ORIGINAL ARTICLE

Risk Factors for Surgical Site Infections Following Adult Spine Operations

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OBJECTIVE. To identify risk factors for surgical site infections (SSIs) after spine operations.

DESIGN. Case-control study of SSIs among patients undergoing spine operations.

SETTING. An academic health center.

PATIENTS. We studied patients undergoing spinal fusions or laminectomies at the University of Iowa Hospitals and Clinics from January 1, 2007, through June 30, 2009. We included patients who acquired SSIs meeting the National Healthcare Safety Network definition. We randomly selected controls among patients who had spine operations during the study period and did not meet the SSI definition.

RESULTS. In total, 54 patients acquired SSIs after 2,309 spine operations (2.3 per 100 procedures). SSIs were identified a median of 20 days after spinal fusions and 17 days after laminectomies; 90.7% were identified after discharge and 72.2% were deep incisional or organ-space infections. *Staphylococcus aureus* caused 53.7% of SSIs. Of patients with SSIs, 64.9% (fusion) and 70.6% (laminectomy) were readmitted and 59.5% (fusion) and 64.7% (laminectomy) underwent reoperation. By multivariable analysis, increased body mass index, Surgical Department A, fusion of 4–8 vertebrae, and operation at a thoracic or lumbar/sacral level were significant risk factors for SSIs after spinal fusions. Lack of private insurance and hypertension were significant risk factors for SSIs after laminectomies. Surgeons from Department A were more likely to use nafcillin or vancomycin for perioperative prophylaxis and to do more multilevel fusions than surgeons from Department B.

CONCLUSIONS. SSIs after spine operations significantly increase utilization of healthcare resources. Possible remediable risk factors include obesity, hypertension, and perioperative antimicrobial prophylaxis.

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Surgical site infections (SSIs) following spine operations may be difficult to diagnose and are often difficult to treat because many SSIs affect implants that cannot be removed. These infections cause significant adverse outcomes, including hospital readmissions, reoperations, prolonged antimicrobial treatment, pain, and disability.[1] Moreover, they increase healthcare costs and decrease reimbursement.[2,3] Numerous studies have assessed risk factors for SSI after spinal procedures[4–14]; however, few factors have been associated consistently with increased SSI risk.

We sought to identify risk factors, particularly remediable factors, for SSI after fusions and laminectomies at our institution. We also assessed service-specific SSI risk factors because 2 surgical departments performed these procedures and SSI rates were higher for Department A than for Department B.

METHODS

Study Population

We studied patients undergoing spine operations done by surgeons in either Department A or Department B at the University of Iowa Hospitals and Clinics (UIHC) from January 1, 2007, through June 30, 2009. We used *International Classification of Disease, 9th Revision, Clinical Modification* (ICD-9-CM) procedure codes to identify spinal fusions and laminectomies (see Online Supplemental Table 1 for the list of ICD-9-CM codes).

A senior infection preventionist (J.P.) independently conducted surveillance for SSI during the study period using a computerized screening algorithm developed and validated at

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PREVIOUS PRESENTATION. We presented part of this study during the 21st Annual Scientific Meeting of the Society for Healthcare Epidemiology of America (SHEA) in Dallas, Texas, April 1–4, 2011.

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the UIHC. The infection preventionist applied the 2009 National Healthcare Safety Network (NHSN) definition of SSIs, which included superficial incisional, deep incisional, and organ-space infections and which required follow-up times of 1 year for spinal fusions and 30 days for laminectomies.[15] We randomly selected controls from among all patients who had spine operations during the study period and who did not meet the SSI definition (average, 4 controls per SSI case).

This study was approved by the University of Iowa Institutional Review Board.

Data Collection

We retrospectively collected data from patient medical records regarding demographic characteristics as well as patient-related and procedure-related factors for cases and controls. We obtained data on SSIs that occurred within 1 year after spinal fusions and within 30 days after laminectomies from the UIHC Program of Hospital Epidemiology. We also collected data on outcomes (ie, length of hospital stay [LOS], readmissions, and reoperations at the UIHC) that occurred within 30 days after the procedures for patients with SSIs.

Statistical Analysis

We analyzed deidentified data using SAS, v. 9.3 (SAS Institute, Cary, NC). We performed bivariable analyses to test the association between each potential risk factor and SSIs and the association between surgical department and possible risk factors for SSIs. We used the Student *t* test or Wilcoxon rank-sum test for continuous variables and the χ^2 test or Fisher's exact test for categorical variables. Because the risk of SSIs varied by operation type, we conducted separate analyses for patients undergoing spinal fusions and for those undergoing laminectomies. To identify factors associated with SSIs, we included clinically relevant factors having $P < .05$ in the bivariable analyses and having no missing values in a multivariable logistic regression model. We used backward elimination to identify factors remaining in the multivariable model ($P < .05$). For the final multivariable models, we included 1 variable per 10 SSIs. Given that there were 37 SSIs after fusions and 17 SSIs after laminectomies, the final multivariable models for spinal fusion and for laminectomy had 4 variables and 2 variables, respectively. We selected the multivariable models with the lowest Akaike information criterion (AIC). All tests were 2-tailed and $P < .05$ were considered significant.

RESULTS

Descriptive Epidemiology of Surgical Site Infections

During the study period, 2,068 patients underwent 2,309 spine operations and 54 patients (2.3 of 100 procedures) acquired SSIs (37 after spinal fusions and 17 after laminectomies). SSIs were identified a median of 20 days (range, 7–68 days) after spinal fusions and a median of 17 days (range, 5–28 days) after laminectomies. Most SSIs (90.7%) were identified after discharge. Overall, 15 SSIs were superficial (27.8%), 31 (57.4%) were deep incisional, and 8 (14.8%) were organ-space.

In total, 47 patients (87.0%) had positive wound cultures (see Online Supplemental Table 2 for the organisms). *Staphylococcus aureus* caused 29 SSIs (53.7%), and 13 of 29 *S. aureus* isolates (44.8%) were resistant to methicillin. Gram-negative organisms alone or in combination with other organisms caused 10 of 42 SSIs (23.8%) after procedures done by Department A and 1 of 12 SSIs (8.3%) after procedures done by Department B ($P = .46$). Gram-positive organisms alone or in combination with other organisms caused 34 of 42 SSIs (80.9%) after procedures done by Department A and 8 of 12 SSIs (66.7%) after procedures done by Department B ($P = .50$).

Of 37 patients who acquired SSIs after spinal fusions, 24 (64.9%) were readmitted and 22 (59.5%) underwent reoperations to treat their SSIs. The mean postoperative LOS was 7.9 ± 5.6 days during the patients' initial admissions and 7.2 ± 9.2 days during readmissions. Of 17 patients who acquired SSIs after laminectomies, 12 (70.6%) were readmitted and 11 (64.7%) underwent reoperations. The mean postoperative LOS was 3.9 ± 3.2 days during initial admissions and 6.8 ± 6.6 days during readmissions.

Associations Between Potential Risk Factors and SSIs

Bivariable analysis of data from all procedures found that patients with SSIs and controls did not differ significantly by age, gender, smoking history, previous operations, reason for the procedure, or preoperative treatment with oral hypoglycemic agents, insulin, steroids, or chemotherapy. Numerous patient- and procedure-related factors differed between patients with SSIs and controls (Table 1).

Because the indication for the procedure and surgical approaches were different between procedure types and because patients undergoing spinal fusions had a 1.5-fold higher risk of SSIs than those undergoing laminectomies ($P = .21$), we performed subgroup analyses by procedure type. In addition, ≥2 Elixhauser's comorbidities and prolonged preoperative length of stay were associated with SSIs after both spinal fusions and laminectomies (Table 2). The association between depression and SSIs was significant for laminectomies and was close to the significance level of 0.05 for spinal fusions. The associations between high American Society of Anesthesiologists (ASA) score and SSIs and between operations performed by surgeons in Department A and SSIs were significant for spinal fusions and were close to the significance level of 0.05 for laminectomies.

Spinal fusions. Bivariable analyses were conducted to identify risk factors that were associated with SSIs after spinal fusions only: higher body mass index (BMI), fluid and electrolyte disorders, fusion or refusion of 4–8 vertebrae, vancomycin as surgical prophylaxis, administration of additional antimicrobial agents during the procedure,

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TABLE 1. Bivariable Associations Between Potential Risk Factors and Surgical Site Infections After Spine Operations[a]

Variable	SSI (N = 54), No. (%)	Control (N = 218), No. (%)	Odds Ratio for SSI (95% CI)	*P* Value
Patient-related factors				
Age, yr ± SD	52.9 ± 14.9	51.8 ± 14.1	…	.62
Male	23 (42.6)	116 (53.2)	0.7 (0.4–1.2)	.16
BMI				
Mean, kg/m^2 ± SD	33.4 ± 9.4	30.9 ± 8.1	…	.04
BMI <18.5 (underweight)	0 (0)	3 (1.4)	…	1.00
BMI >35 (severely obese)	18 (33.3)	50 (22.9)	1.7 (0.9–3.2)	.11
Cigarette or cigar smoking				
Current	14 (25.9)	82 (37.6)	0.58 (0.29–1.1)	.11
Past	28 (51.9)	138 (63.3)	0.62 (0.34–1.1)	.12
Lack of private insurance	28 (51.9)	82 (37.6)	1.8 (1.0–3.3)	.06
Elixhauser's comorbidity				
≥2 comorbidities	42 (77.8)	114 (52.3)	3.2 (1.6–6.4)	.0007
Hypertension	33 (61.1)	98 (45.0)	1.9 (1.0–3.5)	.03
Diabetes without chronic complications	6 (11.1)	27 (12.4)	0.9 (0.3–2.3)	.80
Diabetes with chronic complications	2 (3.7)	2 (0.9)	4.2 (0.6–30.2)	.18
Chronic obstructive pulmonary disease	15 (27.8)	32 (14.7)	2.2 (1.1–4.5)	.02
Obesity	12 (22.2)	29 (13.3)	1.9 (0.9–3.9)	.10
Fluid and electrolyte disorders	15 (27.8)	28 (12.8)	2.6 (1.3–5.3)	.007
Depression	19 (35.2)	37 (17.0)	2.7 (1.4–5.1)	.005
Preoperative paralysis	6 (11.1)	9 (4.1)	2.9 (1.0–8.5)	.09
Preoperative urine incontinence	2 (3.7)	9 (4.1)	0.9 (0.2–4.3)	1.00
Preoperative stool incontinence	0 (0)	2 (0.9)	…	1.00
Preoperative LOS				
Mean, d ± SD	0.78 ± 2.10	0.21 ± 0.76	…	.001
≥1 d	12 (22.2)	18 (8.3)	3.2 (1.4–7.1)	.003
Wound classification[b]				
Clean-contaminated	6 (11.1)	24 (11.0)	1.0 (0.4–2.6)	.99
Contaminated	0 (0)	1 (0.5)	…	.99
ASA score ≥3	30 (55.6)	70 (32.1)	2.6 (1.4–4.9)	.001
Procedure-related factors				
Procedure type				
Laminectomy	17 (31.5)	89 (40.8)	Reference	…
Spinal fusion	37 (68.5)	129 (59.2)	1.5 (0.8–2.8)	.21
Surgical department				
Department A	42 (77.8)	121 (55.5)	2.8 (1.4–5.6)	.003
Department B	12 (22.2)	97 (44.5)	Reference	…
Procedure-related factors				
Procedure scheduling[b]				
Scheduled	49 (90.7)	205 (94.1)	Reference	…
Urgent	4 (7.4)	11 (5.1)	1.5 (0.5–5.0)	.49
Emergent	1 (1.9)	2 (0.9)	2.1 (0.2–23.5)	.55
Reason for procedure				
Fracture	8 (14.8)	15 (6.9)	2.4 (0.9–5.9)	.10
Instability	1 (1.9)	11 (5.1)	0.4 (0.04–2.8)	.47
Scoliosis	1 (1.9)	7 (3.2)	0.6 (0.07–4.7)	1.00
Stenosis	23 (42.6)	85 (39.0)	1.2 (0.6–2.1)	.63
Pain	21 (38.9)	98 (45.0)	0.8 (0.4–1.4)	.42
Tumor	0 (0)	0 (0)	…	…
Other reason	0 (0)	2 (0.9)	…	1.00
Microscopy	8 (14.8)	29 (13.3)	1.1 (0.5–2.6)	.77
Fluoroscopy	36 (66.7)	138 (63.3)	1.2 (0.6–2.2)	.64
Antimicrobial prophylaxis				
Cefazolin	23 (42.6)	117 (53.7)	0.6 (0.4–1.2)	.14
Cefazolin dose, mg ± SD	1,652.2 ± 487 (N = 23)	1,529.9 ± 501.3 (N = 117)	…	.28

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Table 1. *Continued*

Variable	SSI (N = 54), No. (%)	Control (N = 218), No. (%)	Odds Ratio for SSI (95% CI)	*P* Value
Minutes before operation when cefazolin was given, median (IQR)	63 (28–74) (N = 20)	53 (40–75) (N = 107)	…	1.00
Vancomycin	19 (35.2)	43 (19.7)	2.2 (1.2–4.2)	.02
Vancomycin <15 mg/kg	15 (79.0) (N = 19)	37 (86.1) (N = 43)	0.6 (0.1–2.5)	.48
Minutes before operation when vancomycin was given, median (IQR)	56 (48–92.5) (N = 16)	59 (37–72) (N = 39)	…	.46
Operation duration, min ± SD	275 ± 154	230 ± 136	…	.04
Posterior approach	49 (90.7)	160 (73.4)	3.6 (1.3–9.4)	.007
Operation at thoracic or lumbar/sacral level	46 (85.2)	142 (65.1)	3.1 (1.4–6.9)	.004
Instrumentation	9 (16.7)	46 (21.1)	0.7 (0.3–1.6)	.47
Dural tear	12 (22.2)	20 (9.2)	2.8 (1.3–6.2)	.008
Hemovac drain	30 (55.6)	88 (40.4)	1.8 (1.01–3.4)	.04
Inspired oxygen level, % ± SD	41.3 ± 7.8	39.3 ± 9.8	…	.16
CSF leakage	4 (7.4)	7 (3.2)	2.4 (0.7–8.6)	.24
Intraoperative blood loss, mL ± SD	472.9 ± 666.2	326.8 ± 506.9	…	.08
Intraoperative transfusion	10 (18.5)	18 (8.3)	2.5 (1.1–5.8)	.04
Postoperative transfusion	14 (25.9)	19 (8.7)	3.7 (1.7–7.9)	.0005
Preoperative hemoglobin, mg/dL ± SD	13.4 ± 2.0 (N = 54)	14.1 ± 1.6 (N = 211)	…	.007
Procedure-related factors				
Postoperative hemoglobin, mg/dL ± SD	10.9 ± 1.8 (N = 49)	11.4 ± 1.9 (N = 162)	…	.09

NOTE. ASA, American Society of Anesthesiologists; BMI, body mass index; CI, confidence interval; CSF, cerebrospinal fluid; IQR, interquartile range; LOS, length of stay; SSI, surgical site infection; SD, standard deviation.

[a]Data are reported as number (%) of patients or mean value ± standard deviation, unless otherwise indicated.

[b]Odds ratios and *P* values were calculated by bivariable logistic regression.

posterior approach, operations at the thoracic or lumbar/sacral level, perioperative transfusion, and lower perioperative hemoglobin level (Table 2). The associations between dural tears and SSIs and between cerebrospinal fluid (CSF) leakage and SSIs were close to the significance level of 0.05. We included BMI, fluid and electrolyte disorders, preoperative length of stay ≥1 day, ASA score ≥3, Department A, fusion or refusion of 4–8 vertebrae, vancomycin as surgical prophylaxis, posterior approach, operations at the thoracic or lumbar/sacral level, and perioperative transfusion in the model selection process.

Multivariable analysis found that increased BMI, procedure done by surgeons in Department A, fusion or refusion of 4–8 vertebrae, and an operation at the thoracic or lumbar/sacral level were significantly associated with SSIs after spinal fusions (Table 3).

Laminectomies. Bivariable analyses revealed that only lack of private insurance (ie, patients with Medicaid, Medicare, or without health insurance), hypertension, and an increased intraoperative inspired oxygen level were associated with SSI after laminectomies (Table 2). The association between chronic obstructive pulmonary disease (COPD) and SSI after laminectomies was close to the significance level of 0.05. Hypertensive patients were more likely to be obese (BMI ≥ 30) than non-hypertensive patients (55.3% vs 39.0%; OR, 1.9; 95% confidence interval [CI], 0.9–4.2; $P = .09$). Hypertension was not associated with either valvular disease (OR, 4.0; 95% CI, 0.4–39.3; $P = .32$) or peripheral vascular disease (OR, 2.7; 95% CI, 0.5–15.1; $P = .40$). We included lack of private insurance, hypertension, depression, Department A, and excision of intervertebral disc in the multivariable model selection process.

Multivariable analyses indicated that lack of private insurance and hypertension were significantly associated with SSIs after laminectomies (Table 3).

Risk of SSIs Associated with Department A

Our multivariable analyses revealed that the risk of SSI was higher after spinal fusions (3.3-fold) done by surgeons in Department A than those done by surgeons in Department B ($P = .013$; Table 3). Similarly, a bivariable analysis revealed a 2.7-fold increased risk of SSI for laminectomies done by surgeons in Department A ($P = .07$; Table 2). Surgical department was not associated with patient age, gender, BMI, comorbidities, ASA score, preoperative length of stay, posterior approach, spinal fusions, procedure duration, or postoperative CSF leakage (Table 4). However, compared with patients whose procedures were done by surgeons in Department B, patients whose procedures were done by surgeons in

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TABLE 2. Bivariable Associations Between Potential Risk Factors and Surgical Site Infections After Spinal Fusions and Laminectomies[a]

	Spinal Fusions				Laminectomies			
Variable	SSI (N = 37), No. (%)	Control (N = 129), No. (%)	OR for SSI (95% CI)	*P* Value	SSI (N = 17), No. (%)	Control (N = 89), No. (%)	OR for SSI (95% CI)	*P* Value
Patient-related factors								
BMI								
Mean, kg/m^2 ± SD	33.5 ± 9.2	30.5 ± 7.3	…	.04	33.3 ± 10.1	31.3 ± 9.0	…	.42
BMI <18.5 (underweight)	0 (0)	3 (2.3)	…	.93	0 (0)	0 (0)	…	…
BMI >35 (severely obese)	12 (32.4)	30 (23.3)	1.6 (0.7–3.5)	.26	6 (35.3)	20 (22.5)	1.9 (0.6–5.7)	.35
Lack of private insurance	16 (43.2)	48 (37.2)	1.3 (0.6–2.7)	.51	12 (70.6)	34 (38.2)	3.9 (1.3–12.0)	.02
Elixhauser's comorbidity								
≥2 comorbidities	29 (78.4)	75 (58.1)	2.6 (1.1–6.2)	.02	13 (76.5)	39 (43.8)	4.2 (1.3–13.8)	.01
Valvular disease					2 (11.8)	2 (2.3)	5.8 (0.8–44.4)	.12
Hypertension	21 (56.8)	63 (48.8)	1.4 (0.7–2.9)	.40	12 (70.6)	35 (39.3)	3.7 (1.2–11.4)	.02
Diabetes with chronic complications	2 (5.4)	0 (0)	…	.05	0 (0)	2 (2.3)	…	1.00
COPD	9 (24.3)	19 (14.7)	1.9 (0.8–4.6)	.17	6 (35.3)	13 (14.6)	3.2 (1.0–10.1)	.08
Obesity	8 (21.6)	20 (15.5)	1.5 (0.6–3.8)	.38	4 (23.5)	9 (10.1)	2.7 (0.7–10.2)	.22
Fluid and electrolyte disorders	14 (37.8)	24 (18.6)	2.7 (1.2–5.9)	.01	1 (5.9)	4 (4.5)	1.3 (0.1–12.7)	1.00
Depression	13 (35.1)	27 (20.9)	2.0 (0.9–4.5)	.07	6 (35.3)	10 (11.2)	4.3 (1.3–14.2)	.02
Preoperative paralysis	5 (13.5)	6 (4.7)	3.2 (0.9–11.2)	.07	1 (5.9)	3 (3.4)	1.8 (0.2–18.3)	.51
Preoperative LOS, d ± SD	0.84 ± 2.15	0.33 ± 0.95	…	.04	0.65 ± 2.03	0.03 ± 0.24	…	.006
≥1 d	10 (27.0)	16 (12.4)	2.6 (1.1–6.4)	.03	2 (11.8)	2 (2.3)	5.8 (0.8–44.4)	.12
ASA score ≥3	22 (59.5)	47 (36.4)	2.6 (1.2–5.4)	.01	8 (47.1)	23 (25.8)	2.6 (0.9–7.4)	.09
Procedure-related factors								
Surgical department A	28 (75.7)	68 (52.7)	2.8 (1.2–6.4)	.01	14 (82.4)	53 (59.6)	3.2 (0.8–11.8)	.07
Surgical department B	9 (24.3)	61 (47.3)	Reference	…	3 (17.7)	36 (40.5)	Reference	…
Procedure-related factors								
Type of spinal fusion								
Spinal fusion: other cervical fusion, anterior technique	5 (13.5)	49 (38.0)	0.3 (0.1–0.7)	.005	…	…	…	…
Spinal fusion: other cervical fusion, posterior technique	9 (24.30)	15 (11.6)	2.4 (1.0–6.2)	.05	…	…	…	…
Fusion or refusion of 2–3 vertebrae	15 (40.5)	86 (66.7)	0.3 (0.2–0.7)	.004	…	…	…	…
Fusion or refusion of 4–8 vertebrae	19 (51.4)	22 (17.1)	5.1 (2.3–11.3)	<.0001	…	…	…	…
Type of laminectomy								
Other exploration and decompression of spinal canal	…	…	…	…	11 (64.7)	36 (40.5)	2.7 (0.9–7.9)	0.07
Excision of intervertebral disc	…	…	…	…	7 (41.2)	61 (68.5)	0.3 (0.1–0.9)	0.03
Reason for procedure								
Fracture	8 (21.6)	15 (11.6)	2.1 (0.8–5.4)	.12	0 (0)	0 (0)	…	…
Instability	1 (2.7)	9 (7.0)	0.4 (0.05–3.0)	.46	0 (0)	2 (2.3)	…	1.00
Scoliosis	1 (2.7)	7 (5.4)	0.5 (0.06–4.1)	.69	0 (0)	0 (0)	…	…
Stenosis	15 (40.5)	53 (41.1)	1.0 (0.5–2.1)	.95	8 (47.1)	32 (36.0)	1.6 (0.6–4.5)	0.39
Pain	12 (32.4)	45 (34.9)	0.9 (0.4–2.0)	.78	9 (52.9)	53 (59.6)	0.8 (0.3–2.2)	0.61

Tumor	0 (0)	0 (0)	…	…	0 (0)	0 (0)	…	…
Other	0 (0)	0 (0)	…	…	0 (0)	2 (2.3)	…	1.00
Procedure-related factors								
Cefazolin as antibiotic prophylaxis	17 (46.0)	76 (58.9)	0.6 (0.3–1.2)	.16	6 (35.3)	41 (46.1)	0.6 (0.2–1.9)	.41
Nafcillin as antibiotic prophylaxis	5 (13.5)	27 (20.9)	0.6 (0.2–1.7)	.31	7 (41.2)	22 (24.7)	2.1 (0.7–6.3)	.23
Vancomycin as antibiotic prophylaxis	15 (40.5)	19 (14.7)	3.9 (1.7–8.9)	.0006	4 (23.5)	24 (27.0)	0.8 (0.2–2.8)	1.00
Additional intraoperative antibiotic dose[d]	9 (24.3)	7 (5.4)	5.6 (1.9–16.3)	.002	0 (0)	1 (1.1)	…	1.00
Operation duration, min ± SD	320 ± 159	281 ± 152	…	.17	176 ± 82	157 ± 53	…	.36
Posterior approach	32 (86.5)	72 (55.8)	5.1 (1.9–13.8)	.0007	17 (100)	88 (98.9)	…	1.00
Operation at thoracic or lumbar/sacral level (compared with cervical level)	32 (86.5)	68 (52.7)	5.7 (2.1–15.7)	.0002	14 (82.4)	74 (83.2)	0.9 (0.2–3.7)	1.00
Instrumentation	9 (24.3)	46 (35.7)	0.6 (0.3–1.3)	.20	0 (0)	0 (0)	…	…
Dural tears	9 (24.3)	15 (11.6)	2.4 (1.0–6.2)	.05	3 (17.7)	5 (5.6)	3.6 (0.8–16.8)	.12
Graft								
Autograft alone	16 (43.2)	48 (37.2)	Reference	…	0 (0)	0 (0)	…	…
Allograft alone	6 (16.2)	50 (38.8)	0.4 (0.1–1.0)	.05	0 (0)	1 (1.1)	…	…
Autograft and allograft	15 (40.5)	31 (24.0)	1.5 (0.6–3.4)	.38	0 (0)	0 (0)	…	…
Inspired oxygen level, % ± SD[d]	39.6 ± 7.4	39.2 ± 10.3	…	.82	45.2 ± 7.4	39.5 ± 9.1	…	.02
CSF leakage	4 (10.8)	4 (3.1)	3.8 (0.9–16.0)	.07	0 (0)	3 (3.4)	…	1.00
Intraoperative blood loss, mL ± SD	614 ± 761	467 ± 611	…	.22	166 ± 151	124 ± 144	…	.28
Intraoperative transfusion	10 (27.0)	17 (13.2)	2.4 (1.0–5.9)	.04	0 (0)	1 (1.1)	…	1.00
Postoperative transfusion	14 (37.8)	18 (14.0)	3.8 (1.6–8.6)	.001	0 (0)	1 (1.1)	…	1.00
Any transfusion	16 (43.2)	26 (20.2)	3.0 (1.4–6.6)	.004	0 (0)	2 (2.3)	…	1.00
Procedure-Related Factors								
Preoperative hemoglobin[c], mg/dL ± SD	12.9 ± 1.9 (N = 37)	14.1 ± 1.7 (N = 128)	…	.0005	14.5 ± 2.0 (N = 17)	14.2 ± 1.6 (N = 83)	…	.58
Postoperative hemoglobin, mg/dL ± SD	10.4 ± 1.5 (N = 36)	11.0 ± 2.0 (N = 113)	…	.08	12.1 ± 2.1 (N = 13)	12.1 ± 1.2 (N = 49)	…	.94
Microscopy use	6 (16.2)	16 (12.4)	1.4 (0.5–3.8)	.58	2 (11.8)	13 (14.6)	0.8 (0.2–3.8)	1.00
Fluoroscopy use	30 (81.1)	110 (85.3)	0.7 (0.3–1.9)	.54	6 (35.3)	28 (31.5)	1.2 (0.4–3.5)	.76
NHSN risk index 0[b]	6 (16.2)	42 (32.5)	Reference	…	5 (29.4)	47 (52.8)	Reference	…
1	18 (48.7)	58 (45.0)	2.2 (0.8–5.9)	.13	9 (52.9)	33 (37.1)	2.6 (0.8–8.3)	.12
2	13 (35.1)	29 (22.5)	3.1 (1.1–9.2)	.04	3 (17.7)	9 (10.1)	3.1 (0.6–15.5)	.16

NOTE. ASA, American Society of Anesthesiologists; BMI, body mass index; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CSF, cerebrospinal fluid; LOS, length of stay; NHSN, National Healthcare Safety Network; OR, odds ratio; SSI, surgical site infection; SD, standard deviation.

[a]Data are reported as number (%) of patients or mean value ± standard deviation, unless otherwise indicated.

[b]Odds ratios and *P* values were calculated by bivariable logistic regression.

[c]Variable that had $P < .05$ in the bivariable analysis but was excluded in the multivariable model selection because of missing values.

[d]Variables that had $P < .05$ in the bivariable analysis but were excluded in the multivariable model selection because they were unlikely to increase SSI risk.

TABLE 3. Multivariable Analysis for Factors Associated With Surgical Site Infections After Spinal Fusions and Laminectomies

Variable	Odds Ratio for SSI (95% CI)	*P* Value
Spinal Fusions		
Body mass index, 5 unit increase	1.31 (1.02–1.68)	.038
Surgical Department A	3.31 (1.29–8.51)	.013
Fusion or refusion of 4–8 vertebrae	3.91 (1.61–9.49)	.003
Operation at thoracic or lumbar/sacral level	8.40 (2.75–25.64)	.0002
Laminectomies		
Lack of private insurance	5.00 (1.52–16.49)	.008
Hypertension	4.80 (1.45–15.85)	.01

NOTE. CI, confidence interval; SSI, surgical site infection.

Department A were less likely to receive cefazolin for surgical prophylaxis and to have operations at the thoracic or lumbar/sacral level, and they were more likely to have instability as the reason for a procedure, to receive nafcillin or vancomycin for prophylaxis, and to have fusion or refusion of 4–8 vertebrae. After adjusting for the antibiotic given for perioperative prophylaxis, posterior approach, fusion or refusion of 4–8 vertebrae, and operation at a thoracic or lumbar/sacral level in a multivariable model, the association between Department A and SSIs persisted (OR, 4.1; 95% CI, 1.6–10.5; $P = .004$).

DISCUSSION

This study is unique because we evaluated risk factors for and outcomes of SSIs after spinal fusion and laminectomies. We utilized multivariable analysis to assess a range of possible risk factors for SSI after spinal surgeries. We identified several risk factors for SSIs that may be remediable: obesity, hypertension, and practice differences between 2 departments.

Body Mass Index

Our study confirmed the observations of other investigators that high BMI or obesity is associated with SSIs after spinal fusions.[5–8,11,16] Some investigators found that the higher the BMI, the longer the procedure duration and the more difficult the surgical dissection, especially for spine operations using a posterior approach.[7] However, other investigators have not found an association between higher BMI and SSI.[7,9,16,17] Mehta et al. recently found that the body mass distribution may be more predictive of SSI risk than the absolute BMI among obese patients undergoing lumbar spine fusions.[5]

Several studies have demonstrated that penetration of antibiotics into tissue is impaired in obese patients, possibly due to poor perfusion of adipose tissue.[18–20] In addition, inadequate antimicrobial doses could be associated with increased risk of SSIs among obese patients. The American Society of Health-System Pharmacists recommends that adults weighing <120 kg receive 2 g of cefazolin as perioperative prophylaxis and adults weighing ≥120 kg receive 3 g.[21] According to these recommendations, most of our patients were underdosed, but we did not find an association between inadequate doses of prophylactic antimicrobial agents and SSIs in our study population.

Hypertension

Hypertension was associated with increased risk of SSIs after laminectomies. Pull ter Gunne et al[8] found that hypertension was significantly associated with SSIs after adult spine operations by bivariable analysis, but it was not significant in the multivariable analysis. Future studies should investigate this possible association further.

Department A

The difference in SSI risk after operations done by Departments A and B was among our most significant findings. Patient characteristics did not differ by department, but surgeons in Department A were more likely to use intravenous nafcillin or vancomycin for prophylaxis and to do multilevel fusions than were surgeons in Department B. Nafcillin and vancomycin are narrow-spectrum antimicrobial agents that target only Gram-positive organisms, in contrast to cefazolin, which has both Gram-positive and Gram-negative activity. We speculate that frequent use of nafcillin and vancomycin in Department A could have increased the risk of Gram-negative SSIs. During the study period, surgeons from both departments did not put vancomycin solution or powder into the surgical wounds. The frequency at which the departments used vancomycin as prophylaxis and the frequency at which the departments performed multilevel fusions accounted for some but not all of the differences in SSI risk between the 2 departments. We suspect that unmeasured practice differences also contributed to the difference in SSI risk. For example, residents in Department A have more autonomy than those in Department B.

On the basis of our study results and national guidelines, surgeons in Department A began using cefazolin as the primary agent for prophylaxis in June 2011. The overall SSI rate for Department A subsequently decreased significantly from a mean of 3.2% (January 2007–May 2011) to 1.64% (June 2011–July 2015) (rate ratio [RR], 0.45; 95% CI, 0.30–0.68; $P = .0001$) and the Gram-negative SSI rate also decreased from a mean of 0.70% to 0.49% (RR, 0.57; 95% CI, 0.26–1.27; $P = .17$). In contrast, the overall SSI rate for Department B (2.34% vs 2.27%; $P = .56$) and the percent of SSIs caused by Gram-negative organisms (0.58% vs 0.85%; $P = .38$) did not decrease.

Nonmodifiable Risk Factors

Multilevel fusion and operations at the thoracic or lumbosacral region (noncervical region) were significant risk factors

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TABLE 4. Bivariable Associations Between Surgical Site Infection Risk Factors and Surgical Department[a]

Variable	Department A (N = 163)	Department B (N = 109)	Odds Ratio for Department A[b] (95% CI)	*P* Value
Age, year	51.7 ± 13.9	52.6 ± 14.7	…	.59
Male	85 (52.2)	54 (49.5)	1.1 (0.7–1.8)	.67
BMI, kg/m^2	31.1 ± 8.9	31.8 ± 7.6	…	.53
Elixhauser's comorbidity ≥2	92 (56.4)	64 (58.7)	0.9 (0.6–1.5)	.71
Hypertension	78 (47.9)	53 (48.6)	1.0 (0.6–1.6)	.90
Diabetes with chronic complications	3 (1.8)	1 (0.9)	2.0 (0.2–19.7)	.65
COPD	29 (17.8)	18 (16.5)	1.1 (0.6–2.1)	.78
Fluid and electrolyte disorders	26 (16.0)	17 (15.6)	1.0 (0.5–2.0)	.94
Depression	34 (20.9)	22 (20.2)	1.0 (0.6–1.9)	.89
ASA score ≥3	64 (39.3)	36 (33.0)	1.3 (0.8–2.2)	.30
Preoperative LOS ≥1 d	18 (11.0)	12 (11.0)	1.0 (0.5–2.2)	.99
Urgent or emergent procedure	11 (6.7)	7 (6.4)	1.1 (0.4–2.8)	.92
Reason for procedure				
Fracture	10 (6.1)	13 (11.9)	0.5 (0.2–1.1)	.09
Instability	11 (6.8)	1 (0.9)	7.8 (1.0–61.4)	.03
Scoliosis	0 (0)	8 (7.3)	…	<.0001
Stenosis	61 (37.4)	47 (43.1)	0.8 (0.5–1.3)	.35
Pain	79 (48.5)	40 (36.7)	1.6 (1.0–2.7)	.06
Other	2 (1.2)	0 (0)	…	.72
Antibiotic prophylaxis				
Cefazolin alone	42 (25.8)	95 (87.2)	…	<.0001
Cefazolin, gentamicin	1 (0.6)	0 (0)		
Cefazolin, vancomycin	1 (0.6)	1 (0.9)		
Clindamycin alone	0 (0)	11 (10.1)		
Nafcillin alone	61 (37.4)	0 (0)		
Vancomycin alone	26 (16.0)	2 (1.8)		
Vancomycin, ciprofloxacin	1 (0.6)	0 (0)		
Vancomycin, gentamicin	31 (19.0)	0 (0)		
Cefazolin alone or in combination with other antibiotic vs others	44 (27.0)	96 (88.1)	0.05 (0.03–0.1)	<.0001
Nafcillin alone vs others	61 (37.4)	0 (0)	…	<.0001
Vancomycin alone or in combination with other antibiotic vs others	59 (36.2)	3 (2.8)	20.0 (6.1–66.0)	<.0001
Posterior approach	119 (73.0)	90 (82.6)	0.6 (0.3–1.0)	.07
Spinal fusion	92 (56.4)	66 (60.6)	0.8 (0.5–1.4)	.50
Fusion or refusion of 4–8 vertebrae	33 (20.3)	8 (7.3)	3.2 (1.4–7.2)	.004
Operation at thoracic or lumbar/sacral level	101 (62.0)	87 (79.8)	0.4 (0.2–0.7)	.002
Operation duration, min ± SD	232.3 ± 139.0	249.6 ± 143.3	…	.32
CSF leakage	4 (2.5)	7 (6.4)	0.4 (0.1–1.3)	.12

NOTE. ASA, American Society of Anesthesiologists; BMI, body mass index; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CSF, cerebrospinal fluid; LOS, length of stay; SD, standard deviation.

[a]Data are reported as number (%) of patients or mean value ± standard deviation, unless otherwise indicated.

[b]The odds for Department A compared with Department B.

for SSI after spinal fusions. This finding is consistent with those of Olsen et al[6] who found that operations done by orthopaedic surgeons in the cervical region were associated with lower risk of SSI than those performed at other levels. They also found that operations involving 7 or more intervertebral levels were associated with a higher risk of SSI than were operations involving only 1 intervertebral level.[6] Lack of private insurance was significantly associated with increased risk of SSI after laminectomies. Two prior studies on abdominal hysterectomies reported similar results.[22,23] Lack of private insurance is a proxy for low socioeconomic status. Published studies have not determined why lower socioeconomic status may increase the risk of SSI.

We identified negative confounding among some variables in the multivariable models. That is, the adjusted estimates from the multivariable analysis were larger than the unadjusted estimates from bivariable analysis. The negative confounding was most obvious for the variable "operation at

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thoracic or lumbar/sacral level" in the spinal fusion model (unadjusted OR, 5.7 in Table 2; adjusted OR, 8.4 in Table 3). The negative confounding may have been caused by the negative association between Department A and operations at a thoracic or lumbar/sacral level. Although Department A and operation level were both positively associated with increased risk of SSIs, patients whose surgeons were in Department A were less likely to have operations at a thoracic or lumbar/sacral level (Table 4). If "operation level" is the exposure, "SSI" is the outcome, and "Department A" is a confounder, the associations between exposure and outcome, between confounder and outcome, and between exposure and confounder would be positive, positive, and negative, resulting in the negative confounding we observed in the spinal fusion model.[24]

Strengths and Limitations

Our study had several strengths. First, we separately evaluated risk factors for SSIs after spinal fusion and laminectomies because the risk of SSI in these groups is substantially different. Second, we used multivariable analysis to identify factors significantly associated with SSIs and to identify outcomes associated with SSIs while adjusting for potential confounders. Third, we evaluated the risk for SSI on 2 different surgical services at the same hospital, which enabled us to identify practice differences that increased the SSI risk. Our study was limited by the infrequency of SSIs after spine procedures, particularly after laminectomy. Thus, we may have missed some significant risk factors. In addition, we could assess only factors that were documented in patients' medical records and we could not assess the accuracy of some data elements, particularly ICD-9-CM diagnosis codes. Moreover, our findings may not be generalizable to programs with substantially different patient populations.

Our study identified increased BMI (fusion) and hypertension (laminectomy) as possibly modifiable risk factors for SSI after spine operations. The association of Department A with SSIs suggests that surgical prophylaxis with nafcillin or vancomycin, the number of vertebrae fused, and other unidentified practices may also increase SSI risk. Prospective studies are warranted to investigate these associations further. Our study also demonstrated that patients with these infections had long postoperative hospital length of stay, and most were readmitted and underwent additional operations to treat their infections, which may have substantial negative effects on patient well-being and on reimbursement.

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SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/ice.2016.193.

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