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Postoperative Neurological Complications Following Revision Spine Surgery: A State Inpatient Database Analysis

ADITYA MURALIDHARAN, BS,[1] WESLEY SHOAP, BS,[2] KHALED AL ROBAIDI, MD,[3] PARTHASARATHY D. THIRUMALA, MD, MS[3,4]

[1]*College of Literature, Science, and the Arts, University of Michigan, Ann Arbor, Michigan,* [2]*Johns Hopkins University, Baltimore, Maryland,* [3]*Department of Neurological Surgery, University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania,* [4]*University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania*

ABSTRACT

Background: Postoperative neurological complications after spine surgery can result in increased mortality and morbidity. Despite the introduction of new spinal implants and surgical technology, reoperation rates have remained stable over recent years. Understanding the reasons for revision (refusion) surgery and the risk of neurological complications can assist in developing more effective screening protocols for repeat surgeries and early detection of potential neurological complications.

Methods: This study was designed and conducted as a retrospective cohort study. The primary objective of this study was to evaluate whether revision spine surgery increased the risk of postoperative neurological deficits. A secondary objective of the study was to analyze whether deficits following repeat spine surgery increased morbidity and mortality. Data on revision spine procedures were extracted from the California State Inpatient Database for years 2008 to 2011. Patients who developed postoperative neurological deficits were then subdivided into causative procedure: revision anterior cervical discectomy and fusion, revision posterior cervical fusion, and revision thoracolumbar fusion. These data were then used to calculate the total incidence of postoperative neurological deficits following each type of procedure. The impact of neurological deficits on in-hospital morbidity following revision procedures was also calculated.

Results: Revision procedures accounted for 5.84% of all spine procedures in a total of 7645 patients. Among these patients, 67 patients (0.88%) developed a postoperative neurological deficit with an adjusted odds ratio of 1.56 (95% CI, 1.20–2.00, $P < .05$). When using individuals with no neurological deficit as the reference group, the odds of morbidity were 5.3 (95% CI, 3.15–9.00, $P < .05$) in those who sustained neurological deficit following revision procedure.

Conclusions/Clinical Relevance: This study exposes the increased risk of postoperative neurological complications in revision spine surgeries. In response, further studies are needed to evaluate the use of intraoperative neurophysiological monitoring to reduce this risk.

Complications

Keywords: postoperative, neurological, deficits, revision, spine, surgery, morbidity, intraoperative, neurophysiological, monitoring

INTRODUCTION

Postoperative neurological complications are a major problem after spine surgery and range from minor paresthesia to quadriplegia. These complications have the potential to disrupt patient recovery, length of hospital stay, postoperative quality of life, and health care costs.[1] A recent study quantifying the national incidence of postoperative neurological complications (0.82 %) showed an increasing rate of such complications (from 0.68% in 1999 to 1.05% in 2011) following anterior cervical discectomy and fusion, posterior cervical fusion, and thoracolumbar fusion.[2]

Neurological complications associated with spine surgery can occur following anterior cervical discectomy and fusion, posterior cervical fusion, and thoracolumbar fusion. Myelopathic complications are also known as *perioperative spinal cord injuries*. Any direct injury to the spinal cord during procedures is classified as a perioperative spinal cord injury. Other injuries can be more widespread to nerve roots (radiculopathies) and peripheral nerve palsies/neuropathies. All postoperative neurological complications can result in subpar patient

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outcomes, complicate recovery, and increase overall health care costs.[2]

Revision spine surgery is defined as a secondary surgical procedure at the same site as a previous spine surgery. No studies have analyzed the incidence of postoperative neurological complications following revision spinal surgery, which occurs more commonly than anticipated given the sheer volume of spine procedures.[2] Vascular injury, mechanical compression of the spinal cord and nerve roots, and cord and nerve root distraction have the potential to occur more frequently in revision surgery due to the presence of scar tissue and distorted anatomy.[3] With a progressively aging population and the growth of spine fusion surgeries,[4] it is important to understand the impact of postoperative neurological complications for spine surgeries in general and revision surgeries in particular. Anterior cervical discectomy and fusion, posterior cervical fusion, and thoracolumbar fusion are spine surgeries that have been increasingly performed over the past 2 decades[5,6] and are ideal models for epidemiological analysis of postoperative neurological complications following repeat spine surgery.

The primary aim of this study was to evaluate whether revision spine procedures increased the risk of new postoperative neurological deficits. A secondary aim of the study was to analyze whether postoperative neurological deficits following repeat spine surgery increased morbidity. The information gained from this analysis will underscore the impact of postoperative neurological complications after revision surgeries. We believe this analysis can provide information to develop an effective screening or scoring system for patients needing repeat spine surgery, standardize the detecting postoperative neurological complications with intraoperative neurological monitoring, and improve overall patient care and outcomes.

MATERIALS AND METHODS

Database

We used the State Inpatient Database (SID) from the state of California, which has information about "present on admission" (POA). The POA data give information about diagnoses present when a patient is admitted to the hospital. These data are defined as conditions present at the time of inpatient admission orders and can be used to differentiate between preexisting conditions and conditions that developed during an inpatient admission. All conditions that develop during an outpatient encounter, emergency room visit, observation period, or outpatient/same-day surgery leading up to an inpatient hospitalization are included in POA data. The POA data allow for more precise medical diagnoses billing and coding. Data were extracted from the SID from 2008 to 2011 because POA reporting before 2008 was not mandatory, and data after 2011 were not available. The SID files encompassed both insured and uninsured patients. They contained clinical and nonclinical variables, including primary and secondary diagnosis, procedure, admission and discharge status, and patient demographics as defined by the *International Classification of Disease, Ninth Revision, Clinical Modification* (*ICD-9-CM*).

Patients Included

The algorithm used for data extraction and all *ICD-9-CM* codes can be found in the Supplemental Material available online. Two samples were created for analysis (all spinal procedures and revision spinal procedures). Initial analysis on all spinal procedures was done to find the predictors for neurological deficit and the impact of revision procedures on the incidence of new neurological deficits. Subsequent subanalysis on revision spinal procedures was then done to find the effect of neurological deficit on both new-onset and exacerbation of preexisting morbidity. On the basis of previously published studies reporting the incidence of neurological deficit in revision spine surgeries,[7,8] we decided to conduct our analysis with all revision procedures grouped together as opposed to separated by individual procedure type. Within each sample, demographic data were gathered about all patients, regardless of whether they developed postoperative neurological deficits. The total number of patients who developed postoperative spinal deficits following revision procedures was then subdivided into causative procedures: revision anterior cervical discectomy and fusion, revision posterior cervical fusion, and revision thoracolumbar fusion. These data were then used to calculate the total incidence of postoperative neurological deficits following all spinal procedures and following revision spine procedures only.

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In-hospital morbidity was also evaluated and subdivided by age, length of hospital stay, van Walraven patient comorbidity scores (VWS), race, gender, admission source, household income, and payment source. In general, *morbidity* is defined as any departure, subjective or objective, from a state of physiological or psychological well-being. In our case, *morbidity* is defined as development of cardiac, respiratory, gastrointestinal, renal, infection, wound, and/or stroke complications or length of stay greater than 14 days.

Statistical Analysis

Dataset construction and analysis according to our inclusion criteria were performed using SAS version 9.4 (SAS Institute Inc, Cary, NC). We created 2 datasets for analysis: the first included all spinal surgical procedures, and the second was limited to revision procedures. After running a macro, a set of options in Microsoft Excel that can automate tasks, to calculate VWS (an Elixhauser comorbidity index quantifies disease burden in patients), we ran an initial bivariate analysis using χ^2 for categorical variables and t test for continuous variables. Continuous data were presented as means and standard deviations, and categorical data were presented as percentages. Final variables included in the multivariable models were based on initial statistical significance in the bivariate analysis with a .05 level of significance, clinical plausibility, and effect on model C statistics. After testing for multicollinearity, we ran several logistic models to calculate adjusted Wald odds ratios and 95% confidence intervals for predictors of neurological deficits, morbidity, and in-hospital mortality. The mortality model failed to produce any meaningful numbers because the number of patients who developed neurological deficits and died in the hospital was small; thus, we did not report the numbers. We opted to use California's SID starting in 2008 for the present on admission variable reporting to provide an improved accuracy given that postoperative complications scanning became mandatory in late 2007. Any cases fewer than 10 were replaced by an asterisk in accordance with Healthcare Cost and Utilization Project regulations to limit possible patient identification. Statistical significance was defined as a P value $< .05$.

RESULTS

Patient Characteristics and Bivariate Analysis of Predictors of Neurological Deficit in All Spinal Procedures

In our analysis of 130 868 spinal procedures, 69 622 patients (53.2%) were women. A total of 96 975 patients (74.10%) were white; 19 606 patients (14.98%) were Hispanic; 6676 patients (5.10%) were African American; 5238 patients (4.0%) were Asian or Pacific Islander; 67 patients (0.05%) were Native American; and 2306 patients (1.76%) were of another race. A total of 740 patients (0.57%) with a mean age of 59.7 years developed a neurological deficit; however, 130 128 patients (99.43%) with a mean age of 56.4 years did not develop a neurological deficit. There were 376 patients (0.29%) who died during the hospital stay. Of patients who developed neurological deficits, 16 patients (2.16%) died during the hospital stay.

In the bivariate analysis of all spinal procedures shown in Table 1, there were 7645 (5.84%) revision procedures. Among these patients, 67 patients (0.88%) developed a postoperative neurological deficit with an unadjusted odds ratio of 1.61 (95% CI, 1.25–2.07, $P < .05$). A total of 489 patients (0.44%) with a VWS less than 5 developed a neurological deficit. There were 213 patients (1.29%) with a VWS of 5 to 14 who developed a neurological deficit with an odds ratio of 2.99 (95% CI, 2.54–3.52 , $P < .05$) when compared with those with a VWS less than 5; whereas, 38 patients (1.7%) of patients with a VWS greater than 14 developed a neurological deficit with an odds ratio of 3.98 (95% CI, 2.85–5.55, $P < .05$) when compared with those with a VWS less than 5.

Multivariable Analysis Predicting Neurological Deficit in All Spinal Procedures

The multivariable analysis of all spinal procedures presented in Table 2 shows that revision surgery was associated with increased odds of developing a neurological deficit, with an odds ratio of 1.56 (1.207–2.004). When using a VWS less than 5 as a reference, a VWS of 5 to 14 was associated with increased odds of developing a neurological deficit, with an odds ratio of 2.66 (95% CI, 2.25–3.14, $P < .05$). A VWS greater than 14 was also associated with increased odds of developing a neurological deficit, with an odds ratio of 3.45 (95% CI, 2.46–4.84, $P < .05$). With private insurance as

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Table 1. Patient characteristics and bivariate analysis of predictors of neurologic deficit in all spinal procedures.

Variables	% of Patients	Patients Who Developed ND (n = 740), n (%)	Patients Who Did Not Develop ND (n = 130 128), n (%)	Unadjusted Odds Ratio (95% CI)	*P* Value
Revision procedure	5.84	67 (0.88)	7578 (99.12)	1.61 (1.25–2.07)	.0002
Neurological deficits	0.57	NA			
Died during stay	0.29	16 (4.16)	369 (95.84)	NA	
Routine discharge	70.3	311 (0.34)	92116 (99.66)	NA	
Age ± SD	NA	59.7 ± 16.5	56.4 ± 15	NA	<.0001
Age, y					
0–17	2.16	25 (0.88)	2807 (99.12)	REF	REF
18–40	10.55	52 (0.38)	13761 (99.62)	0.42 (0.26–0.68)	.0004
41–60	46.27	263 (0.43)	60296 (99.57)	0.49 (0.32–0.73)	.0007
61–80	36.81	352 (0.73)	47816 (99.27)	0.82 (0.55–1.24)	.3595
> 80	4.20	48 (0.87)	5448 (99.13)	0.98 (0.60–1.60)	.9652
Length of hospital stay	NA	11.1 ± 13.6	4.4 ± 5.5	NA	<.0001
van Walraven Score	NA	3.0 ± 5.9	0.86 ± 4.3	NA	<.0001
< 5	85.70	489 (0.44)	111 710 (99.56)	REF	REF
5–14	12.60	213 (1.29)	16 236 (98.71)	2.99 (2.54–3.52)	<.0001
> 14	1.70	38 (1.71)	2182 (98.29)	3.98 (2.85–5.55)	<.0001
Race					
White	74.10	495 (0.53)	92 398 (99.47)	REF	REF
Black	5.10	45 (0.70)	6348 (99.30)	1.32 (0.97–1.79)	.0730
Hispanic	14.98	129 (0.69)	18 655 (99.31)	1.29 (1.06–1.56)	.0101
Asian or Pacific Islander	4.00	36 (0.72)	4985 (99.28)	1.34 (0.96–1.89)	.0847
Native American	0.05	*	66 (98.51)	2.82 (0.39–20.41)	.3026
Other	1.76	*	2197 (99.59)	0.76 (0.39–1.48)	.4260
Female gender	53.20	416 (0.60)	68 671 (99.40)	1.13 (0.97–1.30)	.0972
Admission source					
Routine	91.99	655 (0.55)	118 576 (99.45)	REF	REF
Emergency department	6.84	61 (0.68)	8896 (99.32)	1.24 (0.95–1.61)	.1075
Another hospital	0.90	11 (0.94)	1164 (99.06)	1.71 (0.94–3.11)	.0788
Another health facility including long term care	1.00	13 (0.95)	1354 (99.05)	1.73 (1.00–3.01)	.0495
Court/Law enforcement	0.10	0 (0.00)	136 (100.00)	NA	NA
Household income (Median income for patient's zip code)					
Fourth quartile	29.20	212 (0.57)	37 188 (99.43)	REF	REF
First quartile	19.80	156 (0.61)	25 211 (99.39)	1.08 (0.88–1.33)	.4384
Second quartile	24.10	171 (0.55)	30 650 (99.45)	0.97 (0.80–1.19)	.8342
Third quartile	26.80	189 (0.55)	34 142 (99.45)	0.97 (0.79–1.18)	.7696
Primary payer					
Private insurance	42.70	223 (0.40)	55 730 (99.60)	REF	REF
Medicare	34.40	350 (0.78)	44 666 (99.22)	1.95 (1.65–2.31)	<.0001
Medicaid	5.10	46 (0.69)	6588 (99.31)	1.74 (1.26–2.39)	.0006
Self-pay	0.70	*	930 (99.68)	0.81 (0.25–2.52)	.7113
Other	17.00	118 (0.53)	22 212 (99.47)	1.32 (1.06–1.66)	.0130

Abbreviations: CI, confidence interval; NA, not applicable; ND, neurological deficit; REF, reference; SD, standard deviation; *, no data available.

the reference group, patients insured through Medicare were at increased odds of developing neurological deficits, with an odds ratio of 1.384 (95% CI, 1.126–1.700, $P < .05$). Patients insured through Medicaid were also at increased odds of developing neurological deficits, with an odds ratio of 1.421 (95% CI, 1.025–1.969, $P < .05$).

Revision Spinal Procedures Breakdown

The breakdown of revision surgeries in Table 3 shows that revision spinal procedures accounted for 5.84% (7645) of all spinal procedures. Within revision surgeries, 2677 procedures (35.02%) were revision of the lumbar and lumbosacral spine anterior column done with a posterior technique. In addition, 1240 procedures (16.22%) were revision

Table 2. Multivariable analysis of predictors of neurologic deficit in all spinal procedures.

	Odds Ratio (95% CI)
Revision surgery	1.56 (1.21-2.00)
Age (categorical), y	
0–17	REF
18–40	0.53 (0.33–0.86)
41–60	0.59 (0.388–0.904)
61–80	0.79 (0.51–1.22)
>80	0.77 (0.46–1.30)
van Walraven (categorical)	
<5	REF
5–14	2.66 (2.25–3.14)
>14	3.45 (2.46–4.84)
Primary payer	
Private insurance	REF
Medicare	1.39 (1.13–1.70)
Medicaid	1.42 (1.02–1.97)
Self-pay	0.78 (0.25–2.43)
Other	1.40 (1.12–1.75)

Abbreviations: CI, confidence interval; REF, reference.

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Table 3. Breakdown of revision spinal procedures.

Surgery	Cases, n (%)	Mean Age, y	Mean LOS	Mean VWS	Incidence of ND, %
Refusion of spine, not otherwise specified	33 (0.43)	57.6 ± 12.2	5.2 ± 6.3	1.1± 4.0	3.03
Refusion of atlas-axis spine	73 (0.95)	52.5 ± 22.2	5.4 ± 4.6	1.7 ± 5.4	0
Refusion of other cervical spine, anterior column, anterior technique	1181 (15.45)	53.5 ± 10.4	3.5 ± 5.5	0.5 ± 4.1	0.34
Refusion of other cervical spine, posterior column, posterior technique	665 (8.70)	54.5 ± 11.2	4.1 ± 4.3	0.4 ± 4.2	1.05
Refusion of dorsal and dorsolumbar spine, anterior column, anterior technique	40 (0.52)	53.8 ± 16.6	10.5 ± 9.1	2.5 ± 5.1	2.50
Refusion of dorsal and dorsolumbar spine, posterior column, posterior technique	833 (10.90)	55.0 ± 19.2	8.06 ± 0.0	2.5 ± 5.6	1.80
Refusion of lumbar and lumbosacral spine, anterior column, anterior technique	800 (10.46)	55.9 ± 13.0	5.5 ± 5.2	0.5 ± 4.1	0.63
Refusion of lumbar and lumbosacral spine, posterior column, posterior technique	1240 (16.22)	58.4 ± 13.7	4.4 ± 3.3	0.5 ± 4.1	0.97
Refusion of lumbar and lumbosacral spine, anterior column, posterior technique	2677 (35.02)	57.7 ± 14.1	4.6 ± 4.2	0.6 ± 4.0	0.82
Refusion of spine, not elsewhere classified	58 (0.76)	56.4 ± 16.5	5.3 ± 12.7	1.3 ± 3.4	0
Fusion or refusion of 2–3 vertebrae	29 (0.38)	57.5 ± 16.6	4.5 ± 4.5	2.2 ± 7.4	0
Fusion or refusion of 4–8 vertebrae	13 (0.17)	55.1 ± 15.3	7.0 ± 6.3	1.9 ± 5.2	0
Fusion or refusion of 9 or more vertebrae	3 (0.04)	41.3 ± 25.4	7.3 ± 4.0	0.6 ± 1.1	0
Overall	7645				0.88

Abbreviations: LOS, length of stay; ND, neurological deficit; VWS, van Walraven score.

of the lumbar or lumbosacral spine posterior column done with a posterior technique, and 1181 procedures (15.45%) were revision of the cervical spine anterior column done with an anterior technique.

Patient Characteristics of Revision Procedures

Patient characteristics of revision spine surgeries in Table 4 show that 4209 patients (55.50%) were women. The average age of patients undergoing revision spine surgery was 56.36 years. Within all revision procedures, the incidence of neurological deficit was 0.88%. Revision of the dorsal and dorsolumbar spine, anterior column, done with an anterior technique had a neurological deficit incidence of 2.50%. Revision of dorsal and dorsolumbar spine, posterior column, done with a posterior technique had a neurological deficit incidence of 1.80%. There were 33 revision cases not otherwise specified in terms of spine segment and technique. The incidence of neurological deficit within this subgroup was 3.03%.

Impact of Neurological Deficit on Morbidity After Revision Procedures

Various patient characteristics were analyzed by bivariate analysis as predictors of morbidity following revision spinal procedures as shown in Table 4. Overall, 7645 patients were included in the analysis, with 6831 (89.35%) suffering no morbidity and 814 (10.65%) suffering morbidity. There were 67 patients who suffered from neurologic deficit following their revision procedures, with 39 of 67 (58.21%) suffering no morbidity and 28 of 67 (41.79%) suffering morbidity. The odds of suffering morbidity after sustaining neurological deficit was 6.20 (95% CI, 3.79–10.13, $P < .05$) when compared with those who had no neurological deficits following revision spinal procedure.

The morbid group had an average age of 58.81 years, whereas the nonmorbid group had an average age of 56.07 years. Average length of hospital stay was 13.27 days in the morbid group and 3.92 days in the nonmorbid group. Using those with a VWS of less than 5 as the reference group, the odds of morbidity was 4.09 (95% CI, 3.46–4.83, $P < .05$) in the group that scored 5 to 14 and 8.46 (95% CI, 5.78–12.38, $P < .05$) in the group that scored greater than 14. Using routine admission as the reference group, the odds of morbidity for emergency department admission was 4.20 (95% CI, 3.26–5.41, $P < .05$); for admission from another hospital, 6.21 (95% CI, 3.52–10.96, $P < .05$); and for admission from another health facility, 3.16 (95% CI, 1.94–5.15, $P < .05$). Using private insurance as the reference group, the odds of morbidity with Medicare was 1.67 (95% CI, 1.40–1.99, $P < .05$) and the odds of morbidity with Medicaid was 1.85 (95% CI, 1.33–2.56, $P < .05$).

Multivariable analysis of the same patient characteristics shown in Table 5 yielded slightly different results. The odds ratio for morbidity in those who sustained neurological deficit following revision procedure was 5.33 (95% CI, 3.15–9.04, $P < .05$). A VWS of 5 to 14 had 3.45 (95% CI, 2.90–4.11, $P < .05$) odds of morbidity, whereas a score greater than 14 had a 5.68 (95% CI, 3.80–8.49, $P < .05$) odds of morbidity. Emergency department admission had a 3.11 (95% CI, 2.37–4.09, $P < .05$) odds of morbidity, another hospital had a 3.76 (95% CI, 2.04–6.95 $P < .05$) odds of morbidity, and another

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Table 4. Patient characteristics and bivariate analysis of predictors of morbidity in revision procedures.

Characteristic	Overall, n (%)	Morbidity			
		No, n (%)	Yes, n (%)	Odds Ratio (95% CI)	*P* Value
Total	7645 (100)	6831 (89.35)	814 (10.65)	NA	NA
Neurological deficits	67 (0.88)	39 (58.21)	28 (41.79)	6.20 (3.79–10.13)	NA
Routine discharge	5211 (68.16)	4906 (94.15)	305 (5.85)	NA	NA
Age ± SD	56.36 ± 14.15	56.07 ± 14.01	58.81 ± 15.03	NA	<.0001
Age group, y					
0–17	129 (1.69)	113 (87.60)	16 (12.40)	REF	NA
18–40	722 (9.44)	658 (91.14)	64 (8.86)	0.68 (0.38–1.23)	NA
41–60	3773 (49.35)	3436 (91.07)	337 (8.93)	0.69 (0.40–1.18)	NA
61–80	2801 (36.64)	2444 (87.25)	357 (12.75)	1.03 (0.60–1.76)	NA
>80	220 (2.88)	180 (81.82)	40 (18.18)	1.56 (0.84–2.93)	NA
Length of hospital stay, d	4.91 ± 5.67	3.92 ± 2.42	13.27 ± 13.22	NA	<.0001
van Walraven score	0.82 ± 4.38	0.5245 ± 3.9623	3.36 ± 6.45	NA	<.0001
<5	6480 (84.76)	5981 (92.30)	499 (7.70)	REF	NA
5–14	1049 (13.72)	782 (74.55)	267 (25.45)	4.09 (3.46–4.83)	NA
>14	116 (1.52)	68 (58.62)	48 (41.38)	8.46 (5.78–12.38)	NA
Race					
White	5665 (76.92)	5039 (88.95)	626 (11.05)	REF	NA
Black	322 (4.37)	280 (86.96)	42 (13.04)	1.21 (0.86–1.68)	NA
Hispanic	1077 (14.62)	975 (90.53)	102 (9.47)	0.84 (0.67–1.05)	NA
Asian or Pacific Islander	182 (2.47)	163 (89.56)	19 (10.44)	0.93 (0.57–1.52)	NA
Native American	*	*	0	*	NA
Other	115 (1.56)	107 (93.04)	8 (6.96)	0.60 (0.29–1.24)	NA
Female gender	4209 (55.50)	3751 (89.10)	459 (10.90)	1.04 (0.90–1.20)	NA
Admission source					
Routine	7180 (93.93)	6505 (90.60)	675 (9.40)	REF	NA
Emergency department	316 (4.13)	220 (69.62)	96 (30.38)	4.20 (3.26–5.41)	NA
Another hospital	51 (0.67)	31 (60.78)	20 (39.22)	6.21 (3.52–10.96)	NA
Another health facility	89 (1.16)	67 (75.28)	22 (24.72)	3.16 (1.94–5.15)	NA
Court/Law enforcement	*	*	*	1.37 (0.16–1.20)	NA
Household income					
Fourth quartile	2183 (29.13)	1936 (88.69)	247 (11.31)	REF	NA
First quartile	1398 (18.65)	1249 (89.34)	149 (10.66)	0.93 (0.75–1.16)	NA
Second quartile	1869 (24.94)	1676 (89.67)	193 (10.33)	0.90 (0.73–1.10)	NA
Third quartile	2045 (27.28)	1837 (89.83)	208 (10.17)	0.88 (0.73–1.07)	NA
Primary payer					
Private insurance	2521 (32.98)	2300 (91.23)	221 (8.77)	REF	NA
Medicare	2883 (37.71)	2483 (86.13)	400 (13.87)	1.67 (1.40–1.99)	NA
Medicaid	344 (4.50)	292 (84.88)	52 (15.12)	1.85 (1.33–2.56)	NA
Self-pay	36 (0.47)	30 (83.33)	6 (16.67)	2.08 (0.85–5.05)	NA
Other	1861 (24.34)	1726 (92.75)	135 (7.25)	0.81 (0.65–1.01)	NA

Abbreviations: CI, confidence interval; n, number of patients; NA, not applicable; REF, reference; SD, standard deviation; *, no data available.

health facility had a 2.46 (95% CI, 1.47–4.11, $P < .05$) odds of morbidity. With payer type, only Medicare had a significant odds of morbidity at 1.30 (95% CI, 1.09–1.56, $P < .05$).

Analysis of mortality was not included due to the very small number of patients who died following revision procedures. Thus, no significant data could be analyzed.

DISCUSSION

On the basis of our analysis, revision procedures are clearly a risk for increased postoperative neurological complications. Patients with revision were 1.61 times more likely to have a neurological deficit than patients undergoing primary procedures. Although the percentage of patients with a VWS greater than 5 was similar between all spinal surgeries and revision procedures (14.30% vs 15.24%), previous studies have shown that revision spinal surgery patients have a higher risk of procedure-related complications with a longer hospital course despite this similarity in comorbidity score and mortality rate.[8,9] Previous surgeries also affect the technical difficulty of a repeat procedure due to development of scar tissue, unpredictable anatomy, increased length of procedures leading to longer time under general anesthesia, and increased chance of a dural tear.[10,11]

Postoperative neurological complications in revision procedures have significant implications both in terms of patient care/outcomes and health care expenditure. Most spinal cord injuries result in paresthesia but can also cause paraplegia, quadriplegia, and sphincter dysfunction. Other complica-

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Table 5. Multivariable analysis for predictors of morbidity in revision procedures.

Variable	Odds Ratio (95% CI) for Morbidity
Neurological deficits	5.33 (3.15–9.04)
van Walraven score	
<5	REF
5–14	3.45 (2.90–4.11)
>14	5.68 (3.80–8.49)
Admission source	
Routine	REF
Emergency department	3.11 (2.37–4.09)
Another hospital	3.76 (2.04–6.95)
Another health facility	2.46 (1.47–4.11)
Court/Law enforcement*	1.49 (0.17–12.76)
Primary Payer	
Private insurance	REF
Medicare	1.30 (1.08–1.56)
Medicaid*	1.28 (0.90–1.82)
Self-pay*	1.96 (0.77–4.95)
Other*	0.90 (0.72–1.13)

Abbreviations: CI, confidence interval; REF, reference.

tions can also contribute to significant forms of deficit, including radiculopathies, dysphagia, recurrent laryngeal nerve palsies, and paralysis in the case of severe nerve root damage. Both categories of neurological injury have the potential to subject patients to long-term disability. These complications also place a sizable burden on the overall health care infrastructure.[12,13]

Although we cannot speculate on deficit severity, it can be extrapolated from our data that deficits occur at a higher rate in revision procedures than in primary procedures (0.88% vs 0.57%). In addition, the results of our study may also highlight the increased rate of neurological deficits in patients of lower socioeconomic status. This health care disparity is reflected by our finding that patients covered by Medicaid were at an increased odds of developing neurological deficits with an odds ratio of 1.421 (95% CI, 1.025–1.969, $P < .05$) compared with patients covered by private insurance.

In patients who suffered from neurological deficit, the rate of morbidity was exceedingly higher than those who did not (10.65% vs 41.79%). In fact, our multivariable analysis showed that neurologic deficit was a significant predictor of morbidity in revision procedures, and the presence of comorbidities increased the postoperative complication rate in those undergoing revision spinal surgeries. The impact of these conditions include learning disability, depression rooted in one's disability, and increased financial demand needed to manage new medical complications.[14] Thus, strategies must be developed moving forward to minimize postoperative neurological deficit, including standard use of intraoperative neurophysiological monitoring with somatosensory evoked potentials and motor evoked potentials, thereby reducing the rate of morbidity and patient suffering.[1]

Many risk models such as the National Surgical Quality Improvement Program and Revised Cardiac Risk Index have been designed to determine a quantitative risk of intraoperative myocardial infarction or cardiac arrest in evaluation of patients prior to noncardiac surgery.[15,16] A similar scoring system was not available for patients undergoing spinal surgery. The purpose of such a protocol, which can be developed using the data presented in this study, would be to determine the risk level a patient undergoing spinal revision surgery would have for sustaining a deficit. In theory, this protocol would compose a system in which patients would receive points for factors associated with higher risk of postoperative spinal cord injury. For example, a VWS of more than14 (odds ratio = 3.98) would contribute a higher risk than a score of 5 to 14 (odds ratio = 2.99). An aggregate percentile could be compiled using all risk factors that we have determined to be significant. This scoring system could be used to determine patients at low risk and high risk, as well as those who should be excluded from surgery altogether.

This study had several limitations that may have affected our final conclusions. The first limitation is that our estimates were based on data with significant underreporting of postoperative neurological complications, which may have been responsible for the low estimates of incidence reported in the study. Underreporting of data could be due to the fact that our estimates are largely based on claims data, which is compiled to maximize the billing process. In addition, the study was not conducted in a prospective manner. Data obtained were not originally collected to answer the questions posed by this study. Lack of specific deficits makes it difficult to draw specific conclusions on the causes of complications and requires a prospective study. Despite our analysis highlighting the increased frequency of complications in the revision procedure, the severity of neurological deficits in patients undergoing revision procedures versus primary procedures could not be quantified. Finally, we were unable to analyze the burden of mortality associated with revision spine surgery, given that most of our results were not significant.

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To summarize, this study exposes the increased risk of postoperative neurological complications in revision spine surgeries. Furthermore, these complications increase the risk of morbidity as measured by length of stay in the hospital and nonneurological complications. We hope that more studies can be done in the future to quantify the severity of neurological deficit in revision procedures when compared with primary procedures and evaluate the use of intraoperative neurophysiological monitoring for potential risk reduction.

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Corresponding Author: Parthasarathy D. Thirumala, MD, MS, Department of Neurological Surgery and Neurology, University of Pittsburgh Medical Center, 200 Lothrop St, PUH B-400, Pittsburgh, PA 15213. Phone: (412) 648-2228; Fax: (412) 383-8999; Email: thirumalapd@upmc.edu.

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