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Surgical Site Infection in Spine Surgery: Who Is at Risk?

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Abstract

Study Design: Retrospective literature review of spine surgical site infection (SSI).

Objective: To perform a review of SSI risk factors and more specifically, categorize them into patient and surgical factors.

Methods: A review of published literature on SSI risk factors in adult spine surgery was performed. We included studies that reported risk factors for SSI in adult spinal surgery. Excluded are pediatric patient populations, systematic reviews, and meta-analyses. Overall, we identified 72 cohort studies, 1 controlled-cohort study, 1 matched-cohort study, 1 matched-paired cohort study, 12 case-controlled studies (CCS), 6 case series, and 1 cross-sectional study.

Results: Patient-associated risk factors—diabetes mellitus, obesity (body mass index >35 kg/m^2), subcutaneous fat thickness, multiple medical comorbidities, current smoker, and malnutrition were associated with SSI. Surgical associated factors—preoperative radiation/postoperative blood transfusion, combined anterior/posterior approach, surgical invasiveness, or levels of instrumentation were associated with increased SSI. There is mixed evidence of age, duration of surgery, surgical team, intraoperative blood loss, dural tear, and urinary tract infection/urinary catheter in association with SSI.

Conclusion: SSIs are associated with many risk factors that can be patient or surgically related. Our review was able to identify important modifiable and nonmodifiable risk factors that can be essential in surgical planning and discussion with patients.

Keywords
infection, cervical, lumbar, thoracic

Introduction

Surgical site infection (SSI), with its associated morbidity, mortality, hospital length of stay (LOS), and cost, remains a common problem among spine surgery patients. The rate of SSI (superficial and deep) can range from 0.2% to 16.7%, depending on a number of patient-, pathology-, and procedure-related factors.[1,2] The treatment for SSI can be challenging requiring prolonged antibiotics, multiple revision surgeries, prolonged hospital stay, and in some patients, advanced soft tissue reconstructions. Numerous studies have attempted to identify the unique risk factors associated with SSI but are all too often limited to one specific diagnosis or procedure. Among previously identified factors associated with increased risk of SSI are excessive intraoperative blood loss, longer operative time, preoperative smoking, obesity, and higher degree of case complexity (as estimated by the Spine Surgery Invasiveness Index).[3] The purpose of this study is to perform a review of risk factors for spine SSI and to categorize them into patient- and surgical-related factors.

Methods

Study Design and Search Strategy

We conducted a review of all published literature discussing risk factors for SSI in adult spine surgery. The search was

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performed using PubMed from its inception to July 20, 2017. Search terms used were (risk factor) AND (surgical site infection) AND (spine).

Study Selection

We included studies that reported risk factors for SSI in adult spinal surgery. Exclusion criteria included those which reported on pediatric patient populations, systematic reviews, meta-analyses, those articles published in languages other than English or articles without an abstract.

Results

Search Results

The initial PubMed search returned 389 unique titles, of which 138 were included. Of those initially included, 1 was in a language other than English, 4 were meta-analyses, 18 were systematic reviews, 19 reported on pediatric populations, and 2 were excluded as full text could not be obtained. This left 94 unique studies for final and complete review.

Overview of Included Studies

A total of 72 cohort studies, 1 controlled-cohort study, 1 matched-cohort study, 1 matched-paired cohort study, 12 case-controlled studies (CCS), 6 case series, and 1 cross-sectional study were identified. A summary of these studies can be found in Table 1. Twenty-one studies evaluated only a single potential risk factor, while 73 studies evaluated multiple potential variables as risk factors. Variables identified as associated or not associated with SSI are summarized in Tables 2, 3, and 4, arranged by study.

Patient-Associated Risk Factors

There were a number of modifiable and nonmodifiable patient-associated risk factors for SSI that were identified, including age, diabetes, nutritional status, smoking, and obesity.

Age

The relationship between patient age and the risk of SSI is not consistently reported in the literature, with numerous studies that implicating advanced age as a risk factor for SSI, and numerous studies finding no such association. Chaichana et al[15] reviewed 817 consecutive lumbar degenerative cases and found age of >70 years to be an independent risk factor for increased SSI. Manoso et al[53] found that Medicaid patients were at an increased risk for SSI but age alone was not an independent factor. In most studies, it was not possible to parse out the effect of age from other age-related comorbidities. Given the heterogeneity of results, it is not possible to definitively determine the role that age plays in the risk of SSI. The intuitive association between age and SSI is most likely related to other age-related comorbidities or the accumulation of comorbidities that are globally manifest as patient frailty.

General Comorbidities

Koutsoumbelis et al[42] reviewed 3128 patients undergoing lumbar fusion at a single institution. The authors found several comorbidities that are associated with increased SSI, including diabetes mellitus (DM), chronic obstructive pulmonary disease (COPD), coronary artery disease (CAD), and osteoporosis. The hypothesis of osteoporosis and the association with SSI is thought to be related to loss of collagen in skin as well as bone, leading to aberrant wound healing.[42] Klemencsics et al[41] concluded that patients with DM, CAD, arrhythmia, chronic liver disease, and autoimmune disease were at a higher risk of SSI. Furthermore, patients with multiple comorbidities are at an increased risk for SSI. Kurtz et al[46] found that patients with Charleston comorbidity index (CCI) of 5 versus 0 had an adjusted hazard ratio of 2.48 in developing a postoperative SSI.

Diabetes Mellitus

It has been clearly established in the literature DM is an independent risk factor for SSI. There are several presumed pathophysiologies for this. Microvascular disease associated with DM can impair nutrition and oxygen delivery to the peripheral tissues and reduce the systemic ability to resist infection. Hyperglycemia can impair leukocyte functions such as adherence, chemotaxis, and phagocytosis. Furthermore, DM can lead to impaired collagen synthesis and fibroblast proliferation that delays wound healing. Browne et al[14] reviewed the Nationwide Inpatient Sample (NIS) database of 11 000 patients who underwent lumbar fusion. The reported that DM was associated with increased SSI, blood transfusion, increased LOS and nonroutine discharge. Chen et al[17] found that patients with DM had an adjusted relative risk of 4.1 of developing an SSI. Golinvaux et al[27] further delineated the risk factors by reporting that insulin dependent DM portends a higher SSI risk than non–insulin-dependent diabetes. In patients with the diagnosis of DM, preoperative glycemic control is essential in minimizing the risk of SSI. Since HbA1c reflects the average blood glucose over a period of 6 to 12 weeks, it is an important indicator of how well diabetes is being managed. Hikata et al[33] found that patients with DM had a higher rate of SSI than nondiabetics (16.7% vs 3.2%). Furthermore, while immediate perioperative glycemic control did not differ between those DM patients that did or did not develop an SSI, the immediate preoperative HbA1C was significantly higher in those who developed SSI (7.6%) than in those who did not (6.9%). In the same study, SSI developed in none of the patients with HbA1C <7.0% and in 35.5% of patients with HbA1C >7.0%. Thus, pre- and perioperative glycemic control are significant modifiable risk factors for SSI and should be part of a systematic infection prevention strategy.

Table 1. Characteristics of Studies Included in Review.

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall)			Group Demographics (Infected)		Group Demographics (Control)—If Applicable		Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
				Number of Patients	Mean Age (y)	Special Characteristics	Number of Patients	Mean Age (y)	Number of Patients	Mean Age (y)							
Abdul-Jabbar et al[4] 2012	Retro, Cohort	Uni-/multivariate logistic regression	III	6628	56.5	Administrative claims database	193		6435		Sacral involvement, number of levels fused (>7), bone or connective tissue cancer, approach (A/P combined)	CAD, DM, surgical region, smoking, obesity, IA, diagnosis, transfusion, procedure type	C/T/L	A/P/Comb	Some	Degenerative, deformity, tumor	Decompression, fusion, deformity
Aoude et al[5] 2016	Retro, Cohort	Multivariate logistic regression	III	13 695	NS	NSQIP database, focused on blood transfusion					Transfusion (lumbar fusion only, not thoracic)	—	T/L	A/P/comb	Y	NS (excluded trauma)	Fusion
Asomugha et al[6] 2016	Retro, Controlled-Cohort	Multivariate logistic regression	III	238							Epidural steroid paste, renal disease, immunosuppression	Procedure type, preoperative admission to hospital, surgical duration, EBL, durotomy, CHF, age, BMI, HTN, CAD, smoking, asthma, COPD	L	P	N	Degenerative	Decompression
Atkinson et al[7] 2016	Retro, Cohort	Uni-/bivariate logistic regression	III	152	60.6	Spinal metastases					Number of levels operated, surgical region (thoracic)	Age, gender, emergency surgery, Waterlow score, BMI, EtOH, smoking, ASA, preoperative albumin, preoperative protein, preoperative WBC, preoperative CRP, incision length, interval between admission and surgery, number of staff in operating room	C/T/L	A/P	NS	Metastases	NS
Babu et al[8] 2012	Retro, Cohort	Uni-/multivariate logistic regression	IV	20	47	Tracheostomy/ACDF for SCI					—	Early tracheostomy	C	A	Y	Trauma, degenerative	Decompression, fusion
Barnes et al[9] 2012	Retro, Cohort	Multivariate logistic regression	III	90	44.8		15		75		Philadelphia collar, trauma	—	C	P	Y	Trauma, degenerative	Decompression, fusion
Berney et al[10] 2008	Retro, Cohort	ANOVA	III	71	40.28 ± 19.22	Tracheostomy in SCI (quadriplegia)					—	Early tracheostomy	C	A/P/comb	Y	Trauma	Fusion
Blam et al[11] 2003	Retro, Cohort	Uni-/multivariate logistic regression	III	256	43	Trauma	24	55	232	37	Delay to surgery (>160 hours), postoperative ICU stay (>1 day), number of surgical teams (orthopedic only vs combined orthopedic/neurosurgery)	Gender, race, BMI, drug use, smoking, open injury/abrasion at surgical site, GCS, ASA, albumin, steroid use, EBL, surgical duration, bone graft use, instrumentation, approach	C/T/L	A/P/comb	Y	Trauma	Decompression, fusion
Bohl et al[12] 2016	Retro, CCS	Multivariate Poisson regression	III	10 825	NS	NSQIP database, focused on malnutrition					Albumin (<3.5 g/dL)	—	L	P	NS	Degenerative, deformity	Fusion
Boston et al[13] 2009	Retro, CCS	Multivariate logistic regression	III				55	44	179	45	Surgical duration, presence of comorbidities	Workers' compensation, method of hair removal, smoking, incontinence	NS	NS	NS	NS	Fusion, laminectomy, other
Browne et al[14] 2007	Retro, Cohort	Multivariate logistic regression	III	197 461	48.95 ± 18.16	Focused on DM					DM	—	L	?	?	Degenerative, deformity	Fusion
Chaichana et al[15] 2014	Retro, Cohort	Multivariate logistic regression	III	817	56 ± 14		37		780		Age (>70 y), DM, obesity, prior spine surgery, LOS (>7 days)	Smoker, number of levels operated, number of levels fused, number of levels decompressed, CSF leak, perioperative DVT/PE	L	P	Y	Degenerative	Decompression, fusion
Chen et al[16] 2009	Retro, Cohort	Multivariate logistic regression	II	244	NS						DM, EBL	Age, gender, BMI, surgical duration, ASA, antibiotic redosing, bone allograft use, drain placement, smoking	L	P	Y	Degenerative, deformity	Fusion
Chen et al[17] 2011	Retro, Cohort	Uni-/multivariate logistic regression	III	45	49.6	Sacral chordoma	16				Albumin, prior surgery, surgical duration (>6 hours)	Gender, obesity, smoking, alcohol, DM, tumor size, radiation, instrumentation	S	P	Some	Tumor (sacral chordoma)	Tumor resection

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall) Number of Patients	Mean Age (y)	Special Characteristics	Group Demographics (Infected) Number of Patients	Mean Age (y)	Group Demographics (Control)—If Applicable Number of Patients	Mean Age (y)	Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
Cizik et al[3] 2012	Retro, Cohort	Multivariate logistic regression	III	1532	49.5		63	53.5	1469	49.4	BMI (>35 kg/m^2), HTN, surgical region (thoracic, lumbosacral), SII (>21), renal disease	Revision, primary diagnosis, bleeding disorder, RA, liver disease, cancer, PVD, asthma, COPD, CVA, CHF, MI, smoking	C/T/L	A/P/comb	Some	Degenerative, tumor, trauma	Decompression, fusion, deformity correction
De La Garza Ramos et al[18] 2015	Retro, Cohort	Student's *t* test, chi-square, univariate analysis, log-binomial model	IV	732	NS	Focused on obesity					Obesity	—	L	P	Y	Degenerative	Fusion
De La Garza Ramos et al[19] 2016	Retro, Cohort	Multivariate logistic regression	III	36 440	NS		264	61.2 ± 11.6	36 176	60.5 ± 11.9	Chronic steroid use, surgical duration, renal disease (lumbar only), hemato-oncological disease (lumbar only), DM (lumbar only), obesity (lumbar only), LOS (lumbar only)	CAD, respiratory disease, hepatobiliary disease, neurologic disease, smoking	C/L	A/P/comb	Some	Degenerative	Decompression or fusion
De La Garza Ramos et al[20] 2017	Retro, CCS	Multivariate logistic regression	III	293	NS	Three-column osteotomy complex spine deformity	15	57 ± 14	278	61 ± 13	Obesity (class II), multilevel 3-column osteotomy	Bleeding disorder, type of deformity, ASA, anemia	T/L	NS	Y	Deformity	Deformity correction and fusion
Demura et al[21] 2009	Retro, Cohort	Uni-/multivariate logistic regression	III	113	56	Spinal metastases	8		113		DM, preoperative radiation	Age, gender, nutrition, ASA, chemotherapy, steroid use, neurologic deficit, emergency surgery, procedure type (en bloc vs debulking versus palliative)	C/T/L	NS	NS	Spinal metastases	Decompression, fusion, tumour resection (en bloc, debulking)
Dubory et al[22] 2015	Pro, Cohort	Uni-/multivariate logistic regression	II	518	47.8 ± 19.1	Acute spinal trauma injury	25		493		Age, DM, surgical duration	BMI, number of levels operated, EBL, approach, neurologic decomp, intraoperative transfusion, bladder catheter, NNIS	C/T/L	A/P	Y	Trauma only	Decompression/fusion
Ee et al[23] 2014	Retro, CCS	Multivariate logistic regression	III				27	61.6 ± 13.7	162	56.8 ± 14.9	Open surgery (compared with MIS), DM, number of levels operated, BMI	Age, surgical duration, preoperative glucose level, gender, race, number of surgical assistants, allograft use, instrumentation, L5-S1 involvement, EtOH, steroid use, smoking, ASA	L	P	Some	NS	Decompression or fusion
Fang et al[24] 2005	Retro, CCS	Uni-/multivariate logistic regression	III			Both adult and pediatric patients; only including adult results	21		29		Age (>60 y), prior infection, EtOH	Prior surgery, steroid use, smoking, BMI, gender, instrumentation, allograft use, EBL, staged procedures, surgical duration, number of levels operated	C/T/L/S	A/P/comb	Some	Deformity, degenerative, disc disease	Decompression, fusion, discectomy, deformity correction, ACDF, other
Fehlings et al[25] 2012	Pro, Cohort	Pearson chi-square, multivariate regression	II	302	57	Cervical spondylotic myelopathy					Approach (posterior)	Procedure type (laminoplasty vs posterior decompression and fusion)	C	A/P/comb	Some	Cervical spondylotic myelopathy	ACDF, corpectomy, decompression and fusion, laminoplasty
Fisahn et al[26] 2017	Retro, Cohort	Chi-square	III	56	NS	Major deformity surgery (>8 level fusion), focused on allogeneic transfusion					Allogenic transfusion	—	C/T/L	P	Y	Degenerative, deformity	Fusion
Glassman et al[27] 2016	Retro, Cohort	Binary logistic regression	III	2653	NS	Based on 3 databases (Denmark, Japan, United States)					Gender, LOS, BMI, number of levels fused	Diagnosis, age, smoking, ASA, surgical duration	L	A/P/lateral/?comb	NS	Degenerative	Fusion

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall)			Group Demographics (Infected)		Group Demographics (Control)—If Applicable		Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
				Number of Patients	Mean Age (y)	Special Characteristics	Number of Patients	Mean Age (y)	Number of Patients	Mean Age (y)							
Golinvaux et al[28] 2014	Retro, Cohort	Multivariate logistic regression	III	15 480	NS	NSQIP database, focused on DM (insulin vs non–insulin dependent)					Insulin-dependent DM (vs non–insulin dependent)		L	A/P/lateral/?comb	NS	NS	Fusion
Gruskay et al[29] 2012	Retro, Cohort	Step-down binary logistic regression	III	6666	NS						Case order (in lumbar decompression only), approach (posterior, in cervical or lumbar fusion only), revision (cervical only), surgical duration (lumbar decompression or fusion), ASA (lumbar fusion only), age (lumbar fusion only)	Surgical duration (cervical only), age (lumbar decompression or cervical only), ASA (lumbar decompression or cervical only), gender, revision (lumbar decompression or fusion only)	C/L	A/P	Some	Degenerative, deformity	Decompression, fusion
Haddad et al[30] 2016	Retro, Cohort	Multivariate logistic regression	III	1 872 327	NS	NIS database					Age, gender (male), race (African American), hospital size (medium or large), hospital type (rural), approach (posterior or combined), trauma, neurologic injury (SCI or myelopathy)	Payer (self-pay vs Medicare), hospital region, calendar year	C	A/P/comb	Yes	Degenerative, trauma, cervical myelopathy	Decompression, fusion, stabilization
Hayashi et al[31] 2015	Retro, Cohort	Multivariate logistic regression	III	125	53.8	Total en bloc spondylectomy for vertebral tumor (primary or metastases)	8		117		Instrumentation, approach (A/P combined)	Age, tumor histology, prior surgery, surgical duration	NS	A/P/comb	Y	En bloc spondylectomy	Fusion, en bloc tumor resection
Hijas-Gomez et al[32] 2017	Retro, Cohort	Uni-/multivariate logistic regression	III	892	55		35	61	857	54	DM, COPD, dirty surgery, surgical duration (>75th percentile)	Gender, obesity, renal disease, cancer, malnutrition, cirrhosis, immunodeficiency, neutropenia, transfusion, emergency surgery, razor shaving, inappropriate antibiotic prophylaxis, drains	C/T/L	A/P/comb	Some	Degenerative, disc disease, cervical myelopathy, deformity, other NS	Decompression, fusion
Hikata et al[33] 2014	Retro, Cohort	Chi-square, Mann-Whitney, Fisher's exact tests	III	347	NS						DM, preoperative HbA1c	Age, gender, BMI, obesity, preoperative LOS, insulin use, steroid use, prior surgery, preoperative muscle weakness, preoperative incontinence, number of levels fused, surgical duration, EBL, transfusion	T/L	P	Y	Degenerative, deformity	Fusion
Jalai et al[34] 2016	Retro, Cohort	Multivariate logistic regression	III	3057	60.71	NSQIP database	35	56.54	3022	60.75	Approach (posterior), surgical duration (>208 min), ASA (>3)	Smoking, steroid use, comorbid conditions, obesity, DM	C	A/P/comb	Y	Cervical spondylotic myelopathy	Decompression, fusion
Kanafani et al[35] 2009	Retro, Cohort	Chi square, T-test	III	997			27	59	54	47	DM, instrumentation, age	Gender, prior surgery, diagnosis, surgical duration, antibiotic duration	NS	NS	Y	Disc disease and tumor	Decompression, fusion
Keam et al[36] 2014	Retro, Cohort	Student's *t* test, Wilcoxon rank-sum test, chi-square, Fisher's exact test	III	165	NS	Spinal metastases with preoperative radiation					—	Type of preoperative radiation (conventional XRT versus hypofractionated)	C/T/L/S	A/P/comb	Some	Tumor/metastases	Decompression, fusion, stabilization, tumor resection
Kerwin et al[37] 2008	Retro, Matched cohort	Student's *t* test	III	16 812	NS	Spinal fracture					—	Time to surgery	C/T/L	C/T/L	NS	Trauma	Stabilization
Kim et al[38] 2014	Retro, Cohort	Multivariate logistic regression	III	4588	NS	NSQIP database, focused on surgical duration					Surgical duration	—	L	A/P/lateral/comb	Y	NS (excluded trauma)	Fusion (single-level)

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall) Number of Patients	Group Demographics (Overall) Mean Age (y)	Group Demographics (Overall) Special Characteristics	Group Demographics (Infected) Number of Patients	Group Demographics (Infected) Mean Age (y)	Group Demographics (Control)—If Applicable Number of Patients	Group Demographics (Control)—If Applicable Mean Age (y)	Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
Kim et al[39] 2017	Retro, Cohort	Multivariate logistic regression, single variate *t* test	III	1831	NS		30	63.7	1801	63.6	Surgical duration	Gender, local bone irrigation, intradiscal irrigation	L	P	Y	NS	Fusion (PLIF)
Klekamp et al[40] 1999	Retro, CCS	Chi-square, Fisher's exact test	III	2614	NS						Lymphopenia, chronic infection, EtOH, recent hospitalization, steroid use	DM, weight, gender, trauma, inpatient status, smoking, UTI, age, cholesterol, albumin, total protein, ESR, triglycerides	C/T/L	NS	Some	NS	NS
Klemencsics et al[41] 2016	Pro, Cohort	Multivariate logistic regression	II	1030	50		37		993		Age, BMI, DM, CAD, arrhythmia, chronic liver disease, autoimmune disease	SII, instrumentation	L	P	Y	Degenerative	Decompression, fusion
Koutsoumbelis et al[42] 2011	Retro, Cohort	Multivariate logistic regression	II	3218	56.9		86	60			Gender (female), DM, osteoporosis, CAD, number of comorbidities, obesity, number of personnel in operating room, dural tear, EBL (>500 cm^3)	Age, smoking, HTN, cholesterol, OSA, CHF, RA, number of comorbidities, number of surgeons, number of residents or fellows, surgical duration, number of drains, LOS, revision	L	P	Y	NS (excluded infection)	Fusion (PLIF)
Kudo et al[43] 2016	Retro, Cohort	Chi-square and Mann-Whitney *U*	III	105	64.4	Infection based on CRP	35	65.9 $\pm$ 16.9	70	63.6 $\pm$ 14.2	Surgical duration	Age, gender, BMI, smoking, EtOH, DM, EBL, instrumentation, preoperative total lymphocyte, preoperative transferrin, preoperative prealbumin, preoperative retinol binding protein	C/T/L	NS	NS	NS	NS
Kukreja et al[44] 2015	Retro, Cohort	Multivariate logistic regression	III	266 439	55.6						Emergency surgery, timing of surgery (after day of incident in emergency cases)	—	L	A/P/comb	Some	Degenerative, deformity, metastases, trauma	Fusion
Kumar et al[45] 2015	Retro, Cohort	Multivariate logistic regression	III	98	60.1	Spinal metastases	17		81		Number of levels operated ($\geq$7), albumin (low), neurologic disability (trend)	Absorbable skin closure material, age, lymphocyte count, perioperative steroids, MUST	NS	P/comb	NS	Spinal metastases	NS
Kurtz et al[46] 2012	Retro, Cohort	Kaplan-Meier survival analysis, Cox regression	III	15 069	NS	Medicare database					Age, obesity, Charleston comorbidity index, socioeconomic status, revision, number of levels fused, approach	Gender, race, smoking, DM, allograft use, transfusion	L	A/P/comb	Y	NS	Fusion
Lee et al[47] 2014	Retro, Cohort	Pearson chi-square, Fisher's exact test, multivariate logistic regression	III	1532	49.5	Spine End Result Registry (SEER)	66				SII, DM, CHF	Age, gender, RA, trauma, BMI	C/T/L	NS	NS	NS	NS
Lee et al[48] 2016	Retro, Cohort	Multivariate logistic regression	III	149	53.5 $\pm$ 15.8						Maximum fat thickness (T12-L5, operated levels or L4), prior surgery	Age, DM, smoking (within 1 y), preoperative albumin, BMI, obesity, number of levels operated, surgical duration	L	P	Some	NS	Decompression, fusion
Li et al[49] 2013	Retro, Cohort	Multivariate logistic regression	III	387	46.4	Sacral tumors					Prior radiation, rectum rupture, surgical duration, CSF leak	Age, gender, DM, preoperative albumin, prior sacral tumor resection, tumor size, histopathological diagnosis, blood control method, incision type (Y vs 2-way), proximal sacral segment resected, instrumentation, EBL	S	A/P/comb	Some	Primary tumor	Tumor resection

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall)			Group Demographics (Infected)		Group Demographics (Control)—If Applicable		Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
				Number of Patients	Mean Age (y)	Special Characteristics	Number of Patients	Mean Age (y)	Number of Patients	Mean Age (y)							
Lieber et al[50] 2016	Retro, Cohort	Multivariate logistic regression	III	60 179	57.1	NSQIP database	1110		59 069		Gender (female), inpatient, BMI, preoperative steroid use, anemia, ASA (>2), surgical duration	Instrumentation, bone graft use, transfusion, DM, functional status, COPD, disseminated cancer, weight loss, preoperative transfusion, dialysis, deformity, hematocrit	C/T/L	A/P/ lateral/ comb	Some	NS (excluded trauma)	NS
Lim et al[51] 2014	Retro, Cohort	Chi-square	III	3353		NSQIP database	86				Obesity, ASA (>2), surgical duration (>6 hours)	Smoking, DM	L	A/P/ lateral/ comb	Y	NS (excluded trauma)	Fusion (single-level)
Lonjon et al[52] 2012	Pro, Cohort	Univariate, Fisher's exact test/ Wilcoxon test	IV	169	50.0 ± 20.1	Spinal trauma					Age, ASA, DM, surgical duration (>3 hours), time from injury to surgery (>3 days), number of levels fused, EBL (>600 cm^3), urinary catheter (>5 days)	Gender, BMI, smoking, EtOH, antiplatelet agent/anticoagulant use, spinal region of trauma, neurologic impairment, surgical time of day (day vs night), approach, MIS, intraoperative transfusion, bedrest duration, drain	C/T/L	A/P/ comb	Y	Trauma	Decompression, stabilization
Manoso et al[53] 2014	Retro, Cohort	Multivariate logistic regression	III	1532							SII, CHF, payer (Medicaid), DM	Age, gender, smoking, EtOH, drug use, BMI, medical comorbidity, prior surgery, primary diagnosis, spinal region, approach	C/T/L	A/P/ comb	Some	Degenerative, trauma, tumor/metastases, infection, deformity, other	Decompression, fusion, stabilization, deformity correction, tumor resection
Maragakis et al[54] 2009	Retro, CCS	Multivariate logistic regression	III				104	55.3	104	55.3	Surgical duration, ASA (≥3), surgical region (lumbo-sacral), approach (posterior), instrumentation, obesity, razor shaving before surgery, intraoperative administration of inspired O_2 <50%	Age, gender, race, smoking, DM, CAD, Karnofsky score, prior surgery, emergent/ urgent surgery, appropriate timing of antibiotic prophylaxis, intraoperative nitrous oxide administration, perioperative glucose, intraoperative temperature, intraoperative infusion rate, dural tear, CSF leak, transfusion	NS (included L/S)	A/P/? comb	Some	NS	Decompression, fusion
Marquez-Lara et al[55] 2014	Retro, Cohort	Chi-square, Student's *t* test	IV	24 196	NS	Focused on BMI					BMI (>24.99 kg/m^2)	—	L	A/P/ comb	Some	NS	Decompression, fusion
Martin et al[56] 2016	Retro, Cohort	Multivariate logistic regression	III	35 777		Focused on smoking					Smoking	—	L	A/P	Some	NS	Decompression, fusion, deformity correction
Mehta et al[57] 2012	Retro, Cohort	Student's *t* test, Wilcoxon signed-rank test, chi-square, logistic regression	III	298			24	56	274	60	Number of levels operated, obesity, skin to lamina distance, thickness of subcutaneous fat	BMI, DM	L	P	Y	NS	Decompression, fusion
Murphy et al[58] 2017	Retro, Cohort	Multivariate logistic regression	III	8744	65	Focused on age					—	Age	L	P	N	Degenerative	Decompression
Northrup et al[59] 1995	Retro, Case series	None	IV	11	30	Tracheostomy in SCI (quadriplegia)					—	Tracheostomy pre-anterior cervical fusion	C	A	Some	Trauma	Decompression, fusion
Ogihara et al[60] 2015	Pro, Cohort	Fisher's exact test, Wilcoxon signed-rank test, multivariate logistic regression	III	2736			24				Steroid use, surgical duration (>3 hours), gender (female)	BMI, ASA, DM, smoking, prior surgery, instrumentation, emergency surgery, intraoperative fluoroscopy, dural tear, iliac crest bone graft, surgical region	T/L	P	Some	Trauma, disc disease, degenerative, tumor/ metastases, deformity	NS

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall) Number of Patients	Mean Age (y)	Special Characteristics	Group Demographics (Infected) Number of Patients	Mean Age (y)	Group Demographics (Control)—If Applicable Number of Patients	Mean Age (y)	Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
Ohya et al[61] 2017	Retro, Cohort	Multivariate logistic regression	III	47 252	65.4	Japanese Diagnosis Procedure Combination Database, focused on effect of month of surgery	438		46 814		Month of surgery (timing when medical staff rotate, only in academic hospitals)		C/T/L	A/P/ comb	Y	NS	Decompression, fusion
Oichi et al[62] 2017	Retro, Matched-pair cohort	Multivariate logistic regression	III	6921		Focused on Parkinson's disease					Parkinson's disease	—	C/T/L	A/P/ comb	Some	NS	NS (included fusion)
Ojo et al[63] 2016	Retro, Cross-section	Fisher's exact test	IV	62	44.2		10				DM, surgical region (cervical), procedure type (laminectomy and fixation), surgical duration	Obesity, TB, anemia, diagnosis, instrumentation	C/L	P	Some	Trauma, degenerative, tumor	Decompression, instrumentation, tumor resection
Olsen et al[64] 2003	Retro, CCS	Uni-/ multivariate logistic regression	III	219			41	54.3	178	52.9	Postoperative fecal incontinence, approach (posterior), tumor resection, obesity (morbid)	Fusion, timing of prophylactic antibiotics, trauma surgery, intraoperative hypothermia, dural tear, instrumentation	C/T/L	A/P/ comb	Y	Degenerative, tumor, trauma	Decompression, fusion, tumor resection
Olsen et al[65] 2008	Retro, CCS	Multivariate logistic regression	III	273	52.4		46		227		DM, timing of prophylactic antibiotics (>1 hour before surgery), preoperative glucose (>125), postoperative glucose (>200), obesity, number of residents (≥2)	Fusion, instrumentation, bone graft use, irrigation with antibiotic solution, number of levels operated, surgical duration, hemovac, intraoperative steroid, number of levels, BMI, diagnosis, transfusion, approach	NS (included C)	A/P/ comb	Y	NS	Decompression, fusion
Omeis et al[66] 2011	Retro, Cohort	*t* test, chi-square	III	678		Nonsacral tumor (primary or metastases)	65	52.1	613	47.4	Prior surgery, preoperative radiation, any comorbidity, number of surgical teams involved (>1), complex plastics closure, LOS, hospital acquired infection	Gender, race, age, albumin, steroid use, intra versus extradural, metastatic versus primary, allograft use, instrumentation	C/T/L/S (LS junction, not primary S)	A/P/ comb	Some	Tumor/metastases	Tumor resection
Pull ter Gunne et al[1] 2009	Retro, Cohort	Cochran/ Mantel-Haenszels chi-square, multivariate	III	3174	55.6 ± 15.5						Obesity, approach (not anterior), DM, prior SSI, EBL (>1 L), surgical duration (>2 hours)	Gender, HTN, prior surgery, diagnosis, number of levels fused, procedure type	C/T/L/S	A/P/ comb	Some	Hardware irritation, trauma, disc herniation, degenerative, deformity, stenosis, tumor/metastases, arthritis, pseudoarthrosis	Discectomy, decompression, fusion, deformity correction, ROH, debridement, soft tissue
Pull ter Gunne et al[67] 2010 (deformity)	Retro, Cohort	Chi-square, multivariate	III	830	55.4 ± 16.1	Adult spinal deformity					Obesity, history of SSI	Gender, DM, NSAID use, HTN, other cardiovascular pathology, smoking, preoperative protein, preoperative albumin, prior surgery, number of levels fused, approach, procedure type, surgical region, surgical duration, EBL, number of attending surgeons	C/T/L/S	A/P/ comb	Y	Deformity	Deformity correction and fusion
Pull ter Gunne et al[68] 2010 (osteotomy)	Retro, Cohort	Multivariate logistic regression	III	363	55.8	Types of osteotomies	20		343		VCR, obesity	—	C/T/L	A/P/ comb	Y	NS (excluded infection)	Fusion/osteotomy
Radcliff et al[69] 2013	Retro, Cohort	Student's *t* test	III	7991	53.7	Focused on anesthesia ready time	276	58.4			Anesthesia ready time (>1 hour)	—	C/T/L	A/P/ comb	Some	NS (excluded infection)	Decompression, fusion, tumor resection

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall) Number of Patients	Group Demographics (Overall) Mean Age (y)	Group Demographics (Overall) Special Characteristics	Group Demographics (Infected) Number of Patients	Group Demographics (Infected) Mean Age (y)	Group Demographics (Control)—If Applicable Number of Patients	Group Demographics (Control)—If Applicable Mean Age (y)	Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
Ramos et al[70] 2016	Retro, Cohort	Unadjusted and adjusted logistic regression analysis	IV	668	63.9	Also included arthroplasty patients; review only looking at spine cohort; Focused on *S aureus* colonization	10				—	*S aureus* colonization	C/T/L	NS	NS	NS	NS
Rao et al[71] 2011	Retro, CCS	Uni-/multivariate logistic regression	III				57	55 ± 15	181	57±15	BMI, gender (male), drain duration	Age, DM, CAD, HTN, COPD, active malignancy, smoking, revision, diagnosis, emergency surgery, timing of antibiotic prophylaxis, number of surgical teams (orthopedic-neurosurgery combined vs either alone), approach, graft type, EBL, intraoperative transfusion, intraoperative temperature, surgical duration	NS	P	NS	Degenerative, deformity, trauma, tumor	Fusion
Rechtine et al[72] 2001	Retro, Case series	Not listed	IV	117	NS	Thoracolumbar fracture	12				Complete neurologic injury	Incomplete neurologic injury	T/L	A/P	Y	Trauma	Decompression, stabilization
Rodgers et al[73] 2010	Retro, Cohort	Multivariate logistic regression, Student's *t* test, chi-square	III	600	61.4	Focused on XLIF procedure					Open surgery (vs XLIF)	—	L	XLIF	Y	Degenerative	Fusion
Ruggieri et al[74] 2012	Retro, Case series	Kaplan-Meier survival analysis, log-rank test	IV	82	47	Primary sacral tumors					Procedure type (intralesional vs marginal vs wide resection), surgical duration	Age, level of resection (proximal vs distal), location of prior treatment (same institution vs other institution), tumor volume, neurological status (bowel-bladder continence)	S	A/P/ comb	Some	Primary tumor	Tumor debulking or resection
Saeedinia et al[75] 2015	Retro, Cohort	Chi-square, ANOVA, multivariate regression	III	978	46		27		951		Muscle weakness, sphincter dysfunction, DM, HTN, smoking, bedridden, preoperative glucose, surgical region, instrumentation, allograft use, dural tear, incision length, number of levels operated, surgical time of day, surgical duration, LOS	Age, gender, BMI, myelopathy, IVDU, approach, revision	C/T/L	A/P	Some	Trauma, tumor, degenerative, disc disease, intradural (tumor, tethered cord)	NS
Salvetti et al[76] 2017	Retro, Case-control cohort	Chi-square, multivariate logistic regression	III				32		74		Prealbumin (low), DM	Age, gender, BMI, surgical duration, comorbidities	C/T/L	P	NS	NS (excluded trauma, infection, tumor)	NS (included fusion)
Satake et al[77] 2013	Retro, Cohort	Chi-square, Mann-Whitney *U*	III	110			11				DM, proteinurea	Age, BMI, ASA, smoking, creatinine, BUN, EBL, surgical duration	NS	NS	Y	NS	Instrumentation, not otherwise specified
Schimmel et al[2] 2010	Retro, Cohort	Uni-/multivariate logistic regression	III	1568			36		135		Prior surgery, number of levels operated, DM, smoking	Gender, age, height, weight, BMI, presence of any comorbidity, CAD, respiratory disease, RA, spinal region, surgical duration, bone graft type, approach, instrumentation	C/T/L	A/P/AP	Y	Degenerative, deformity	Fusion, deformity correction
Schoenfeld et al[78] 2013	Retro, Cohort	Uni-/multivariate logistic regression	III	5887	55.9	NSQIP database					BMI, resident involvement, ASA (>2), surgical duration	Age, DM, respiratory disease, CAD, HTN, PVD, renal disease, neurologic disease, infection, steroid use, preoperative albumin, spinal region, procedure type, diagnosis	C/T/L	A/P	Y	NS	Fusion

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall)			Group Demographics (Infected)		Group Demographics (Control)—If Applicable		Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
				Number of Patients	Mean Age (y)	Special Characteristics	Number of Patients	Mean Age (y)	Number of Patients	Mean Age (y)							
Schwarzkopf et al[79] 2010	Retro, CCS	Multiple logistic regression	III			Focus on blood transfusion	61	56	71	53	BMI, transfusion	Gender, smoking, EtOH, DM, HTN, steroid use	T/L	?	Some	NS	Discectomy, decompression, fusion
Sciubba et al[80] 2008	Retro, Cohort	Univariate, Fisher's exact test	IV	46	46	Sacral tumors					Prior lumbosacral surgery, number of surgeons	Preoperative albumin, EBL, CSF leak, DM, instrumentation, laminectomies, obesity, plastic surgery closure, prior radiation, gender, smoking, age, bowel-bladder dysfunction, complex tissue reconstruction	S	A/P/ comb	Some	Primary tumor	Tumor resection
Sebastian et al[81] 2016	Retro, Cohort	Student's *t* test, chi-square/ Fisher's exact test, multivariate	III	5441	59 ± 13.6	NSQIP database	160	56.9 ± 12.2			BMI (>35 kg/m^2), chronic opioid use, surgical duration (>197 min)	Type of posterior surgery, DM, smoking, resident involvement, paralysis	C	P	Some	NS	Decompression, fusion, laminoplasty
Shousha et al[82] 2014	Retro, Cohort	NS	IV	139	53.6	Transoral approach for upper cervical spine					Indication (rheumatologic or tumor cases higher risk)	Age, gender, presence of metal implant	C	Transoral	Some	Infection, trauma, congenital anomaly, rheumatologic, tumor	Odontoidectomy, fusion, stabilization, tumor resection
Singla et al[83] 2017	Retro, Cohort	Chi-square	III	88 540		Lumbar epidural steroid injection prior to surgery	1411		87 129		Lumbar epidural steroid injection (within 3 mo) prior to surgery	—	L	P	Y	Degenerative	Fusion
Skovrlj et al[84] 2015	Retro, Cohort	Chi-square	III	5117	51.8	Adult scoliosis, focused on surgeon experience					Less surgeon experience	—	T/L	NS	Y	Deformity	Deformity correction and fusion
Stambough et al[85] 1992	Retro, Case series	NS	IV				19	44			Malnutrition, trauma, UTI (all based on % of patients with these risk factors, no formal analysis)	No formal analysis	C/T/L	NS	Some	Trauma, degenerative, deformity, tumor, disc disease	Decompression, fusion, deformity correction
Sugita et al[86] 2016	Retro, Cohort	Mann-Whitney *U*, chi-square	III	279	63	Spinal metastases with intraoperative radiation	41	62	238	64	Katagiri/Tokuhashi's prognostic score, postoperative Frankel score, preoperative radiation, and postoperative performance	Surgical duration, EBL	NS	P	Y	Spinal metastases	Decompression/ fusion, radiation
Tempel et al[87] 2015	Retro, Case series	None	IV				83	56			Serum prealbumin below normal range (no formal analysis)	No formal analysis	C/T/L/S	NS	Some	Degenerative, trauma, tumor, deformity, hematoma, syringomyelia	Fusion, decompression, shunt
Tominaga et al[88] 2016	Retro, Cohort	Mann-Whitney *U* and Fisher's, multiple logistic regression	III	825	59		14	57.5	811	59	Surgical duration, ASA (class 3), instrumentation, surgical region (thoracic in non-instrumented cases)	Two stage, revision, DM, smoking, BMI, anemia, preoperative UTI, number of levels, incision length, number of personnel or surgeons		A/P/ comb	Y	Degenerative, infection, tumor, scoliosis	Decompression, fusion, deformity
Veeravagu et al[89] 2009	Retro, Cohort	Uni-/ multivariate logistic regression	III	24 774	NS	Veterans Affairs' NSQIP database	752				DM, ASA (>2), weight loss, dependent functional status, intraoperative transfusion, cancer, fusion/instrumentation, surgical duration (>3 hours)	Age, gender, race, emergency surgery, bleeding disorder, smoking, EtOH, WBC, creatinine	C/T/L	NS	Some	NS (excluded trauma)	Decompression, fusion, instrumentation
Watanabe et al[90] 2010	Retro, Cohort	Uni-/ multivariate logistic regression	III	223	53	Focused on effect of intraoperative irrigation	14	49	209	53	DM, trauma	Surgical duration, EBL, instrumentation, gender, age, smoking, obesity	C/T/L	A/P/ comb	Y	Trauma, tumor, degenerative, deformity	Decompression, fusion, deformity

(continued)

Table 1. (continued)

Author	Study Design	Analysis	Level of Evidence	Group Demographics (Overall)			Group Demographics (Infected)		Group Demographics (Control)—If Applicable		Significant Variables	Non-significant Variables	Spinal levels	Approach	Instrumentation?	Indication for Surgery	Surgical Procedure
				Number of Patients	Mean Age (y)	Special Characteristics	Number of Patients	Mean Age (y)	Number of Patients	Mean Age (y)							
Weinstein et al[91] 2000	Retro, Case series	None	IV				46	57.2			Type of surgery (based on overall rate of infection, not statistically challenged)	No formal analysis	C/L	A/P	Some	Degenerative, cervical myelopathy, nonunion, metastases, trauma, disc disease	Decompression, discectomy, fusion, instrumentation
Wimmer et al[92] 1998	Retro, Cohort	*F* test, paired Wilcoxon	III	850		Included some pediatric patients	22				Preoperative hospitalization (extended), surgical duration, EBL (>1 L), prior surgery, DM, smoking, EtOH, obesity, steroid use	NS	NS	A/P	Some	Deformity, trauma, degenerative	Fusion, instrumentation, not otherwise specified
Woods et al[93] 2013	Retro, CCS	Conditional logistic regression	III			Focused on perioperative transfusions	56	61 ± 12	91	60 ± 14.8	Perioperative transfusion	—	L	A/P	Some	NS	Decompression, fusion
Yang et al[94] 2016	Retro, Cohort	Pearson chi-square	III	18 931		Patients >65, lumbar epidural steroid injection prior to surgery	196				Lumbar epidural steroid injection (within 3 months) prior to OR	—	L	P	N	Degenerative	Decompression

Abbreviations: ACDF, anterior cervical discectomy and fusion; ASA, American Society of Anesthesiologists class; BMI, body mass index; CAD, coronary artery disease; CCS, case-controlled study; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CSF, cerebrospinal fluid; CVA, cerebrovascular accident; DM, diabetes mellitus; DVT, deep vein thrombosis; EBL, estimated blood loss; EtOH, alcohol use; GCS, Glasgow Coma Scale; HTN, hypertension; IA, inflammatory arthropathy; IVDU, intravenous drug use; LOS, length of stay; MI, myocardial infarction; MIS, minimally invasive surgery; MUST, Malnutrition Universal Screening Tool score; NNIS, National Nosocomial Infection Surveillance index; NS, not specified; NSAID, nonsteroidal anti-inflammatory drug; NSQIP, National Surgical Quality Improvement Program; OSA, obstructive sleep apnea; PE, pulmonary embolus; Pro, prospective; PVD, peripheral vascular disease; RA, rheumatoid arthritis; Retro, retrospective; SCI, spinal cord injury; SII, surgical invasiveness index; UTI, urinary tract infection; XLIF, extreme lateral interbody fusion. C, cervical; T, thoracic; L, lumbar; A, anterior; P, posterior; Comb, A/P combined.

Table 2. Patient-Associated Variables and Association With Surgical Site Infection by Study.

Author	Age	Albumin/Protein/Nutrition	Alcohol Use	ASA Class	Asthma/COPD	Bleeding Disorder/ Anticoagulation	BMI	Congestive Heart Failure	Coronary Artery Disease	Diabetes	Fat Thickness	Gender	Glucose/HbA1c	History of Infection	Hypertension	Immunodeficiency	Incontinence/Bowel-Bladder Dysfunction	Inflammatory Arthropathy	Insulin Use	Liver Disease	Neurologic Deficit/Injury	Neurologic Disorder	Obesity	Prior Surgery	Renal Disease	Smoking	Steroid Use	White Blood Cell Count
Abdul-Jabbar et al[4] 2012									N	N								N					N			N		
Aoude et al[5] 2016																												
Asomugha et al[6] 2016	N				N		N	N							N	Y									Y	N		
Atkinson et al[7] 2016	N		NN				N					N																
Babu et al[8] 2012																												N
Barnes et al[9] 2012																												
Berney et al[10] 2008																												
Blam et al[11] 2003			N	N			N					N														N	N	
Bohl et al[12] 2016		Y																										
Boston et al[13] 2009																	N									N		
Browne et al[14] 2007										Y																		
Chaichana et al[15] 2014	Y									Y													Y	Y		N		
Chen et al[16] 2009	N						N			Y		N														N		
Chen et al[17] 2011		Y	N							N		N											N			N		
Cizik et al[3] 2012					N	N	Y	N	N						Y			N		N					Y	N		
De La Garza Ramos et al[18] 2015																							Y					
De La Garza Ramos et al[19] 2016					N				N	Y										N		N	Y		Y	N	Y	
De La Garza Ramos et al[20] 2017				N		N																	Y					
Demura et al[21] 2009	N	N		N						Y		N									N						N	
Dubory et al[22] 2015	Y						N			Y																		
Ee et al[23] 2014	N		N	N			Y			Y		N														N	N	
Fang et al[24] 2005	Y		Y				N					N		Y										N		N	N	
Fehlings et al[25] 2012																												
Fisahn et al[26] 2017																												
Glassman et al[27] 2016	N			N			Y					Y														N		
Golinvaux et al[28] 2014										C									Y									
Gruskay et al[29] 2012	C			C								N																
Haddad et al[30] 2016	Y											Y									Y							
Hayashi et al[31] 2015	N																							N				
Hijas-Gomez et al[32] 2017		N			Y					Y		N				N				N			N		N			N
Hikata et al[33] 2014	N									Y		N	Y				N						N	N			N	
Jalai et al[34] 2016										N													N			N	N	

(continued)

Table 2. (continued)

Author	Age	Albumin/Protein/Nutrition	Alcohol Use	ASA Class	Asthma/COPD	Bleeding Disorder/ Anticoagulation	BMI	Congestive Heart Failure	Coronary Artery Disease	Diabetes	Fat Thickness	Gender	Glucose/HbA1c	History of Infection	Hypertension	Immunodeficiency	Incontinence/Bowel-Bladder Dysfunction	Inflammatory Arthropathy	Insulin Use	Liver Disease	Neurologic Deficit/Injury	Neurologic Disorder	Obesity	Prior Surgery	Renal Disease	Smoking	Steroid Use	White Blood Cell Count
Kanafani et al[35] 2009	Y									Y		N												N				
Keam et al[36] 2014																												
Kerwin et al[37] 2008																												
Kim et al[38] 2014																												
Kim et al[39] 2015												N																
Klekamp et al[40] 1999	N	N	Y							N		N		Y									N			N	Y	Y
Klemencsics et al[41] 2016	Y						Y		Y	Y										Y								
Koutsoumbelis et al[42] 2011	N							N	Y	Y		Y			N			N					Y			N		
Kudo et al[43] 2016	N	N	N				N			N																N		N
Kukreja et al[44] 2015	N																											
Kumar et al[45] 2015	N	Y																			Y							N
Kurtz et al[46] 2012	Y									N		N											Y			N		
Lee et al 472014	N						N	Y		Y		N						N										
Lee et al[48] 2016	N	N					N			N	Y												N	Y		N		
Li et al[49] 2013	N	N								N		N																
Lieber et al[50] 2016				Y	N		Y			N		Y																
Lim et al[51] 2014				Y						N													Y			N		
Lonjon et al[52] 2012	Y		N	Y		N	N			Y		N									N					N		
Manoso et al[53] 2014	N		N				N	Y		Y		N												N		N		
Maragakis et al[54] 2009	N			Y					N	N		N	N										Y	N		N		
Marquez-Lara et al[55] 2014							Y																					
Martin et al[56] 2016																										Y		
Mehta et al[57] 2012							N			N	Y												Y					
Murphy et al[58] 2017	N																											
Northrup et al[59] 1995																												
Ogihara et al[60] 2015				N			N			N		Y													N	N	Y	
Ohya et al[61] 2017																												
Oichi et al[62] 2017																						Y						
Ojo et al[63] 2016										Y													N					
Olsen et al[64] 2003																	Y						Y					
Olsen et al[65] 2008							N			Y			Y										Y					

(continued)

Table 2. (continued)

Author	Age	Albumin/Protein/Nutrition	Alcohol Use	ASA Class	Asthma/COPD	Bleeding Disorder/ Anticoagulation	BMI	Congestive Heart Failure	Coronary Artery Disease	Diabetes	Fat Thickness	Gender	Glucose/HbA1c	History of Infection	Hypertension	Immunodeficiency	Incontinence/Bowel-Bladder Dysfunction	Inflammatory Arthropathy	Insulin Use	Liver Disease	Neurologic Deficit/Injury	Neurologic Disorder	Obesity	Prior Surgery	Renal Disease	Smoking	Steroid Use	White Blood Cell Count
Omeis et al[66] 2011	N	N										N												Y			N	
Pull ter Gunne et al[1] 2009										Y		N		Y	N								Y	N				
Pull ter Gunne et al[67] 2010 (deformity)		N								N		N		Y	N								Y	N		N		
Pull ter Gunne et al[68] 2010 (osteotomy)																							Y					
Radcliff et al[69] 2013																												
Ramos et al[69] 2016																												
Rao et al[71] 2011	N				N		Y		N	N		Y			N											N		
Rechtine et al[72] 2001																					C							
Rodgers et al[73] 2010																												
Ruggieri et al[74] 2012	N																N											
Saeedinia et al[75] 2015	N						N			Y		N		Y	Y						N					Y		
Salvetti et al[76] 2017	N	Y					N			Y		N																
Satake et al[77] 2013	N			N						Y																N		
Schimmel et al[2] 2010	N						N		N	Y		N						N						Y		Y		
Schoenfeld et al[78] 2013	N	N		Y			Y		N	N				N	N							N			N		N	
Schwarzkopf et al[79] 2010			N				Y			N		N			N											N	N	
Sciubba et al[80] 2008	N									N		N					N						N			N		
Sebastian et al[81] 2016										N											N					N		
Shousha et al[82] 2014	N											N																
Singla et al[83] 2017																												
Skovrlj et al[84] 2015																												
Stambough et al[85] 1992		Y																										
Sugita et al[86] 2016																												
Tempel et al[87] 2015	Y																											
Tominaga et al[88] 2016				Y			N			N																N		
Veeravagu et al[89] 2009	N		N	Y		N				Y		N														N		N
Watanabe et al[90] 2010	N									Y		N											N			N		
Weinstein et al[91] 2000																												
Wimmer et al[92] 1998			Y							Y													Y	Y		Y	Y	
Woods et al[93] 2013																												
Yang et al[94] 2016																												

Abbreviations: Y, yes–association found; C, conditional–association under certain conditions; N, no association found; BMI, body mass index; COPD, chronic obstructive pulmonary disease.

Table 3. Diagnosis-Associated Variables and Association With Surgical Site Infection by Study.

Author	Deformity	Intra- vs Extradural	Tumor Size	Tumor Histopathological Diagnosis	Primary vs Metastatic Tumor
Abdul-Jabbar et al[4] 2012				Y	
Aoude et al[5] 2016					
Asomugha et al[6] 2016					
Atkinson et al[7] 2016					
Babu et al[8] 2012					
Barnes et al[9] 2012					
Berney et al[10] 2008					
Blam et al[11] 2003					
Bohl et al[12] 2016					
Boston et al[13] 2009					
Browne et al[14] 2007					
Chaichana et al[15] 2014					
Chen et al[16] 2009					
Chen et al[17] 2011					
Cizik et al[3] 2012					
De La Garza Ramos et al[18] 2015					
De La Garza Ramos et al[19] 2016					
De La Garza Ramos et al[20] 2017	C				
Demura et al[21] 2009					
Dubory et al[22] 2015					
Ee et al[23] 2014					
Fang et al[24] 2005					
Fehlings et al[25] 2012					
Fisahn et al[26] 2017					
Glassman et al[27] 2016					
Golinvaux et al[28] 2014					
Gruskay et al[29] 2012					
Haddad et al[30] 2016					
Hayashi et al[31] 2015				N	
Hijas-Gomez et al[32] 2017					
Hikata et al[33] 2014					
Jalai et al[34] 2016					
Kanafani et al[35] 2009					
Keam et al[36] 2014					
Kerwin et al[37] 2008					
Kim et al[38] 2014					
Kim et al[39] 2015					
Klekamp et al[40] 1999					
Klemencsics et al[41] 2016					
Koutsoumbelis et al[42] 2011					
Kudo et al[43] 2016					
Kukreja et al[44] 2015					
Kumar et al[45] 2015					
Kurtz et al[46] 2012					
Lee et al[47] 2014					
Lee et al[48] 2016					
Li et al[49] 2013			N	N	
Lieber et al[50] 2016	Y				

(continued)

Table 3. (continued)

Author	Deformity	Intra- vs Extradural	Tumor Size	Tumor Histopathological Diagnosis	Primary vs Metastatic Tumor
Lim et al[51] 2014					
Lonjon et al[52] 2012					
Manoso et al[53] 2014					
Maragakis et al[54] 2009					
Marquez-Lara et al[55] 2014					
Martin et al[56] 2016					
Mehta et al[57] 2012					
Murphy et al[58] 2017					
Northrup et al[59] 1995					
Ogihara et al[60] 2015					
Ohya et al[61] 2017					
Oichi et al[62] 2017					
Ojo et al[63] 2016					
Olsen et al[64] 2003					
Olsen et al[65] 2008					
Omeis et al[66] 2011		N			N
Pull ter Gunne et al[1] 2009					
Pull ter Gunne et al[67] 2010 (deformity)					
Pull ter Gunne et al[68] 2010 (osteotomy)					
Radcliff et al[69] 2013					
Ramos et al[70] 2016					
Rao et al[71] 2011					
Rechtine et al[72] 2001					
Rodgers et al[73] 2010					
Ruggieri et al[74] 2012			N		
Saeedinia et al[75] 2015					
Salvetti et al[76] 2017					
Satake et al[77] 2013					
Schimmel et al[2] 2010					
Schoenfeld et al[78] 2013					
Schwarzkopf et al[79] 2010					
Sciubba et al[80] 2008					
Sebastian et al[81] 2016					
Shousha et al[82] 2014					
Singla et al[83] 2017					
Skovrlj et al[84] 2015					
Stambough et al[85] 1992					
Sugita et al[86] 2016					
Tempel et al[87] 2015					
Tominaga et al[88] 2016					
Veeravagu et al[89] 2009					
Watanabe et al[90] 2010					
Weinstein et al[91] 2000					
Wimmer et al[92] 1998					
Woods et al[93] 2013					
Yang et al[94] 2016					

Abbreviations: Y, yes–association found; C, conditional–association under certain conditions; N, no association found.

Table 4. Surgery-Associated Variables and Association With Surgical Site Infection by Study.

Author	Antibiotic Timing/Redosing	Approach	Bone Graft	Case Order	Cervical Collar	Complex Closure	Delay to Surgery	Drain Presence/Duration	Dural Tear/CSF Leak	Early Tracheostomy	EBL	Emergency Surgery	Epidural Steroid	Incision Length	Instrumentation	Intraoperative Temperature	Length of Stay	Number of Levels Operated/Fused	Number of Staff	Number of Surgical Teams	Open vs MIS	Preoperative Admission	Procedure Type	Resident-Fellow	Revision	Surgical Duration	Surgical Invasiveness	Surgical Region	Transfusion	UTI
Abdul-Jabbar et al[4] 2012		Y																Y					N					N	N	
Aoude et al[5] 2016																													C	
Asomugha et al[6] 2016											N		Y									N	N			N				
Atkinson et al[7] 2016							N					N		N				Y	N									Y		
Babu et al[8] 2012										N																				
Barnes et al[9] 2012					Y																									
Berney et al[10] 2008										N																				
Blam et al[11] 2003		N	N				Y				N				N					Y						N				
Bohl et al[12] 2016																														
Boston et al[13] 2009																										Y				
Browne et al[14] 2007																														
Chaichana et al[15] 2014									N								Y	N												
Chen et al[16] 2009	N		N					N			Y															N				
Chen et al[17] 2011															N											Y				
Cizik et al[3] 2012																									N		Y	Y		
De La Garza Ramos et al[18] 2015																														
De La Garza Ramos et al[19] 2016																										Y				
De La Garza Ramos et al[20] 2017																							C							
Demura et al[21] 2009												N											N							
Dubory et al[22] 2015		N									N							N								Y			N	
Ee et al[23] 2014			N												N			Y	N		Y					N				
Fang et al[24] 2005			N								N				N			N					C							
Fehlings et al[25] 2012		Y																					N							
Fisahn et al[26] 2017																													Y	
Glassman et al[27] 2016																		Y								N				
Golinvaux et al[28] 2014																														
Gruskay et al[29] 2012		C		C																					C	C				
Haddad et al[30] 2016		Y																												
Hayashi et al[31] 2015		Y													Y											N				
Hijas-Gomez et al[32] 2017	N							N				N														Y			N	
Hikata et al[33] 2014							N				N							N				N				N			N	

(continued)

Table 4. (continued)

Author	Antibiotic Timing/Redosing	Approach	Bone Graft	Case Order	Cervical Collar	Complex Closure	Delay to Surgery	Drain Presence/Duration	Dural Tear/CSF Leak	Early Tracheostomy	EBL	Emergency Surgery	Epidural Steroid	Incision Length	Instrumentation	Intraoperative Temperature	Length of Stay	Number of Levels Operated/Fused	Number of Staff	Number of Surgical Teams	Open vs MIS	Preoperative Admission	Procedure Type	Resident-Fellow	Revision	Surgical Duration	Surgical Invasiveness	Surgical Region	Transfusion	UTI
Jalai et al[34] 2016		Y																								Y				
Kanafani et al[35] 2009															Y											N				
Keam et al[36] 2014																														
Kerwin et al[37] 2008						N																								
Kim et al[38] 2014																										Y				
Kim et al[39] 2015																										Y				
Klekamp et al[40] 1999																														
Klemencsics[41] et al 2016															N												N			
Koutsoumbelis et al[42] 2011								N	Y		Y						N		Y					N	N	N				
Kudo et al[43] 2016											N				N											Y				
Kukreja et al[44] 2015							Y					Y																		
Kumar et al[45] 2015																		Y												
Kurtz et al[46] 2012		Y	N															Y							Y				N	
Lee et al[47] 2014																											Y			
Lee et al[48] 2016																		N								N				
Li et al[49] 2013									Y		N				N															
Lieber et al[50] 2016			N												N											Y			N	
Lim et al[51] 2014																										Y				
Lonjon et al[52] 2012		N					Y	N			Y							Y			N					Y		N	N	
Manoso et al[53] 2014		N																									Y	N		
Maragakis et al[54] 2009	N	Y							N			N			Y	N										Y		Y	N	
Marquez-Lara et al[55] 2014																														
Martin et al[56] 2016																														
Mehta et al[57] 2012																		Y												
Murphy et al[58] 2017																														
Northrup et al[59] 1995										N																				
Ogihara et al[60] 2015			N						N			N			N											Y		N		
Ohya et al[61] 2017																														
Oichi et al[62] 2017																														
Ojo et al[63] 2016															N								Y			Y		Y		
Olsen et al[64] 2003	N	Y							N						N	N							N							
Olsen et al[65] 2008	Y	N	N					N							N			N					N	Y		N			N	

(continued)

Table 4. (continued)

Author	Antibiotic Timing/Redosing	Approach	Bone Graft	Case Order	Cervical Collar	Complex Closure	Delay to Surgery	Drain Presence/Duration	Dural Tear/CSF Leak	Early Tracheostomy	EBL	Emergency Surgery	Epidural Steroid	Incision Length	Instrumentation	Intraoperative Temperature	Length of Stay	Number of Levels Operated/Fused	Number of Staff	Number of Surgical Teams	Open vs MIS	Preoperative Admission	Procedure Type	Resident-Fellow	Revision	Surgical Duration	Surgical Invasiveness	Surgical Region	Transfusion	UTI
Omeis et al[66] 2011			N			Y									N		Y			Y										
Pull ter Gunne et al[1] 2009		Y									Y							N					N			Y				
Pull ter Gunne et al[67] 2010 (deformity)		N									N							N	N				N			N		N		
Pull ter Gunne et al[68] 2010 (osteotomy)																							Y							
Radcliff et al[69] 2013																														
Ramos et al[70] 2016																														
Rao et al[71] 2011	N	N	N					Y			N	NN				N				N					N	N			N	
Rechtine et al[72] 2001																														
Rodgers et al[73] 2010																					Y									
Ruggieri et al[74] 2012																							Y			Y		N		
Saeedinia et al[75] 2015		N	Y						Y					Y	Y		Y	Y							N	Y		Y		
Salvetti et al[76] 2017																										N				
Satake et al[77] 2013											N															N				
Schimmel et al[2] 2010		N	N												N			Y								N		N		
Schoenfeld et al[78] 2013																							N		Y	Y		N		
Schwarzkopf[79] et al 2010																													Y	
Sciubba et al[80] 2008						N			N	N					N				Y											
Sebastian et al[81] 2016																							N	N		Y				
Shousha et al[82] 2014															C															
Singla et al[83] 2017													Y																	
Skovrlj et al[84] 2015																														
Stambough et al[85] 1992																														Y
Sugita et al[86] 2016											N															N				
Tempel et al[87] 2015																														
Tominaga et al[88] 2016														N	Y			N	N						N	Y		C		N
Veeravagu et al[89] 2009												N			Y											Y			Y	
Watanabe et al[90] 2010											N				N											N				
Weinstein et al[91] 2000																							Y							
Wimmer et al[92] 1998							Y				Y															Y				
Woods et al[93] 2013																													Y	
Yang et al[94] 2016													Y																	

Abbreviations: Y, yes–association found; C, conditional–association under certain conditions; N, no association found; CSF, cerebrospinal fluid; EBL, estimated blood loss; MIS, minimally invasive surgery; UTI, urinary tract infection.

Nutrition

There are several serum markers such as transferrin, prealbumin, albumin, total lymphocyte count that can be measured for early detection of nutritional deficits. Bohl et al[12] performed a retrospective review of the ACS-NSQIP database and found the overall prevalence of hypoalbuminemia (defined as <3.5 g/dL) as 4.8% in patients who underwent posterior lumbar fusion of 1 to 3 levels. The authors found patients with preoperative hypoalbuminemia had a higher risk of wound dehiscence, SSI and urinary traction infection. Furthermore, those patients also had longer inpatient stay and a higher risk of unplanned hospital readmission within 30 days of surgery. Chen et al[17] found that hypoalbuminemia was an independent risk factor for SSI in a cohort of patients who underwent sacral chordoma resection.

While albumin has been routinely used as a surrogate marker for nutritional status, recent studies have shown that prealbumin (half-life of 2 days) may also be used to assess a patient's nutritional status in the perioperative period. Salvetti et al[76] found that preoperative prealbumin level of <20 mg/dL had higher risk of developing SSI with adjusted hazard ratio of 2.12. This collection of literature would suggest that for the reduction of SSI, it is advisable to assess nutritional status preoperatively by checking prealbumin, albumin and total lymphocyte count. Nutritional supplementation may be considered if the patient is malnourished and undergoing complex surgical reconstruction.

Smoking

Nicotine leads to peripheral vasoconstriction and tissue hypoxia and results in impaired local angiogenesis and epithelialization. Smoking leads to decreased wound collagen production in in vitro and in animal studies. Martin et al[56] in 2016 found that active smokers are at a significantly higher risk of SSI compared with former smokers. That study from the ACS-NSQIP database, of patients who underwent elective lumbar surgery, categorized patients into: never smoked, former smoker (quit 12 months ago) and active smoker. Active smokers had a significantly higher risk of SSI compared with nonsmokers. Former smoker had an increased risk, but it was not significantly different from nonsmokers. Pack years of 1 to 20 and 20 to 40 were both found to have increased risk for SSI.

Obesity/Body Mass Index

Much has been studied about the relationship between obesity/body mass index (BMI) and SSI. Cizik et al[3] performed a retrospective review of all patients who had spine surgery at a single institution and found that BMI >35 kg/m^2 was an independent risk factor for increased risk of SSI. In a retrospective cohort review, De la Garza-Ramos et al[18] found that obesity (BMI >30 kg/m^2) resulted in an increased risk of SSI (risk ratio 3.11) in patients who underwent one to three level lumbar fusion surgery. Marquez-Lara et al[55] also found that BMI >30 kg/m^2 (class I obesity) had increased risk of superficial wound infection. Furthermore, Mehta et al[57] found that body mass distribution, in particular increased skin to lamina distance and subcutaneous fat thickness, are independent risk factors for SSI. This study may indicate that although higher BMI is an independent risk factor associated with increased SSI, in patients with higher muscle mass, BMI may not be the most accurate variable to predict postoperative SSI. Lee et al[48] found that for every 1-mm of thickness in subcutaneous fat there was 6% increase in risk of SSI. Patients with at least 50 mm of posterior lumbar fat thickness had 4-fold increase in risk of SSI compared to those with less than 50 mm.

Surgery-Associated Risk Factors

Timing and Duration of Surgery

Most studies have found no significant association between "emergency surgery" and SSI.[7,21,31,52,54,60,71,89] Three studies have shown that increased duration from time of injury or admission to time of surgery was associated with increased risk of SSI.[11,44,52] Lonjon et al[52] found no association between the risk of SSI and surgery being done at night or after-hours.

A large number of studies have found that increased operative time increases the risk of SSI,* with a smaller number of contradicting studies.[6,11,16,23,27,35,48,67,71,86] Several studies used a cutoff of surgical duration in determining an association with SSI, although this varies between papers, ranging anywhere from 100 minutes to 5 hours,[13,24] and no conclusions can be made with regards to a specific duration as an inflection point in the risk for SSI.

Surgical Approach, Procedure, and Invasiveness

Surgical Approach: Anterior, Posterior, or Combined. If one considers studies that evaluate only cervical[25,30,34] or only lumbar procedures[2,46] separately, or separately analyzed approach in each spinal level subgroup,[28,64] most find an association between approach and SSI. In all studies with either cervical only groups or cervical subanalysis,[25,28,30,34,64] a posterior approach is consistently reported as a risk factor for SSI as compared with an anterior approach. Of those examining lumbar procedures,[2,28,46,64] for the most part, a combined anterior-posterior or posterior only approach was a risk factor for SSI as compared with anterior approach. Only 1 study had a thoracic subgroup analysis for approach, with Olsen et al[64] finding a posteriorly only approach to be associated with SSI as compared anterior alone. For the most part, those studies that have not found an association[11,22,52,65,68,71,75,77] have included a combination of cervical, thoracic, and lumbar procedures, which may confound the significance of approach given that the relative risk of an anterior versus posterior approach is different at various spinal levels. In those studies showing approach to be a risk factor for SSI,[1,4,25,28,30,31,34,46,54,64] the general trend is for a combined anterior-posterior approach to

*References 1, 4, 13, 19, 22, 28, 31, 34, 38, 39, 43, 51, 52, 54, 60, 63, 78, 81, 92.

have the highest risk for SSI, followed by a posterior approach, with the anterior approach often reducing the risk for SSI.

Minimally Invasive Versus Open Surgery. Both Ee et al[23] and Rodgers et al[73] found that open surgery was associated with a higher risk of SSI as compared to MIS techniques (procedures performed through a tubular retractor system or extreme lateral interbody fusion (XLIF)) in elective lumbar spine surgery. Dubory et al[22] and Lonjon et al[52] found no such difference in SSI rates in spinal trauma. It should be noted the latter studies come from the same group, one of two that utilized only univariate analysis, and the type of MIS technique used was not defined, making it difficult to compare these results with those of either Ee et al[23] or Rodgers et al[73]

Surgical "Invasiveness". Surgical invasiveness can be considered a composite of a number of variables as previously described, including number of levels operated on, the type of procedure performed at each level, and approach used. To allow comparison of the invasiveness of disparate spinal procedures, a surgical invasiveness index (SII) was developed by Mirza et al.[95] This index is a composite score based on the number of vertebral levels operated on, the type of intervention on each vertebra—decompression, fusion, instrumentation—as well as the approach used at each level, and has been validated against both blood loss and surgical duration. Of the 4 studies that evaluated SII as a variable with regards to SSI, 3 found that an increase in SII was associated with SSI.[3,48,53] However, Klemencsics et al[1] found no such association. This may be related to the populations and procedure types studied, as Klemencsics et al[1] looked at elective routine degenerative lumbar procedures, with a maximal SII of 15, while the other 3 studies looked across a broad range of surgery types using large databases and presumed higher maximal SII scores.[3,48,53] If this is the case, the association between SII and SSI may only exist in the upper range of the SII.

Perioperative Interventions

Tracheostomy. Despite theoretical concerns, all 3 studies evaluating the potential of cross-contamination, have found no increased SSI risk for early tracheostomy (either pre- or postoperatively) in anterior cervical spine surgery. Babu et al[8] and Berney et al[10] found a low rate of SSI with early tracheostomy after anterior cervical stabilization for acute cervical trauma with spinal cord injury. Northrup et al,[59] in a review of 11 spinal cord injury patients, concluded that an existing tracheostomy was not a risk factor for SSI for subsequent anterior cervical spine stabilization.

Cervical Orthosis. Barnes et al[9] reported that the use of a Philadelphia collar for a minimum of 48 hours postoperatively increased the rate of SSI in posterior cervical spine surgery. This is in keeping with the known effects of pressure on skin and soft tissue from cervical orthoses.[96]

Blood Transfusion. Transfusion is an independent risk factor for SSI in other surgical specialties,[97,39,98] and it has been strongly suggested to similarly be a risk factor in adult spine surgery. There exists some conflict in the literature to date, with a majority of studies finding a significant increase in SSI associated with transfusion,[4,5,28,61,79,89,93] but others finding it not to be of significance.[22,31,33,46,52,54,71] However, of those studies that have focused on the implications of blood transfusion in adult spine surgery,[5,28,79,93] all 4 have shown transfusion to be an independent risk factor for SSI. The association of transfusion with SSI has been thought to be a result of transfusion-related immunomodulation (TRIM), a phenomenon whereby antigens in blood products may result in T-cell unresponsiveness and subsequent immunosuppression.[99] Bacterial contamination of blood products are another potential explanation for the effects of transfusion on SSI.[100]

Urinary tract infection (UTI) has been investigated as a possible source and hence risk factor for SSI,[88,101] and presence of a catheter is a well-established risk for UTI.[102] However, there has been limited study into urinary catheters as an independent risk factor for SSI in spine surgery, with both articles on this topic coming from the same group.[22,52] While Dubory et al[22] found that presence of a bladder catheter was not a significant risk for SSI after multivariate analysis, Lonjon et al[52] did find that a prolonged duration of catheterization greater than five days was associated with SSI after univariate analysis, although no multivariate analysis was performed. Based on these results, limited if any conclusion about urinary catheterization and SSI can be made.

Radiation is known to have deleterious effects on tissue, both in short-term effects on wound healing such as skin breakdown, lower tensile strength, and delayed healing rates from damage to epithelial cells and fibroblasts,[103] and in long-term effects on soft tissue resulting in fibrosis, poor vascularity, and a higher propensity to go onto atrophy or necrosis.[104] As such, preoperative radiation, whether recent or remote, has been regarded as a substantial risk factor for SSI. In nonsacral tumors, 3 studies focused on risk factors for SSI in spinal metastases or primary spinal tumors found preoperative radiation to be a significant risk for SSI.[21,66,86] In primary sacral tumors, the results have been more mixed, with 2 studies suggesting no significant association between previous radiation and SSI[17,80] against 1 study finding previous radiation to be a risk factor.[49] This is unsurprising, given the complexities of sacral tumor resection, higher infection rates, and smaller case numbers within each study by which to find association.

Evidence from a single controlled-cohort study suggests that use of epidural steroid paste in lumbar decompression is a risk factor for SSI, with the rate of SSI in the steroid paste group being 5.83% as compared to 1.11% in the control group.[5]. Two studies from the same institution have shown preoperative lumbar epidural injections, if within 3 months of surgery, can also be a risk factor for SSI in both lumbar decompression[94] and lumbar fusion[83] surgery.

Surgical Team

Only 1 study has looked at surgeon experience in relation to SSI, with Skovrlj et al[84] finding that in adult scoliosis surgery, candidate members as compared with active members for the Scoliosis Research Society had a 2-fold increase in the rate of superficial, though not deep, SSI which was statistically significant. In regards to the effect of resident involvement and experience, 3 studies looking at different aspects of this have found an association with SSI.[61,65,78] Looking at seasonal variation in the risk of reoperation for SSI, Ohya et al.[61] found that April, during which medical staff turnover in Japan, was associated with the highest rate of SSI and reoperation for the same in academic centers while no such seasonal variation occurred in nonacademic hospitals, suggesting that the influx in new and henceforth inexperienced staff may be a contributor to this result. More directly, Schoenfeld et al.[78] found that resident involvement was an independent risk factor for SSI even after multivariate analysis encompassing procedure time and patient comorbidity, while Olsen et al.[65] found that the participation of 2 or more residents increased the risk of SSI although the latter assumed this to be a proxy for surgical complexity rather than a result of resident involvement. Koutsoumbelis et al,[42] however, found no significant association between number of residents and fellows and SSI and Sebastian et al[81] found no association between resident involvement and SSI. As such, it remains unclear as to the effect of residents on SSI.

The number of surgeons involved in spine surgery does not appear to be a significant risk factor, with 3 studies,[23,67,88] finding no significant association between number of scrubbed or senior surgeons and SSI. However, Sciubba et al.[80] found a larger number of surgeons to be associated with SSI in sacral tumor resection, where a multidisciplinary surgical team is often required. Koutsoumbelis et al[42] found that the overall number of personnel may be a risk if 10 or more personnel are present in the operating room. Operating room traffic and the number of personnel both have been linked to an increase in airborne contaminants[103] and could thereby increase the risk of contamination of the surgical wound.

The effects of involvement of more than one surgical team on SSI is not well studied and is confounded by the fact the presence of additional surgical teams may imply greater surgical complexity and therefore potential risk for infection. Blam et al[11] found that the combined involvement of both orthopedic and neurosurgical teams had a reduced rate of SSI as compared with orthopedics alone, with a trend toward the same as compared with neurosurgery alone, despite the greater operating room traffic involved although no clear explanation could be had for this effect. On the other hand, Rao et al[71]found no significant association between involvement of both services as compared with either orthopedics or neurosurgery alone. Involvement of more than 1 surgical team was found by Omeis et al[66] to be a risk for SSI in spinal tumors. However, in most cases this was due to involvement of plastic surgery and the requirement of a complex soft tissue reconstruction with its attendant risks with regard to infection, confounding the effect on SSI. In the case of sacral tumors, Sciubba et al[80] found no statistically significant association between having a plastic surgeon for closure and SSI.

Intraoperative Concerns and Complications

Increased intraoperative blood loss has not been clearly shown to be a risk factor for SSI, with a number of studies on either side of whether an association exists or not.[†] It is difficult to separate blood loss from other confounding variables such as surgical duration, invasiveness, as well as the need for transfusion. Only 3 studies reporting on intraoperative blood loss also reported on transfusion, with one showing an independent association between each and SSI,[93] one showing no association between either and SSI,[22] and one showing an association between blood loss but not transfusion and SSI.[52] Enough contradiction exists to preclude any conclusions with regard to blood loss as a possible risk factor.

Intraoperative hypothermia has been viewed as a potential risk factor for of SSI due to its induction of vasoconstriction and its negative effects on oxygenation, neutrophil function, and wound healing.[105] However, intraoperative temperature has not been found to be a risk factor so far for SSI in spine surgery, with all three studies including this variable demonstrating no significant association between intraoperative temperature and SSI.[54,64,71] In the lone study examining the effect of intraoperative inspired oxygen, Maragakis et al[54] found that intraoperative administration of fractionated inspired oxygen less than 50% was an independent risk factor for SSI, even after adjusting for other variables. The authors suggested that its effects may be related to the role of oxygen in the bactericidal process of leukocytes.

The argument behind a potential association between intraoperative dural tear and SSI is based on the longer surgical time required to repair a dural tear, as well as the risk of persistent cerebrospinal fluid leakage compromising wound healing. However, no clear relationship between intraoperative dural tear and SSI has been found. Three studies demonstrated no association between dural tear and spinal SSI,[54,60,64] in contrast to a single study finding dural tear to be associated with an increased risk of SSI.[42] In sacral tumors, no definitive association can be made between CSF leak and SSI, as the 2 studies found opposing results.[49,80]

Discussion

SSIs are associated with many risk factors that can be patient or surgically related. Our review was able to identify important modifiable and nonmodifiable risk factors that can be essential in surgical planning and discussion with patients.

[†]References 1, 6, 11, 16, 22, 33, 42, 43, 49, 52, 67, 80, 86, 92, 93.

Factor	Conclusion
Patient-associated factors	
Age	In general, the literature suggests a mixed finding of association between age and SSI.
Diabetes mellitus (DM)	In general, the literature suggests a strong association between DM/A1c and SSI.
General comorbidities	In general, the literature has mixed finding of specific comorbid conditions in association of SSI. There is evidence to suggest higher number of comorbidities is associated with SSI.
Nutrition	In general, the literature suggests malnutrition is associated with SSI.
Smoking	In general, the literature has mixed results of association between smoking and SSI. More recent evidence would suggest there is correlation between the two.
Obesity/Body mass index	In general, the literature suggests a strong association between obesity and SSI.
Surgery-associated factors	
Time and duration of surgery	In general, the literature is mixed, with conflicting results, making it difficult to firmly establish an association.
Surgical approach/ Invasiveness	In general, the literature is mixed with general trend indicating combined approach have highest incidence of SSI, followed by posterior approach. There is strong evidence increased invasiveness is associated with SSI.
Perioperative interventions	Preoperative radiation and postoperative blood transfusion have strong association with SSI. There is mixed evidence of UTI/ urinary catheter in association of SSI.
Surgical team	In general, there is mixed evidence of resident/ fellow involvement, number of surgeons and SSI, unable to establish an association.
Intraoperative concerns and complications	There is mixed evidence of intraoperative blood loss, dural tear, hypothermia and SSI, no established association can be made.

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