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Perioperative Retinal Artery Occlusion: Incidence and Risk Factors in Spinal Fusion Surgery from the US National Inpatient Sample 1998–2013

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Abstract

Introduction—Retinal artery occlusion (RAO) is a rare but devastating complication of spinal fusion surgery. We aimed to determine its incidence and associated factors.

Methods—Hospitalizations involving spinal fusion surgery were identified by searching the National Inpatient Sample, a database of hospital discharges, from 1998–2013. RAO cases were identified using ICD-9-CM codes. Using the STROBE guidelines, postulated risk factors were chosen based on literature review and identified using ICD-9-CM codes. Multivariate logistic models with RAO as outcome, and risk factors, race, age, admission, and surgery type evaluated associations.

Results—An estimated 4,784,275 spine fusions were performed in the U.S. from 1998–2013, with 363 (CI: 291–460) instances of RAO, an overall incidence of 0.76/10,000 spine fusions (CI: 0.61–0.96). Incidence ranged from 0.35/10,000 (CI: 0.11–1.73) in 2001–2002 to 1.29 (CI: 0.85–

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2.08) in 2012–2013, with no significant trend over time ($P = 0.39$). Most strongly associated with RAO were: stroke, unidentified type (odds ratio, OR: 14.33, CI: 4.54–45.28, $P < 0.001$), diabetic retinopathy (OR: 7.00, CI: 1.18–41.66, $P = 0.032$), carotid stenosis (OR: 4.94, CI: 1.22–19.94, $P = 0.025$), aging (OR for age 71–80: 4.07, CI: 1.69–10.84, $P = 0.002$), and hyperlipidemia (OR: 2.96, CI: 1.85–4.73, $P < 0.001$). There was an association between RAO and trans-foraminal lumbar inter-body fusion (OR: 2.95, CI: 1.29–6.75, $P = 0.010$). Elective surgery was inversely associated with RAO (OR: 0.40, CI: 0.23–0.68, $P < 0.001$).

Conclusions—Patient specific associations with RAO in spinal fusion include aging, carotid stenosis, diabetic retinopathy, hyperlipidemia, stroke, and specific types of surgery. Diabetic retinopathy may serve as an observable biomarker of heightened risk of RAO in patients undergoing spine fusion.

Keywords

Carotid artery stenosis; diabetes; diabetic retinopathy; retinal artery occlusion; spinal fusion

Background

Perioperative visual loss (POVL) is a rare but devastating complication that occurs most commonly after spinal fusion or cardiac surgery.¹ The three primary causes of POVL are ischemic optic neuropathy (ION), cortical blindness, and retinal artery occlusion (RAO).² Although perioperative ION is classically associated with spinal fusion surgery, and perioperative RAO with cardiac surgery,² presumably related to embolism, a minority of those with POVL have RAO in spinal fusion surgery. Better understanding of these less common events remains significant since U.S. spinal fusion volume is the highest in the world,³ and the impact of RAO on a patient's life is considerable, with disability from what is often irreversible visual loss.⁴

Proposed mechanisms for RAO in spine fusion surgery are embolic or compression. Both have been described almost exclusively in case reports. Possible embolization has been reported with a patent foramen ovale in an adolescent who underwent spinal fusion for scoliosis.⁵ Compression of the eye has been reported from apparently poorly or improperly fitted headrests.⁶ Another potential source of compressive injury associated with RAO is pressure of a retractor on the carotid artery during cervical spine fusion leading to decreased flow through the carotid artery.^{7,8}

Non-perioperative RAO is associated with stroke, coronary artery disease, atrial fibrillation, and carotid stenosis and is most commonly embolic.⁹ Associations have also been described between RAO or stroke and hypercoagulable states,¹⁰ relevant to patients undergoing spine surgery for cancer metastasis.^{11,12} RAO associated with cardiac surgery is also thought to be embolic, and is associated with valvular heart surgery, giant cell arteritis, carotid stenosis, hypercoagulable state, ophthalmic diabetic complications and male gender. It is inversely associated with acute coronary syndrome, atrial fibrillation, congestive heart failure, diabetes without ophthalmic complications and smoking.² A unique postulated cause of RAO in spine surgery is eye compression related to prone positioning, evident when signs and symptoms such as eye pain, ophthalmoplegia, and bruising are also present.¹³ In a study of

visual loss in spine surgery from the American Society of Anesthesiologists Postoperative Visual Loss Registry, of 10 patients with RAO, 3 had no reported signs of eye compression.¹⁴ Thus eye compression does not account for all cases, and accordingly, more rigorous study of the etiology and risk factors of RAO in spinal fusion surgery is necessary.¹⁵⁻¹⁷

Determining the mechanism of perioperative RAO in spine surgery may enable identification of high-risk patients,¹⁸ better informed consent, and modification of the surgical plan. We hypothesized that perioperative RAO in spinal fusion is associated with risk factors for spontaneous RAO, with spine operations for cancer, and in instances where the head is more likely to move and the eyes could be compressed during surgery, i.e., cervical spine operations. To test our hypotheses, we examined hospital discharges in the National Inpatient Sample (NIS) for posterior spinal fusion surgery evaluating the incidence for and associations with RAO.

Methods

NIS, maintained by the Healthcare Cost and Utilization Project (HCUP) of the Agency for Healthcare Research and Quality (AHRQ), is an approximately 20% stratified sample of US inpatient discharges. Included are demographics, diagnoses (principal and secondary), procedures (principal and secondary), charges (in dollars), length of stay (in days), discharge status, outcomes, and medical diagnoses. Diagnoses and procedures are coded using the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM). Since there are no specific patient identifiers, the Institutional Review Boards of the University of Chicago and the University of Illinois deemed this study “exempt.”

Data Classification

Discharges with posterior cervical, thoracic, lumbar, or sacral spine fusion surgery in the NIS from 1998–2013 were studied as earlier reported.^{19,20} Operations with anterior approach to the spine were excluded, and the number of vertebrae fused was included as a proxy for intraoperative time or procedure complexity (Supplemental Table 1). ICD-9-CM codes were compared against Current Procedural Technology (CPT) spinal fusion codes using EncoderPro.com (Optum, Salt Lake City, UT). Patients discharged with a primary or secondary diagnostic ICD-9-CM code for RAO (362.30–362.34), and a relevant spine procedure were considered to have developed RAO during the hospitalization.

Missing Data and Sources of Bias

To account for missing data for race and admission type in the multivariate analysis, we performed multiple (10) imputations by chained equations,²¹ with race, gender, admission type, and age in the imputation model. The most important potential source of data bias is the possibility of misclassification from erroneous or absent coding of procedures and diagnoses.

Patient Characteristics

Patient characteristics included: age (years divided into 10-year periods, categorical variable), gender, length of hospital stay (days), yearly inflation-adjusted total hospital

charges (both as continuous variables), type of admission (elective vs non-elective), discharge status (routine, short-term hospital, home healthcare, died, other), and race.

Surgical factors included the medical diagnosis prompting surgery, divided into degenerative disc disease, scoliosis, or cancer of the spine. The number of levels operated on was determined from ICD-9-CM codes. Hospital conditions included anemia, transfusion, and postoperative bleeding. Potential risk factors for RAO were identified before analysis based upon previous case series, large database reviews, and case reports as recommended in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.²² (STROBE Statement Checklist appears in Supplemental Materials). Medical diagnoses (Supplemental Table 2) were: atrial fibrillation, coronary artery disease,²³ carotid artery stenosis,^{23,24} stroke, diabetes mellitus (type 1 and 2) without complications,²⁵ diabetes with complications (ophthalmic, renal, or neurological),²⁶ hypertension,²⁴ hypertension with cardiac complications,²⁷ obesity,²⁴ peripheral vascular disease, smoking,²⁸ congestive heart failure, atrial fibrillation,²³ giant cell arteritis,²⁹ thrombocytopenia, and hypercoagulable state (including primary and secondary hypercoagulable states, homocystinuria, and presence of antiphospholipid antibodies).³⁰⁻³² Stroke was classified as embolic, thrombotic, transient ischemia, unspecified, or iatrogenic.³³

Analysis

We used the AHRQ “trend weights” (hcupnet.ahrq.gov) to ensure accurate weighting,³⁴ as previously described,²⁰ with the “Survey” function in Stata (Stata Corp., College Station, TX). To calculate the incidence of RAO in spine fusion surgery, the 16 years of data were divided into two-year periods (1998–1999, 2000–2001, 2002–2003, 2004–2005, 2006–2007, 2008–2009, 2010–2011, and 2012–2013). This enabled the numerator (cases per time period) to reach the threshold for reporting (>10), while the denominator was the number of procedures per time period. (AHRQ does not allow reporting of any result < 10).

Patient characteristics, surgical factors, and RAO as a primary or secondary diagnosis from 1998–2013 were tabulated using national estimates. Multivariate logistic regressions were conducted with RAO as the dependent variable and postulated risk factors (patient characteristics excluding length of stay, total charges, discharge status; surgical factors; medical diagnoses) as independent variables as described previously.²⁰ Because RAO is a rare outcome, the study design maximized analysis power by comparing affected to unaffected patients. There was no attempt to exclude any unaffected (control) cases.²⁰ Results are reported as odds ratios (OR) with 95% confidence intervals (CI). $P < 0.05$ was considered significant for associations. Stata v14.0-MP (College Station, TX) was used for statistical analyses. A post-hoc power analysis for logistic regression was performed using G-power 3.1 (<http://gpower.hhu.de/>). Since RAO is rare, analysis was adjusted using Hsieh's formula.³⁵

Results

There were an estimated 4,828,126 spine fusions in the United States from 1998–2013, with 363 (CI: 291–460) instances of RAO, an overall incidence of 0.76/10,000 spine fusions (CI: 0.61–0.96). Incidence (Figure 1) ranged from 0.35/10,000 (CI: 0.11–1.73) in 2001–2002 to

1.29 (CI: 0.85–2.08) in 2012–2013, with no significant trend for change over time ($P = 0.39$).

A post hoc logistic regression power analysis was performed with total sample size 4.8 million, adjusted for rare outcome. For detecting associations with a low prevalence (e.g., 1%), the database was adequately powered ($\alpha = 0.05$, power = 80%) to detect an odds ratio as low as 1.6. With more prevalent parameters (e.g., 40%), an odds ratio as low as 1.2 could be robustly detected ($\alpha = 0.05$, power = 80%).

Table 1 shows the patients' characteristics, surgical factors, and medical diagnoses. Age was missing in < 0.1% and 2.8% (non-affected and RAO, respectively), race in 18.9% and 20.3%, and discharge status was missing or “other” in 39.4% and 13.6% of discharges. Those who sustained RAO had higher total hospital costs (\$136,648, CI: \$110,130–\$163,166) than the unaffected (\$78,726, CI: 76,456–80,997). Non-elective admission occurred in 28.3% and in 12.9% in RAO and unaffected cases, respectively. Discharge was “routine” in 41.1% of RAO cases, and in 75.6% non-RAO.

The clinical conditions most strongly associated with RAO in a multivariate model (Table 2) were: stroke other than embolic or thrombotic, i.e., “unspecified” (OR: 14.33, CI: 4.54–45.28, $P < 0.001$), diabetes with ophthalmic complications (OR: 7.00, CI: 1.18–41.66, $P = 0.032$), carotid stenosis (OR: 4.94, CI: 1.22–19.94, $P = 0.025$), and hyperlipidemia (OR: 2.96, CI: 1.85–4.73, $P < 0.001$). Age > 71 years was associated with RAO (OR: 4.07, CI: 1.69–10.84, $P = 0.002$), gender had no impact, and neither did the number of levels operated upon, nor cancer of the spine. The level of the spine procedure (cervical, thoracic, lumbar, sacral) was not associated with RAO, but there was an association with trans-foraminal lumbar inter-body fusion (TLIF, OR: 2.95, CI: 1.29–6.75, $P = 0.010$). Having surgery electively was inversely associated with RAO (OR: 0.40, CI: 0.23–0.68, $P < 0.001$).

Discussion

We identified an overall RAO incidence of 0.76/10,000 posterior spinal fusion surgeries, with no significant change during the 16-year study period. RAO was associated with age > 71 years old, diabetic retinopathy (DR), carotid stenosis, “unspecified” stroke, and hyperlipidemia. Associated surgical factors were non-elective surgery and TLIF. Some factors identified in this study were similar to those associated with spontaneous RAO, and with RAO in cardiac surgery. Carotid stenosis overlapped with associations found with spontaneous RAO, and with RAO in cardiac surgery. As in spontaneous RAO, we found an association with stroke and RAO in spinal fusion. We did not identify any associations between RAO in spinal fusion and other factors reported in association with spontaneous RAO and/or RAO in cardiac surgery including gender, giant cell arteritis, hypercoagulable state, atrial fibrillation and coronary artery disease.

Carotid stenosis was previously reported in association with spontaneous and cardiac surgery-related RAO,²⁴ and this study adds spinal fusion-associated RAO to the list. A potential mechanism is that carotid stenosis predisposes to RAO due to an increased risk of hypoperfusion of the ophthalmic artery. Systemic hemodynamic factors may contribute to

RAO among patients with carotid stenosis by exacerbating locally impaired perfusion.²⁵ Carotid stenosis could predispose to an embolic event causing RAO via plaque dislodging from the carotid artery. It is not known if head positioning during surgery contributes. This common association suggests some shared pathophysiology between spontaneous, cardiac surgery-associated and spinal surgery-associated RAO.

We demonstrated association between RAO in spinal fusion surgery and one systemic vascular risk factor, hyperlipidemia. While DM has been cited as a risk factor for spontaneous RAO,²⁵ we did not find uncomplicated DM, or DM with complications, other than diabetic retinopathy (DR), to be associated with RAO in spinal fusion surgery. Other vascular risk factors including hypertension and smoking also lacked significant associations. This suggests that the mechanism of RAO in spinal fusion surgery is not likely related to systemic vascular disease.

The association between DR and RAO in spinal fusion surgery is new and builds on our report of association between DR and RAO in cardiac surgery.² DR is characterized by loss of retinal capillary pericytes, increased retinal vascular permeability, neovascularization secondary to chronic hypoxia, and eventually degeneration of retinal neurons.³⁶ The increased risk of RAO in patients with DR may be due to susceptibility of the retinal vasculature^{37,38} to systemic alterations during complex spine surgery, including blood loss, hypotension, and systemic inflammation.³⁹ However, this remains conjectural and further studies are required. Caution should be exercised in interpreting the results because there were 10 RAO subjects with DR, and the degree of DR was not assessable.

With respect to the surgical procedure, there was no influence of the number of levels operated upon to development of RAO, suggesting that the amount of time to perform the procedure was not a factor, unlike our previous findings for perioperative ION in spine fusion.¹⁴ Also, contrary to our theory, surgical site, i.e., cervical, thoracic, lumbar, or sacral, was not related to RAO. However, the TLIF procedure was associated with RAO. This procedure necessitates a more difficult surgical approach,⁴⁰ but we cannot conclude from the study why it was associated with RAO. The elderly patient undergoing spine fusion was more susceptible to RAO. These patients tend to undergo more complex spine surgery due to more advanced disease,⁴¹ but no further conclusions about the association with RAO can be made from our data.

There are limitations to our study. It is likely that many, if not all, patients that developed RAO underwent a detailed neurological and ophthalmologic examination leading to increased documentation of ophthalmic diagnoses such as DR. Furthermore, the presence of visual loss, particularly if unilateral, might prompt testing for carotid artery stenosis. Thus, the associations of diabetic eye complications and carotid stenosis with RAO in our study may partly reflect heightened diagnosis intensity and resultant differential misclassification. We cannot determine if stroke diagnoses were used to represent RAO as a stroke to the eye or concurrent intracranial stroke.

The NIS, an administrative database of discharge records, is susceptible to undocumented diagnoses, over- or under-diagnosis, and coding errors. The severity of visual loss and

unilateral or bilateral involvement cannot be determined. Longitudinal follow-up for progression or improvement after discharge is not possible. Similarly, it cannot be determined with certainty if a diagnosis was pre-existent or developed during the hospitalization. The incidence of RAO in the general population is far less than our results, about 1/100,000,⁴² suggesting that our findings reflect a new diagnosis. Our study is limited to identification of factors associated with RAO during hospitalization for surgery and cannot conclusively address causation or independent risk factors, although the present results suggest new areas for research into the mechanisms of perioperative RAO. We also are unable to assess the impact of important recent trends in spine surgery, including minimally invasive spine surgery,⁴³ which was without a specific ICD-9-CM procedure code until 2014.

In conclusion, DR, stroke, and carotid stenosis are associated with RAO in patients undergoing spine fusion surgery. Other associations include age greater than 71 years, hyperlipidemia, and the TLIF procedure. Screening for eye disease and carotid artery stenosis should be considered for identifying heightened risk of RAO in spine surgery. Additional studies in the perioperative environment could afford a unique window into the natural history of RAO and give greater insight into potential mechanisms and treatment options.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

CI	confidence interval
DM	diabetes mellitus

ICD-9-CM	International Classification of Diseases, Ninth Revision, Clinical Modification
NIS	National Inpatient Sample
OR	odds ratio
POVL	perioperative visual loss
RAO	retinal artery occlusion
TLIF	trans-foraminal lumbar inter-body fusion

Figure 1.
Incidence of retinal artery occlusion (RAO) among patients undergoing spinal fusion in the National Inpatient Sample.

Table 1

Characteristics of all spinal fusion cases with and without retinal artery occlusion (RAO) in the National Inpatient Sample (NIS), 1998 to 2013.

		All Cases: RAO	All Cases: Unaffected
All patients: number of discharges		363	4,783,912
Patient Characteristics			
Age group (years)	18–30	10 (2.8%)	177,986 (3.7%)
	31–40	10 (2.8%)	605,204 (12.7%)
	41–50	34 (9.5%)	1,176,738 (24.6%)
	51–60	58 (15.9%)	1,192,665 (24.9%)
	61–70	102 (28.0%)	934,483 (19.5%)
	71–80	135 (37.2%)	573,312 (12.0%)
	>80	34 (9.5%)	123,526 (2.6%)
		Missing	10 (2.8%)
Gender	Male	186 (51.1%)	2,223,810 (46.5%)
	Female	178 (48.9%)	2,557,569 (53.5%)
	Missing	0 (0%)	2,532 (<0.1%)
Race	White	252 (69.3%)	3,172,465 (66.3%)
	Black	10 (2.8%)	288,939 (6.0%)
	Hispanic	19 (5.2%)	208,075 (4.4%)
	Asian or Pacific Islander	10 (2.8%)	40,529 (0.8%)
	Native American	10 (2.8%)	15,250 (0.3%)
	Other	10 (2.8%)	87,656 (1.8%)
	Missing	69 (18.9%)	970,949 (20.3%)
	Mean length of stay days (95% CI)	7.9 (5.8–10.0)	3.9 (3.8–3.9)
Mean total charges, \$ (95% CI) (inflation adjusted to 2013)		136,648 (110,130–163,166)	78,726 (76,456–80,997)
Type of Admission	Elective	232 (71.7%)	3,496,113 (87.4%)
	Non-elective	92 (28.3%)	505,303 (12.6%)
	Missing	40 (11.0%)	782,496 (16.4%)
Discharge Status	Routine	149 (41.1%)	3,613,039 (75.5%)
	Short-term hospital	10 (2.8%)	24,081 (0.5%)
	Home health care	61 (16.7%)	484,085 (10.1%)
	Other/Missing	143 (39.4%)	650,048 (13.6%)
	Died	10 (2.8%)	12,660 (0.3%)
Surgical Factors			
Spine disease			
Degenerative disc disease		80 (21.9%)	1,158,047 (24.2%)
Scoliosis and kyphosis		33 (9.2%)	211,821 (4.4%)
Malignant neoplasm of spine		0 (0%)	1,996 (<0.1%)
Secondary malignant neoplasm of spine		0 (0%)	5,551 (0.1%)

	All Cases: RAO	All Cases: Unaffected
Missing/other	250 (68.9%)	3,406,145 (71.2%)
<i>Procedure</i>		
Cervical fusion	95 (26.0%)	2,005,104 (41.9%)
Thoracic fusion	29 (8.1%)	203,643 (4.3%)
Lumbar fusion of posterior column	41 (11.2%)	574,009 (12.0%)
Lumbar fusion of anterior column	173 (47.5%)	1,784,229 (37.3%)
Repeat fusion	26 (7.2%)	216,928 (4.5%)
Fusion of 2 or 3 vertebrae	212 (58.4%)	2,835,579 (59.3%)
Fusion of 4–8 vertebrae	60 (16.5%)	541,962 (11.3%)
Fusion of 9 or more vertebrae	15 (4.0%)	39,883 (0.8%)
<i>Hospital factors</i>		
Anemia	11 (2.9%)	70,010 (1.5%)
Postoperative bleed	61 (16.6%)	399,191 (8.3%)
Transfusion	74 (20.5%)	401,044 (8.4%)
Comorbidities (potential risk factors)		
Atrial fibrillation	31 (8.5%)	113,957 (2.4%)
Carotid artery stenosis	15 (4.2%)	10,674 (0.2%)
Congestive heart failure	15 (4.2%)	71,377 (1.5%)
Coronary artery disease	62 (17.1%)	425,080 (8.9%)
DM type 1 without complications	0 (0%)	23,293 (0.5%)
DM type 2 without complications	42 (11.6%)	584,108 (12.2%)
DM with neurological manifestations	0 (0%)	38,134 (0.8%)
DM with ophthalmic manifestations	10 (2.8%)	9,062 (0.2%)
DM with renal manifestations	10 (2.8%)	9,406 (0.2%)
Giant cell arteritis	0 (0%)	944 (<0.1%)
Hypercoagulable state	0 (0%)	7,836 (0.2%)
Hyperlipidemia	196 (54.0%)	915,903 (19.1%)
Hypertension	243 (66.9%)	1,892,347 (39.6%)
Hypertension with cardiac complications	0 (0%)	14,255 (0.3%)
Obesity	30 (8.3%)	429,622 (9.0%)
Peripheral vascular disease	15 (4.1%)	48,470 (1.0%)
Smoking	78 (21.6%)	1,181,919 (24.7%)
Stroke – embolic	10 (2.8%)	997 (<0.1%)
Stroke – iatrogenic	0 (0%)	0 (0%)
Stroke – thrombotic	0 (0%)	98 (<0.1%)
Stroke – transient	0 (0%)	8,189 (0.2%)
Stroke – unspecified	19 (5.2%)	5,832 (0.1%)
Thrombocytopenia	14 (3.9%)	51,073 (1.1%)

Results are nationwide estimates using NIS weighting and Stata survey function. Numbers are presented as count estimates or means with percent in parentheses and respective 95% confidence intervals (CI) in brackets when indicated. Results with n = 0 could not be reported due to AHRQ

regulations. See Methods for ICD-9-CM diagnostic codes used to identify noted characteristics. Total charges were inflation adjusted to 2013 dollars using Bureau of Labor Statistics (<http://www.bls.gov/data/>). DM: diabetes mellitus

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Multivariable analysis for retinal artery occlusion (RAO) and spinal fusion in the National Inpatient Sample (NIS), 1998 to 2013

Table 2

Covariate	Odds ratio [95%CI]	P-Value	VIF
Patient Factors			
Age:			1.36
18–30	–	–	
31–40	–	–	
41–50	Referent		
51–60	1.28 [0.48–3.41]	0.62	
61–70	2.26 [0.89–5.74]	0.09	
71–80	4.07 [1.69–10.84]	0.002	
>80	4.50 [1.41–14.35]	0.011	
Gender (male=0, female=1)	0.72 [0.44–1.19]	0.20	1.04
Race			1.01
White	Referent		
Black	0.68 [0.18–2.49]	0.56	
Hispanic	1.29 [0.43–3.82]	0.65	
Asian or Pacific Islander	0.97 [0.12–7.38]	0.96	
Native American	–	–	
Other	1.43 [0.34–6.07]	0.63	
Elective admission	0.40 [0.23–0.68]	<0.001	1.06
Surgical factors			
<i>Spine disease</i>			
Degenerative disc disease	0.91 [0.50–1.67]	0.76	1.08
Scoliosis and kyphoscoliosis	1.06 [0.43–2.59]	0.90	1.13
Malignant neoplasm of spine	–	–	–
Secondary malignant neoplasm of spine	–	–	–
<i>Procedure</i>			
Cervical fusion	2.11 [0.78–5.71]	0.14	8.86
Thoracic fusion	2.15 [0.92–5.05]	0.077	2.37

Covariate	Odds ratio [95%CI]	P-Value	VIF
Lumbar fusion of posterior column	1.54 [0.60–3.93]	0.37	3.94
Lumbar fusion of anterior column	2.95 [1.29–6.75]	0.010	7.65
Repeat fusion	2.09 [0.71–6.21]	0.18	1.90
Fusion of 2 or 3 vertebrae	0.71 [0.39–1.29]	0.26	2.83
Fusion of 4–8 vertebrae	0.63 [0.29–1.33]	0.22	1.96
Fusion of 9 or more vertebrae	1.61 [0.43–6.01]	0.48	1.22
<i>Hospital factors</i>			
Anemia	0.93 [0.23–3.77]	0.92	1.02
Postoperative bleed	1.06 [0.47–2.39]	0.88	1.16
Transfusion	1.48 [0.76–2.87]	0.25	1.18
Comorbidities (potential risk factors)			
Atrial fibrillation	1.30 [0.57–2.97]	0.54	1.06
Carotid stenosis	4.94 [1.22–19.94]	0.025	1.01
Congestive heart failure	1.13 [0.37–3.44]	0.83	1.05
Coronary artery disease	0.70 [0.37–1.31]	0.27	
DM 1	–	–	–
DM 2	0.51 [0.25–1.05]	0.069	1.11
DM with neurological complications	–	–	–
DM with ophthalmic complications	7.00 [1.18–41.66]	0.032	1.04
DM with renal complications	1.41 [0.10–20.49]	0.80	1.04
Giant cell arteritis	–	–	–
Hypercoagulable state	–	–	–
Hyperlipidemia	2.96 [1.85–4.73]	<0.001	1.20
Hypertension	1.60 [0.90–2.85]	0.11	1.25
Hypertension with cardiac complications	–	–	–
Obesity	0.79 [0.34–1.84]	0.58	1.05
Peripheral vascular disease	1.56 [0.44–5.46]	0.49	1.02
Smoking	0.98 [0.54–1.77]	0.95	1.04

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Covariate	Odds ratio [95%CI]	P-Value	VIF
Stroke – unspecified	14.33 [4.54–45.28]	<0.001	1.03
Stroke – embolic	4.53 [0.54–37.92]	0.16	1.02
Stroke – iatrogenic	–	–	–
Stroke – thrombotic	–	–	–
Stroke – transient	–	–	–
Thrombocytopenia	1.43 [0.43–4.76]	0.56	1.03

“–” Indicates insufficient numbers for analysis. There were no cases of RAO for age groups 18–30 and 31–40; therefore, the reference category was set to 41–50. DM: diabetes mellitus; 95%CI: 95% confidence interval; VIF: variance inflation factor.