corroborate this finding and examine where resident and fellow education as well as differences in patient selection and pre-operative optimization may improve patient outcomes for both specialties.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.spinee.2023.05.012.

References

[1] Daniels AH, Ames CP, Smith JS, Hart RA. Variability in spine surgery procedures performed during orthopaedic and neurological surgery residency training: an analysis of ACGME case log data. J Bone Joint Surg Am 2014;96(23):e196. https://doi.org/10.2106/JBJS.M.01562.

[2] Daniels A, Ames C, Garfin S, Shaffrey CIS, Riew KD, Smith JS, et al. Spine surgery training: is it time to consider categorical spine surgery residency? Spine J 2014:15(7). https://doi.org/10.1016/j.spinee.2014.08.452.

[3] Grabel ZJ, Hart RA, Clark AJ, Park SH, Shaffrey CIS, Scheer JK, et al. Adult spinal deformity knowledge in orthopedic spine surgeons: impact of fellowship training, experience, and practice characteristics. Spine Deform 2018;6(1):60–6. https://doi.org/10.1016/j.jspd.2017.06.003.

[4] Pham MH, Jakoi AM, Wali AR, Lenke LG. Trends in spine surgery training during neurological and orthopaedic surgery residency: a 10-year analysis of ACGME case log data. J Bone Joint Surg Am 2019;101(22):e122. https://doi.org/10.2106/JBJS.19.00466.

[5] Daniels AH, DePasse JM, Magill ST, Fischer SA, Paulmbo MA, Ames CP, et al. The current state of United States spine surgery training: a survey of residency and spine fellowship program directors. Spine Deform 2014;2(3):176–85. https://doi.org/10.1016/j.jspd.2014.02.005.

[6] Herkowitz HN, Connolly PJ, Gundry CR, Varlotta GP, Zdeblick TA, Truumees E. Resident and fellowship guidelines: educational guidelines for resident training in spinal surgery. Spine (Phila Pa 1976) 2000;25(20):2703–7. https://doi.org/10.1097/00007632-200010150-00026.

[7] Seicean A, Alan N, Seicean S, Neuhauser D, Benzel EC, Weil RJ. Surgeon specialty and outcomes after elective spine surgery. Spine (Phila Pa 1976) 2014;39(19):1605–13. https://doi.org/10.1097/BRS.0000000000000489.

[8] Kim BD, Edelstein AI, Hsu WK, Lim S, Kim JYS. Spine surgeon specialty is not a risk factor for 30-day complication rates in single-level lumbar fusion: a propensity score-matched study of 2528 patients. Spine (Phila Pa 1976) 2014;39(15):E919–27. https://doi.org/10.1097/BRS.0000000000000394.

[9] Baek J, Malik AT, Khan I, Yu E, Kim J, Khan SN. Orthopedic versus neurosurgery-understanding 90-day complications and costs in patients undergoing elective 1-level to 2-level posterior lumbar fusions by different specialties. World Neurosurg 2019;131:e447–53. https://doi.org/10.1016/j.wneu.2019.07.194.

[10] McCutcheon BA, Ciacci JD, Marcus LP, Noorbakhsh A, Gonda DD, McCafferty R, et al. Thirty-day perioperative outcomes in spinal fusion by specialty within the NSQIP database. Spine (Phila Pa 1976) 2015;40(14):1122–31. https://doi.org/10.1097/BRS.0000000000000599.

[11] Alomari S, Porras JL, Lo SFL, Theodore N, Sciubba DM, Witham T, et al. Does the specialty of the surgeon performing elective anterior/lateral lumbar interbody fusion for degenerative spine disease correlate with early perioperative outcomes? World Neurosurg 2021;155:e111–8. https://doi.org/10.1016/j.wneu.2021.08.010.

[12] Mabud T, Norden J, Veeravagu A, Swinney C, Cole T, McCutcheon BA, et al. Complications, readmissions, and revisions for spine procedures performed by orthopedic surgeons versus neurosurgeons: a retrospective, longitudinal study. Clin Spine Surg 2017;30(10):E1376–81. https://doi.org/10.1097/BSD.0000000000000426.

[13] Bronheim RS, Cheung ZB, Phan K, White SJW, Kim JS, Cho SK. Anterior lumbar fusion: differences in patient selection and surgical outcomes between neurosurgeons and orthopaedic surgeons. World Neurosurg 2018;120:e221–6. https://doi.org/10.1016/j.wneu.2018.08.034.

[14] Lambrechts MJ, Canseco JA, Toci GR, Karamian BA, Kepler CK, Smith ML, et al. Spine surgical subspecialty and its effect on patient outcomes: a systematic review and meta-analysis. Spine 2023;48(9):625–35. https://doi.org/10.1097/BRS.0000000000004554.

[15] Patel SA, McDonald CL, Reid DBC, DiSilvestro KJ, Daniels AH, Rihn JA. Complications of thoracolumbar adult spinal deformity surgery. JBJS Reviews 2020;8(5):e0214. https://doi.org/10.2106/JBJS.RVW.19.00214.

[16] Lerman BJ, Popat RA, Assimes TL, Heidenreich PA, Wren SM. Association between heart failure and postoperative mortality among patients undergoing ambulatory noncardiac surgery. JAMA Surgery 2019;154(10):907–14. https://doi.org/10.1001/jamasurg.2019.2110.

[17] Gupta H, Ramanan B, Gupta PK, Fang X, Polich A, Modrykamien A, et al. Impact of COPD on postoperative outcomes: results from a national database. Chest 2013;143(6):1599–606. https://doi.org/10.1378/chest.12-1499.

[18] Burton DC, Sethi RK, Wright AK, Daniels AH, Ames CP, Reid DB, et al. The role of potentially modifiable factors in a standard work protocol to decrease complications in adult spinal deformity surgery: a

systematic review, part 1. Spine Deform 2019;7(5):669–83. https://doi.org/10.1016/j.jspd.2019.04.003.

[19] Adogwa O, Martin JR, Huang K, Verla T, Fatemi P, Thompson P, et al. Preoperative serum albumin level as a predictor of postoperative complication after spine fusion. Spine (Phila Pa 1976) 2014;39 (18):1513–9. https://doi.org/10.1097/BRS.0000000000000450.

[20] Tempel Z, Grandhi R, Maserati M, Panczykowski D, Ochoa J, Russavage J, et al. Prealbumin as a serum biomarker of impaired perioperative nutritional status and risk for surgical site infection after spine surgery. J Neurol Surg A Cent Eur Neurosurg 2015;76(2):139–43. https://doi.org/10.1055/s-0034-1394188.

[21] Johnson KG, Alsoof D, McDonald CL, Berreta RS, Cohen EM, Daniels AH. Malnutrition, body mass index, and associated risk of complications after posterior lumbar spine fusion: a 3:1 matched cohort analysis. World Neurosurg 2022;163:e89–97. https://doi.org/10.1016/j.wneu.2022.03.065.

[22] Yoshikawa R, Katada J. Effects of active smoking on postoperative outcomes in hospitalised patients undergoing elective surgery: a retrospective analysis of an administrative claims database in Japan. BMJ Open 2019;9(10):e029913. https://doi.org/10.1136/bmjopen-2019-029913.

[23] Diebo BG, Shah NV, Boachie-Adjei O, Zhu F, Rothenfluh DA, Paulino CB, et al. Adult spinal deformity. The Lancet 2019;394 (10193):160–72. https://doi.org/10.1016/S0140-6736(19)31125-0.

[24] Mok JM, Cloyd JM, Bradford DS, Hu SS, Deviren V, Smith JA, et al. Reoperation after primary fusion for adult spinal deformity: rate, reason, and timing. Spine 2009;34(8):832–9. https://doi.org/10.1097/BRS.0b013e31819f2080.

[25] Diebo BG, Lavian JD, Murray DP, Liu S, Shah NV, Beyer GA, et al. The impact of comorbid mental health disorders on complications following adult spinal deformity surgery with minimum 2-year surveillance. Spine (Phila Pa 1976) 2018;43(17):1176–83. https://doi.org/10.1097/BRS.0000000000002583.

[26] Daubs MD, Lenke LG, Cheh G, Stobbs G, Bridwell KH. Adult spinal deformity surgery: complications and outcomes in patients over age 60. Spine (Phila Pa 1976) 2007;32(20):2238–44. https://doi.org/10.1097/BRS.0b013e31814cf24a.

[27] Schwab FJ, Hawkinson N, Lafage V, Smith JS, Hart R, Mundis G, et al. Risk factors for major peri-operative complications in adult spinal deformity surgery: a multi-center review of 953 consecutive patients. Eur Spine J 2012;21(12):2603–10. https://doi.org/10.1007/s00586-012-2370-4.

[28] Worley N, Marascalchi B, Jalai CM, Yang S, Diebo B, Vira S, et al. Predictors of inpatient morbidity and mortality in adult spinal deformity surgery. Eur Spine J 2016;25(3):819–27. https://doi.org/10.1007/s00586-015-4104-x.

[29] Fruergaard S, Ohrt-Nissen S, Pitter FT, Hoy K, Lindberg-Larsen M, Eiskjaer S, et al. Revision risk after pediatric spinal deformity surgery: a nationwide study with 2-year follow-up. Spine J 2021;21(4):642–52. https://doi.org/10.1016/j.spinee.2020.12.002.

[30] Clark AJ, Garcia RM, Keefe MK, Koski TR, Rosner MK, Smith JS, et al. Results of the AANS membership survey of adult spinal deformity knowledge: impact of training, practice experience, and assessment of potential areas for improved education: Clinical article. J Neurosurg Spine 2014;21(4):640–7. https://doi.org/10.3171/2014.5.SPINE121146.

[31] Glaser JA, Jaworski BA, Cuddy BG, Albert TJ, Hollowell JP, McLain RF, et al. Variation in surgical opinion regarding management of selected cervical spine injuries. A preliminary study. Spine (Phila Pa 1976) 1998;23(9):975–82 discussion 983. https://doi.org/10.1097/00007632-199805010-00002.

[32] Irwin ZN, Hilibrand A, Gustavel M, McLain R, Shaffer W, Myers M, et al. Variation in surgical decision making for degenerative spinal disorders. Part I: lumbar spine. Spine (Phila Pa 1976) 2005;30 (19):2208–13. https://doi.org/10.1097/01.brs.0000181057.60012.08.

[33] Grauer J, Vaccaro A, Beiner J, Kwon BK, Hilibrand AS, Harrop JS, et al. Similarities and differences in the treatment of spine trauma between surgical specialties and location of practice. Spine (Phila Pa 1976) 2004;29(6):685−96. https://pubmed.ncbi.nlm.nih.gov/15014280/. Accessed January 2, 2022.

[34] Stein JD, Flora L, Paul PL, William 3rd LR, Anne LC. Use of health care claims data to study patients with ophthalmologic conditions. Ophthalmology 2014;121(5):1134–41. https://pubmed.ncbi.nlm.nih.gov/24433971/. Accessed June 6, 2023.

[35] Pugely AJ, Martin CT, Harwood J, Ong KL, Bozic KJ, Callaghan JJ. Database and registry research in orthopaedic surgery: part I: claims-based data. J Bone Joint Surg Am 2015;97(15):1278–87. https://doi.org/10.2106/JBJS.N.01260.