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Risk Factors for Surgical Site Infection Following Orthopaedic Spinal Operations

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Background: Surgical site infections are not uncommon following spinal operations, and they can be associated with serious morbidity, mortality, and increased resource utilization. The accurate identification of risk factors is essential to develop strategies to prevent these potentially devastating infections. We conducted a case-control study to determine independent risk factors for surgical site infection following orthopaedic spinal operations.

Methods: We performed a retrospective case-control study of patients who had had an orthopaedic spinal operation performed at a university-affiliated tertiary-care hospital from 1998 to 2002. Forty-six patients with a superficial, deep, or organ-space surgical site infection were identified and compared with 227 uninfected control patients. Risk factors for surgical site infection were determined with univariate analyses and multivariate logistic regression.

Results: The overall rate of spinal surgical site infection during the five years of the study was 2.0% (forty-six of 2316). Univariate analyses showed serum glucose levels, preoperatively and within five days after the operation, to be significantly higher in patients in whom surgical site infection developed than in uninfected control patients. Independent risk factors for surgical site infection that were identified by multivariate analysis were diabetes (odds ratio = 3.5, 95% confidence interval = 1.2, 10.0), suboptimal timing of prophylactic antibiotic therapy (odds ratio = 3.4, 95% confidence interval = 1.5, 7.9), a preoperative serum glucose level of >125 mg/dL (>6.9 mmol/L) or a postoperative serum glucose level of >200 mg/dL (>11.1 mmol/L) (odds ratio = 3.3, 95% confidence interval = 1.4, 7.5), obesity (odds ratio = 2.2, 95% confidence interval = 1.1, 4.7), and two or more surgical residents participating in the operative procedure (odds ratio = 2.2, 95% confidence interval = 1.0, 4.7). A decreased risk of surgical site infection was associated with operations involving the cervical spine (odds ratio = 0.3, 95% confidence interval = 0.1, 0.6).

Conclusions: Diabetes was associated with the highest independent risk of spinal surgical site infection, and an elevated preoperative or postoperative serum glucose level was also independently associated with an increased risk of surgical site infection. The role of hyperglycemia as a risk factor for surgical site infection in patients not previously diagnosed with diabetes should be investigated further. Administration of prophylactic antibiotics within one hour before the operation and increasing the antibiotic dosage to adjust for obesity are also important strategies to decrease the risk of surgical site infection after spinal operations.

Level of Evidence: Prognostic Level III. See Instructions to Authors for a complete description of levels of evidence.

Surgical site infection is the most common hospital-acquired infection that occurs in the early postoperative period in surgical patients[1]. United States hospitals participating in the National Nosocomial Infections Surveillance (NNIS) System, a voluntary performance-measurement system operated by the Centers for Disease Control and Prevention (CDC), monitor rates of surgical site infection following laminectomy and spinal arthrodesis. The most recent NNIS

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summary by the CDC reported a 1.25% rate of surgical site infection after laminectomy and a 2.1% rate following spinal arthrodesis[2]. Rates of surgical site infection reported from individual institutions have ranged from 0% to 15%, depending on the reason for the operation, the site, the approach, and the use of instrumentation[3-8].

A wide variety of risk factors for surgical site infection after spinal operations have been reported in the literature. However, many of the studies were limited by their relatively small sample size, which restricts the ability to perform multivariate analyses to identify independent risk factors for infection[9]. Another potential problem with the currently available literature is the use of nonstandard definitions and variable time-frames for surveillance of surgical site infection, which makes comparison of results between studies difficult. A third problem is that many studies included only a small fraction of all potential risk factors for surgical site infection in their analyses. In order to accurately identify independent risk factors for surgical site infection, studies with relatively large numbers of patients with surgical site infection need to be performed, with the investigators including a wide variety of potential risk factors, using standard accepted definitions of surgical site infection, and controlling for the occurrence of multiple risk factors within individual patients by performing multivariate statistical analyses.

We recently described independent risk factors for surgical site infection following spinal operations performed by neurosurgeons[10]. In that study, we found postoperative incontinence, a posterior surgical approach, an operation for tumor resection, and morbid obesity to be associated with an increased risk of surgical site infection in a multivariate analysis of a population of patients treated with spinal surgery in which the overall rate of surgical site infection was 2.76%. We undertook a subsequent retrospective case-control study to determine if we could identify unique risk factors for surgical site infection in patients undergoing orthopaedic spinal surgery. We suspected that the risk factors in our orthopaedic patient population might be different from those in the neurosurgical spine population. This report describes risk factors for surgical site infection following spinal operations performed by orthopaedic surgeons over a five-year time period at a tertiary-care university-affiliated hospital.

Materials and Methods

Study Design and Inclusion and Exclusion Criteria

We performed a retrospective nested case-control study at a tertiary-care university-affiliated hospital after obtaining approval from our institutional review board. Patients who had undergone a spinal operation were identified by querying the hospital Medical Informatics database for admissions coded with International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) procedure codes for laminectomy (03.02 and 03.09), discectomy (80.50 and 80.51), and/or spinal arthrodesis (81.00 to 81.09) from January 1998 through December 2002. Eligible operations were restricted to those performed by an orthopaedic surgeon at our institution in patients fifteen years of age or older (n = 2316). Other spinal procedures and operations performed by neurosurgeons were excluded. In addition, operations performed in patients with an admission ICD-9-CM diagnosis code for intraspinal abscess (324.1), osteomyelitis (730.08, 730.18, and 730.28), or surgical site infection (998.5, 998.51, and 998.59) were excluded. The basic demographic and surgical characteristics of the cohort are shown in Table I.

TABLE I Demographics and Surgical Characteristics of the 2316 Patients Treated with Orthopaedic Spinal Surgery from 1998 to 2002

Characteristic	
Mean age (range) *(yr)*	52.4 (15.2-94.4)
Female gender *(no.)*	1213 (52.4%)
Mean body mass index (range) *(kg/m²)*	28.4 (16.1-57.6)
Type of surgery *(no.)*	
Laminectomy only (including laminoplasty)	326 (14.1%)
Discectomy ± laminectomy	309 (13.3%)
Arthrodesis ± instrumentation	1657 (71.5%)
Instrumentation only	24 (1.0%)
Admissions with >1 spinal op. *(no.)*	87 (3.8%)

Identification of Surgical Site Infection

Patients likely to have a surgical site infection were identified with use of a combination of ICD-9-CM diagnosis codes suggestive of infection, a readmission diagnosis of infection, and/or positive microbiological cultures of specimens from the wound. The ICD-9-CM codes used as indicators of possible surgical site infection included codes for surgical site infection (998.5, 998.51, and 998.59), cellulitis (682.1, 682.2, and 682.6), osteomyelitis (730.08 and 730.28), dehiscence (998.3 and 998.32), or intraspinal abscess (324.1). The medical records of patients with indicators of potential surgical site infection during the hospitalization for the initial surgery or at the time of readmission to the hospital within one year after the operation were reviewed for recorded signs and symptoms of surgical site infection. In addition, all microbiology, radiology, pathology, and operative reports were reviewed to determine if the CDC/NNIS definitions of surgical site infection were met[11]. Included in the CDC/NNIS definition is any physician diagnosis of surgical site infection; therefore, if the spine surgeon or consulting infectious disease physician noted the presence of infection in the medical record, that was considered proof of surgical site infection. The CDC/NNIS definitions include deep surgical site and organ-space infections if they had an onset within thirty days after the operation (or within one year if the operation included placement of an implant) and superficial surgical site infection with an onset within thirty days after the operation[11]. Deep surgical site infection involved deep soft tissues (fascia and muscle), whereas organ-space infections included osteomyelitis, meningitis, and empyema (following

anterior thoracic procedures). All surgical site infections were confirmed by the nurse infection-control practitioner responsible for spine operations (J.M.).

Forty-six patients had a confirmed surgical site infection involving the spinal incision. In addition, four patients with an ICD-9-CM code indicating surgical site infection were excluded because the infection involved only the bone-graft donor site (the hip), and three were excluded because the infection was at a distant site (unrelated to the spine operation). In five patients with an ICD-9-CM code indicating surgical site infection at the time of readmission, the infection did not meet the CDC/NNIS definition of surgical site infection; those patients were excluded as well. The medical records of 227 control patients without a surgical site infection, selected with use of a random-number generator from the cohort of patients treated with an orthopaedic spinal operation at our institution from 1998 to 2002, were reviewed. This resulted in approximately five uninfected control patients for each patient with a surgical site infection. Fifteen control patients without a surgical site infection had had a two-stage spinal operation performed on separate days during the surgical admission. In order to perform subsequent analyses that included surgical variables at the patient level, one of the two staged operations was randomly selected for all subsequent analyses. One patient with a surgical site infection had been scheduled to undergo two staged operations, but an infection was diagnosed during the second operation. Since the surgical site infection was attributed to the first operation, that operation was used for the analysis.

Data Collection

All data, including the type, approach, and level of the operative procedure; potential risk factors for surgical site infection; and signs and symptoms of surgical site infection were collected from the medical records by two investigators (J.J.N. and M.A.O.), using a standardized data collection form. In addition, the orthopaedic spine surgeons' database was used to verify the type of operative procedure, approach, level, source of bone graft, and use of instrumentation. Potential risk factors for surgical site infection included a wide variety of demographic, comorbid, operative, and postoperative variables, derived primarily from our previous study of surgical site infection after spinal operations[10] and a thorough review of the literature. Data from the first fifty medical records and a random subset of the remaining records were collected in duplicate, to ensure comparability of collected data between the two investigators. Extensive logic checks were performed to identify illogical or impossible data, with resolution of results by repeat review of the medical and computer records.

Data Analysis

Associations between surgical site infection and potential risk factors were analyzed with use of the chi-square test and the calculation of an odds ratio and 95% confidence intervals. Significant differences between continuous variables were determined with the t test or the Mann-Whitney U test. A p value of <0.05 was considered significant. Multivariate logistic regression analysis was used to identify independent risk factors for surgical site infection. Variables eligible for inclusion in the multivariate models included those reported to be associated with an increased risk of surgical site infection in the literature, those with clinical and/or biologic plausibility, and those with p values of <0.20 in the univariate analyses. After identification of the main effects in the logistic regression models, all clinically meaningful two-way interaction factors were tested in the models. The final model(s) were checked for goodness of fit with the Hosmer and Lemeshow test and by colinearity and residuals diagnostics, to ensure they were well specified and fit the data[12].

Results

The incidence of surgical site infection following orthopaedic spinal operations performed from 1998 to 2002 was 2.0% (forty-six of 2316). Twenty (43%) of the forty-six infections were classified as deep incisional (involving fascia and/or muscle); eight (17%), as organ space (involving an anatomic space opened during the surgery other than the incision, and including osteomyelitis, empyema, and meningitis); and eighteen (39%), as superficial incisional (involving only skin or subcutaneous tissues). The median time from the operation to the diagnosis of the infection was eleven days, with a minimum of two days and a maximum of 236 days for a patient with osteomyelitis. All surgical site infections were treated with intravenous antibiotics in the hospital, and thirty-six (78%) of the forty-six patients had a repeat operation to treat the infection. Seven of the ten patients who did not have a repeat operation were diagnosed with a superficial surgical site infection and responded to intravenous antibiotic therapy.

The patient-level factors that were found to be associated with a significantly increased risk of surgical site infection in the univariate analysis are shown in Table II. They included diabetes, an elevated serum glucose level, a perioperative transfusion, postoperative incontinence (bowel or bladder, or both), and any incontinence (preoperative or postoperative). There was no difference in the risk of surgical site infection between patients with insulin-dependent diabetes mellitus and diabetic patients treated with oral therapy (a surgical site infection developed in two of four insulin-dependent diabetic patients compared with twelve of twenty-two diabetic patients treated with oral therapy only). Only three diabetic patients were managed solely with diet, and a surgical site infection did not develop in any of them. Obesity, defined as a body mass index of 30 to 35 kg/m^2, was associated with an increased risk of surgical site infection, although morbid obesity (a body mass index of >35 kg/m^2) had only a marginal association with surgical site infection ($p = 0.075$). Diagnoses of herniated disc and nerve root compression were associated with a significantly lower risk of surgical site infection, whereas a diagnosis of vertebral fracture was associated with a higher risk of surgical site infection. More severe illness, as indicated by an American Society of Anesthesiologists score of 3 or 4, was associated with an increased risk of surgical site infection. Malnutrition, defined as a serum albumin level of

TABLE II Univariate Comparisons of Individual Risk Factors in Patients with and without Surgical Site Infection Following Orthopaedic Spinal Operations

Patient-Level Characteristics	No. (%) of Patients with Surgical Site Infection (N = 46)	No. (%) of Uninfected Patients (N = 227)	Odds Ratio (95% Confidence Interval)	P Value
Body mass index				
Normal (≤25 kg/m^2)	9 (20)	84 (37)	1.0	
Overweight (>25 and <30 kg/m^2)	11 (24)	77 (34)	1.3 (0.5, 3.4)	0.546
Obese (≥30 and ≤35 kg/m^2)	18 (39)	37 (16)	4.5 (1.9, 11.0)	0.001
Morbidly obese (>35 kg/m^2)	8 (17)	29 (13)	2.6 (0.9, 7.3)	0.075
Diabetes and hyperglycemia				
Neither (no diabetes or hyperglycemia)	20 (43)	179 (79)	1.0	
Serum glucose >75th percentile	12 (26)	33 (15)	3.3 (1.5, 7.3)	0.004
Diabetes	14 (30)	15 (7)	8.4 (3.5, 19.8)	<0.001
Diagnoses				
Herniated disc	6 (13)	63 (28)	0.4 (0.2, 1.0)	0.036
Fracture	6 (13)	9 (4)	3.6 (1.2, 10.8)	0.025
American Society of Anesthesiologists class 3 or 4	22 (48)	59 (26)	2.6 (1.4, 5.0)	0.003
Nerve root compression	22 (48)	153 (67)	0.4 (0.2, 0.8)	0.012
Transfusion				
Cell Saver or autologous blood	10 (22)	35 (15)	2.2 (0.9, 5.0)	0.071
Packed red blood cells or platelets	15 (33)	33 (14.5)	3.4 (1.6, 7.4)	0.001
Postoperative incontinence	8 (17)	14 (6)	3.2 (1.3, 8.2)	0.018
Preoperative or postoperative incontinence	13 (28)	27 (12)	2.9 (1.4, 6.2)	0.004

<2.5 g/dL (<25 g/L) in blood collected during the most recent clinic visit within thirty days before the operation or the surgical admission, was not associated with surgical site infection ($p = 1.000$).

The univariate associations of selected surgical-level factors and the risk of spinal surgical site infection are shown in Table III. Operations on the cervical spine, intravenous use of steroids intraoperatively, and use of cefazolin alone for infection prophylaxis were all associated with a significantly lower risk of surgical site infection. Performance of the operation through a posterior approach was associated with a significantly increased risk of surgical site infection. There was no association between surgical site infection and the use of bone graft ($p = 0.479$), the use of instrumentation ($p = 0.901$), or a previous operation at the same site ($p = 0.775$). Suboptimal timing of prophylactic antibiotics therapy, defined as the administration of cefazolin more than sixty minutes before the incision or any antibiotic(s) first given after the incision, was associated with an increased risk of surgical site infection, as was a suboptimal dose of prophylactic cefazolin in obese patients (1 g of cefazolin in persons with a body mass index of >30 kg/m^2). Other operative variables associated with an increased risk of surgical site infection included aminoglycoside prophylaxis, irrigation of the surgical wound with an antibiotic solution (cefazolin or bacitracin), use of a drain for three or more days after the operation, and two or more surgical residents participating in the operation.

The median duration of the operation was significantly longer (181 compared with 150 minutes, $p = 0.009$) and the median estimated blood loss was significantly higher (275 mL compared with 150 mL, $p = 0.033$) in the patients with a surgical site infection than in the control patients. As shown in Table III, an extensive operation involving seven or more intervertebral levels was associated with a higher risk of surgical site infection than was an operation involving only one intervertebral level. This finding is consistent with the association between the duration of the operation and the risk of surgical site infection since the median number of intervertebral levels involved in operations with a duration of longer than the 75th percentile was four compared with two levels for operations lasting less than the 75th percentile. Participation in the operation by two or more surgical residents was also associated with a significantly longer duration of the operation and an operation involving a larger number of intervertebral levels ($p < 0.001$ for both). Of all of the patient-level and operative characteristics, only a body mass index of 30 to 35 kg/m^2, diabetes, and transfusion of packed red blood cells or platelets met the criterion for significance after correction for multiple testing ($\alpha = 0.001$).

The association between preoperative and postoperative serum glucose levels and surgical site infection was assessed. The results of serum glucose tests were not available for all patients at all time-points, so the number of subjects varied depending on the timing of the glucose testing. Patients with a surgical site infection had significantly higher serum glucose

TABLE III Univariate Comparisons of Surgical Risk Factors in Patients with and without Surgical Site Infection Following Orthopaedic Spinal Operations

Operative Characteristics	No. (%) of Patients with Surgical Site Infection (N = 46)	No. (%) of Uninfected Patients (N = 227)	Odds Ratio (95% Confidence Interval)	P Value
Cervical level	11 (24)	97 (43)	0.4 (0.2, 0.9)	0.017
Posterior approach	42 (91)	172 (76)	3.4 (1.2, 9.8)	0.020
Suboptimal timing of prophylactic antibiotic therapy*	15 (33)	31 (14)	3.1 (1.5, 6.3)	0.002
Suboptimal dosage of prophylactic antibiotic†	20 (43.5)	51 (22.5)	2.7 (1.4, 5.1)	0.003
Only cefazolin used as prophylactic antibiotic	24 (52)	168 (74)	0.4 (0.2, 0.7)	0.003
Aminoglycoside used as prophylactic antibiotic	17 (37)	41 (18)	2.7 (1.3, 5.3)	0.004
Intravenous steroids during operation	8 (17)	85 (37)	0.4 (0.2, 0.8)	0.009
Wound irrigated with antibiotic-containing solution	40 (87)	162 (71)	2.7 (1.1, 6.6)	0.028
No. of intervertebral levels				
1	10 (22)	83 (37)	1.0	
2-3	21 (46)	94 (41)	1.9 (0.8, 4.2)	0.135
4-6	7 (15)	30 (13)	1.9 (0.7, 5.5)	0.218
≥7	8 (17)	20 (9)	3.3 (1.2, 9.5)	0.025
Duration of operation >75th percentile‡	18 (39)	49 (22)	2.4 (1.2, 4.6)	0.012
Hemovac drain placed	26 (56.5)	95 (42)	1.8 (1.0, 3.4)	0.068
Drains in place ≥3 days	33 (72)	108 (48)	2.8 (1.4, 5.6)	0.003
≥2 resident surgeons	32 (70)	109 (48)	2.5 (1.3, 4.9)	0.008

*Cefazolin given more than sixty minutes before the incision or after the incision, or another antibiotic given after the incision. Two hundred and twenty-nine (84%) of the 273 patients received prophylactic cefazolin, alone (192), in combination with an aminoglycoside (thirty-four), or in combination with another antibiotic (three). †One gram of cefazolin used as a prophylactic antibiotic in patients with a body mass index of ≥30.0 kg/m^2. ‡The 75th percentile for fusion was 310.5 minutes; the 75th percentile for non-fusion operations was 145 minutes.

levels at the time of the most recent preoperative clinic testing (within thirty days before the surgical admission) and significantly higher postoperative serum glucose levels (with use of the highest value within five days after the operation for the analysis) (Table IV). The blood collected for glucose testing at the most recent preoperative clinic visit and the postoperative blood were obtained randomly, since patients had not been told to fast.

Since few patients (20%) had serum glucose tests within twenty-four hours before the operation, the results of the random preoperative laboratory testing were combined with the results of fasting serum glucose tests performed on the day before the operation to create a preoperative serum glucose variable (with the most recent result used if both had been obtained). The 75th percentile for this combined preoperative serum glucose level was 125 mg/dL (6.9 mmol/L), and the 75th

TABLE IV Association Between an Elevated Serum Glucose Level and the Risk of Surgical Site Infection Following Orthopaedic Spinal Operations

	Glucose Level *(mg/dL*)*				
	Patients with Surgical Site Infection		Uninfected Patients		
	Mean ± Standard Deviation	Median (Range)	Mean ± Standard Deviation	Median (Range)	P Value†
At most recent preoperative visit (n = 189)	131 ± 49.4	108 (73-267)	101 ± 38.8	92 (56-300)	<0.001
Within 24 hr before operation (n = 53)	154 ± 38.4	144 (117-239)	126 ± 47.9	116 (72-311)	0.122
Within 5 days after operation (n = 146)	206 ± 80.9	187 (109-576)	169 ± 56.7	156 (99-460)	0.003

*The conventional unit (mg/dL) is converted to the SI unit (mmol/L) by multiplying by 0.0555. †Derived with the Mann-Whitney U test.

TABLE V Risk of Spinal Surgical Site Infection According to Categorization of Serum Glucose Results

Glucose Level* *(mg/dL [mmol/L])*	No. of Patients with Surgical Site Infection/ No. Tested (%)	No. of Uninfected Patients/ No. Tested (%)	Odds Ratio (95% Confidence Interval)	P Value
Preoperative† >125 (>6.9)	20/39 (51)	30/182 (16)	5.3 (2.5, 11.2)	<0.001
Postoperative >200 (>11.1)	14/35 (40)	21/111 (19)	2.9 (1.2, 6.5)	0.011
Preoperative >125 or postoperative >200	25/45 (56)	45/215 (21)	4.7 (2.4, 9.3)	<0.001

*These values represent the 75th percentiles, which were used as the cutoffs in the analysis. †The result of testing twenty-four hours before the operation, if performed, or the result of the most recent preoperative laboratory test.

TABLE VI Multivariate Logistic Regression Model for the Development of Spinal Surgical Site Infection*

Risk Factor	Adjusted Odds Ratios (95% Confidence Interval)	P Value
Diabetes	3.5 (1.2, 10.0)	0.020
Suboptimal timing of prophylactic antibiotic therapy	3.4 (1.5, 7.9)	0.005
Elevated serum glucose level (>125 mg/dL [>6.9 mmol/L]) preoperatively or >200 mg/dL [>11.1 mmol/L]) postoperatively	3.3 (1.4, 7.5)	0.005
Obesity (body mass index >30.0 kg/m^2)	2.2 (1.1, 4.7)	0.034
≥2 resident surgeons	2.2 (1.0, 4.7)	0.048
Operation involving cervical levels	0.3 (0.1, 0.6)	0.002

*The c-statistic for the model = 0.807. The Hosmer and Lemeshow goodness-of-fit chi-square p = 0.734 (7 degrees of freedom), and the Nagelkerke R^2 = 0.305.

percentile for the random postoperative serum glucose level was 200 mg/dL (11.1 mmol/L). When the serum glucose levels were categorized according to these cutoffs, a preoperative level of >125 mg/dL was associated with a 5.3-fold increased risk of surgical site infection, and any postoperative glucose level (within five days after the operation) of >200 mg/dL was associated with a 2.9-fold increased risk of surgical site infection (Table V). Either a preoperative or any postoperative serum glucose level of >75th percentile was associated with a 4.7-fold increased risk of surgical site infection.

We also analyzed the association of the preoperative glucose level with surgical site infection after taking into account receipt of total parenteral nutrition before the surgery. Twenty-seven patients received total parenteral nutrition during their hospital stay, although only six of the twenty-seven patients received total parenteral nutrition before the eligible operation. Using a cutoff of 200 mg/dL for the preoperative serum glucose level in patients receiving total parenteral nutrition instead of 125 mg/dL decreased the effect size for the association of the preoperative glucose level and the risk of surgical site infection only slightly (odds ratio = 4.7, $p < 0.001$, compared with odds ratio = 5.3; Table V).

The results of the multivariate analysis to identify independent risk factors for spinal surgical site infection are shown in Table VI. Diabetes had the strongest association with surgical site infection, with an adjusted odds ratio of 3.5 after we controlled for the other variables in the model. Other variables that remained independently associated with an increased risk of surgical site infection included suboptimal timing of prophylactic antibiotic therapy (odds ratio = 3.4), an elevated serum glucose level (a preoperative random or fasting serum glucose level of >125 mg/dL or a postoperative random serum glucose level of >200 mg/dL) (odds ratio = 3.3), obesity (odds ratio = 2.2), and participation in the operation by two or more surgical residents (odds ratio = 2.2). An operation involving cervical levels was associated with a significantly lower risk of spinal surgical site infection (odds ratio = 0.3). The model had good predictive ability, with a c-statistic of 0.807.

Discussion

This study extends the work that we did previously to determine independent risk factors for surgical site infection after spinal operations[10]. We performed this second study to determine whether there were unique risk factors in our patients undergoing orthopaedic spinal surgery as compared with patients undergoing spinal neurosurgery based on underlying differences in the patient populations. An additional rationale for undertaking a second study was to collect more detailed data regarding some potential risk factors, such as hyperglycemia, drain utilization, and local and systemic steroid use, than had been collected in our initial study. In the present study, diabetes, suboptimal timing of prophylactic antibiotic

therapy, elevated serum glucose levels, obesity, and participation in the operation by two or more surgical residents were found to be independently associated with infection involving the spinal incision after laminectomy, discectomy, and/or spinal arthrodesis. Surgery at a cervical level was independently associated with a significantly decreased risk of surgical site infection following orthopaedic spinal operations.

Contrary to some reports in the literature, we found no association between arthrodesis and an increased risk of surgical site infection. Our hospital is a regional referral center for spine operations, and it is likely that more complex laminectomies and discectomies are performed at our institution than at community or smaller tertiary-care hospitals. This is consistent with our surgical site infection rates as compared with the CDC/NNIS rates; the surgical site infection rate after laminectomies and discectomies performed by orthopaedic surgeons at our institution from 1998 to 2002 was 2.3%, higher than the mean CDC/NNIS rate of 1.5%[2]. The surgical site infection rate at our institution after orthopaedic spinal arthrodeses was 1.9%, which is slightly lower than the mean CDC/NNIS rate of 2.1%[2].

Diabetes and Increased Risk of Surgical Site Infection

A diagnosis of diabetes was associated with the greatest independent risk of spinal surgical site infection, and elevated serum glucose levels remained significantly associated with surgical site infection after we controlled for diabetes and other variables. To our knowledge, this is the first study to demonstrate the independent risk of surgical site infection after spine operations associated with hyperglycemia. Numerous authors have found that the increased risk of deep sternal surgical site infection following cardiac operations can be ameliorated in diabetic patients by careful perioperative monitoring and control of serum glucose levels[13-15]. We are aware of no studies on the effects of such a strategy for patients undergoing spinal surgery, although the univariate association of diabetes with spinal surgical site infection has been reported in a number of studies[8,16-19]. We previously found an association between perioperative hyperglycemia and surgical site infection following spinal neurosurgery[10]. In our previous study, this association did not remain significant in the multivariate analysis, possibly because of a more strict definition of hyperglycemia (a glucose level of >200 mg/dL during the surgical admission) compared with that used in the current study. Confirmation of these findings might lead to studies of intensive perioperative glucose control in patients with diabetes undergoing orthopaedic operations. Additional study is needed to confirm the risk of surgical site infection due to hyperglycemia in patients not previously diagnosed with diabetes.

Other Independent Predictors of Surgical Site Infection

Suboptimal timing of prophylactic antibiotic therapy was associated with a 3.4-fold increased risk of surgical site infection in the multivariate model, a finding very similar to the results reported by Classen et al.[20]. Because of the relatively small size of this case-control study, we included receipt of a cephalosporin more than one hour before the incision or any prophylactic antibiotic given after the incision in the "suboptimal" category. The current recommendation for antibiotic prophylaxis for neurosurgical and orthopaedic procedures is for 1 to 2 g of cefazolin to be given in the hour before the incision in nonallergic patients[21]; thus, administration of an antibiotic outside of this period would be considered suboptimal. The finding of an increased risk of surgical site infection associated with prophylactic antibiotic administration outside of the one-hour window before the incision supports the recommendations of the Surgical Care Improvement Project (SCIP) to establish quality-improvement measures to ensure timely administration of prophylactic antibiotics[22].

Obesity was associated with an increased risk of spinal surgical site infection in this study, a finding similar to those after other operations[11,23]. The SCIP advisory panel recommends a 2-g dose of cefazolin for prophylaxis in patients who weigh ≥80 kg[24]. We could not accurately determine the effect of increased cefazolin dosage on the risk of surgical site infection in obese persons because of the small number of obese persons who were given a 2-g dose. However, given the minimal side effects of cefazolin in nonallergic patients, it appears reasonable to give 2 g to all patients weighing ≥80 kg to decrease the risk of surgical site infection associated with obesity.

Participation in the operative procedure by two or more surgical residents was also associated with an increased risk of surgical site infection. We assume that this variable was a proxy for the duration of the operation and the complexity of the operative procedure. We could not determine from the chart review if the residents were present at the same time or moved in and out of the operating room.

An operation at the cervical level was independently associated with a decreased risk of surgical site infection. Zeidman et al. previously reported a low rate of surgical site infection following cervical spinal operations[25]. In our previous study of spinal operations by neurosurgeons, we identified the posterior surgical approach as a risk factor for surgical site infection[10]. The posterior approach may not have remained independently associated with an increased risk of surgical site infection in the present study because of the inclusion of cervical operations in the model and the relatively small number of anterior operations.

Limitations and Strengths of This Study

The observational nature of this study precluded complete analysis of some potentially important risk factors for surgical site infection, such as malnutrition. The serum albumin level was measured at the discretion of the operating surgeon and was therefore not available for all patients. The analyses of serum glucose levels were also hampered by incomplete testing. It was thus not possible to determine if the risk of surgical site infection associated with persistently high serum glucose levels was higher than that associated with only a single high value. Sequential serum glucose testing needs to be performed before and after spinal operations in order to more accurately determine the association between hyperglycemia and surgical site infection.

The strengths of this study include the wide variety of potential risk factors that were analyzed and the relatively large number of patients with spinal surgical site infection compared with the numbers in most studies of this complication. We used multivariate logistic regression analysis to determine independent risk factors for surgical site infection, which is particularly important when determining the magnitude of risk associated with factors, such as diabetes and obesity, that tend to cluster within individual patients[26]. We extracted data for many patient and surgical risk factors, including the type and duration of use of surgical drains, irrigant solutions, prophylactic antibiotics, and serum glucose levels, in order to perform detailed analyses of these variables. To our knowledge, this is the most in-depth and comprehensive analysis of risk factors for surgical site infection following spinal operations that has been published.

Additional studies are warranted to determine whether careful monitoring and control of serum glucose levels in the perioperative period are associated with a decreased risk of infection following spinal operations. While the risk of surgical site infection can never be reduced to zero, establishing quality-improvement programs to monitor and ensure compliance with recommendations regarding antibiotic prophylaxis and maintenance of normoglycemia may prevent a subset of these infections and improve outcomes for patients undergoing spinal operations. ■

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