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Current Strategies in Prevention of Postoperative Infections in Spine Surgery

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Abstract

Study Design: Narrative review.

Objectives: Postoperative surgical site infections (SSIs) are among the most common acute complications in spine surgery and have a devastating impact on outcomes. They can lead to increased morbidity and mortality as well as greater economic burden. Hence, preventive strategies to reduce the rate of SSIs after spine surgery have become vitally important. The purpose of this article was to summarize and critically analyze the available evidence related to current strategies in the prevention of SSIs after spine surgery.

Methods: A literature search utilizing Medline database was performed. Relevant studies from all the evidence levels have been included. Recommendations to decrease the risk of SSIs have been provided based on the results from studies with the highest level of evidence.

Results: SSI prevention occurs at each phase of care including the preoperative, intraoperative, and postoperative periods. Meticulous patient selection, tight glycemic control in diabetics, smoking cessation, and screening/eradication of *Staphylococcus aureus* are some of the main preoperative patient-related preventive strategies. Currently used intraoperative measures include alcohol-based skin preparation, topical vancomycin powder, and betadine irrigation of the surgical site before closure. Postoperative infection prophylaxis can be performed by administration of silver-impregnated or vacuum dressings, extended intravenous antibiotics, and supplemental oxygen therapy.

Conclusions: Although preventive strategies are already in use alone or in combination, further high-level research is required to prove their efficacy in reducing the rate of SSIs in spine surgery before evidence-based standard infection prophylaxis guidelines can be built.

Keywords

spine surgery, surgical site infection, prevention

Introduction

Surgical site infection (SSI) following spine surgery is a relatively common complication and has a devastating impact on outcomes. The reported incidence of deep SSIs after spine surgery ranges from 1% to 4%.[1,2] Previous evidence indicates that postoperative infections are recognized as one of the most common complications causing hospital readmission following spine surgery.[3,4]

The effects of SSIs after spine procedures on patient outcomes and the cost of care can be dismal. This drastic complication may result in prolonged hospitalization, long-term intravenous (IV) antibiotic treatment, reoperations, work-day

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loss, permanent disability, or mortality.[5-13] Calderone et al[6] reported a more than 4 times increase in the total cost of care as result of the additional expenses involved in treating patients with deep SSI after lower back fusion. Petilon et al[10] showed that patients who suffered postoperative SSI after instrumented lumbar spinal fusion had significantly worse back pain scores ($P = .02$) compared with patients who did not have postoperative infection. Moreover, a significantly smaller proportion of patients in the infection group (27%) achieved the minimum clinically important difference on the Oswestry Disability Index when compared with the patients in the no-infection group (60%; $P = .018$). Casper et al[13] found significantly higher mortality rates in patients with postoperative spinal infections compared with a matched control group at 1 year (4.62% vs 1.2%; $P = .006$), 2 years (7.73% vs 2.25%; $P = .001$), and 5 years (15.45% vs 3.43%; $P = .0002$).

Preventive strategies to reduce the rate of SSIs after spine surgery have become critically important due to the deleterious impacts of this complication on patients and health care systems. These strategies can be separated into 3 main categories: preoperative optimization of patient-related risk factors, intraoperative, and postoperative measures to prevent SSIs.

Preoperative Optimization of Patient-Related Risk Factors

Demographic Variables, Patient Selection, and Comorbidity Assessment

Patient-related risk factors for SSI after spine surgery have been well described in the literature, with suggestions for modification of individual factors.[2,14] However, patient selection considering age, sex, nutritional status, and comorbidities as a whole, along with the risks associated with the planned spinal procedure, can aid in reducing the incidence of preventable catastrophic outcomes. Although older age has not been shown to be an independent risk factor for SSIs,[15] studies indicate that the mean age of patients who develop SSIs after spine surgery tends to be higher,[16,17] and patients older than the mid-50s can have a significantly higher risk for developing SSI.[18,19] Similarly, gender has not been shown to be one of the predictors of SSIs in various studies[15,17]; however, there is sporadic evidence that female sex is an independent risk factor.[20]

Obesity with body mass index (BMI) above 30 kg/m^2 and diabetes mellitus (DM) are among the important patient-related factors that have been shown to be associated with an increased risk of SSIs.[17,20] Although obesity is an independent risk factor for SSIs, poor nutritional status and low albumin or recent weight loss may also affect body's immune defense mechanisms negatively and predispose patients to SSIs after spine surgery.[20,21] In a retrospective comparative study by Wang et al,[22] the mean serum albumin was significantly lower in patients who developed SSIs after posterior lumbar spinal procedures compared with those who had similar surgeries but did not develop SSIs (36.9 vs 43.2, respectively; $P < .0001$). It is advisable to approach patients with serum albumin below 35 g/L as "high risk for SSI" and improve their nutritional status before spinal procedures.

DM, congestive heart failure (CHF), steroid use, smoking, alcohol abuse, and anemia (adult hematocrit < 35) have all been revealed as important risk factors for SSIs after spine surgery by different researchers.[17,19,20,23] In a study including 1532 surgical spine patients whose demographic, comorbidity, and complication data was collected prospectively, Lee et al[23] showed that the odds of an SSI in patients with a history of CHF were 3.07 times greater than the odds for those without CHF (95% confidence interval [CI]: 1.33-7.06; $P = .008$). Those with a history of DM had a 2.09 odds of having SSI (95% CI: 1.08-4.06; $P = .03$). Fang et al[19] reviewed 1095 patients who underwent spinal procedures. Data from 48 patients who developed postoperative SSIs was compared with data from a randomly selected group of 95 uninfected patients. Smoking and alcohol abuse were found to be significant predictors for postoperative SSI ($P = .03$ and $P = .04$, respectively). Lieber et al[20] reviewed 1110 patients with SSIs following spinal surgery and showed that hematocrit less than 35 and preoperative steroid use of more than 10 days were significant risk factors for development of SSIs. In a prospective multicenter surveillance and risk factor analysis, Ogihara et al[24] showed that preoperative oral steroid therapy is an independent risk factor for the development of deep SSIs after posterior thoracolumbar spinal surgeries. Patients with preoperative oral steroid therapy had an 8.53 times higher risk for developing deep SSIs compared with patients without steroid therapy (95% CI: 2.49-25.82; $P = .001$).

Currently, there is a paucity of literature reporting the effects of immunodeficiencies and other chronic diseases, such as liver or kidney failure, on postoperative spinal infection rates. However, it is would be reasonable to expect an increased SSI risk in such patients.

In the pediatric age group, several studies report an increased SSI risk in patients with underlying medical conditions such as spina bifida, cerebral palsy, Marfan syndrome, muscular dystrophy, and the presence of ventriculoperitoneal shunt.[25-27] Paralleling these reports, SSI rates for healthy children with idiopathic spine disorders range between 1% and 3%, whereas up to 17% of spine operations involving children with neuromuscular disease are complicated by SSIs.[28,29]

It is also important to note that previous spine surgery has been described as one of the independent and unmodifiable risk factors for SSI. Healing of a surgical wound results in scar tissue formation that contains mainly fibroblasts and nonrandomly aligned collagen fibers with inferior functional and structural quality compared to normal tissue. Therefore, spine surgeons have to meet the challenges of working through previously damaged soft tissues in revision surgeries. In a retrospective study, Kurtz et al[30] showed that the overall incidence of SSIs in adult patients after instrumented lumbar fusion was 12.2% in revisions and 8.5% in primary procedures with an adjusted hazard ratio of 1.66 (95% CI: 1.28-2.15; $P < .001$). Likewise, Warner et al[31] reported that the incidence of deep

Table 1. Patients With High Risk for Postoperative SSIs After Spine Surgery.

Staphylococcus aureus colonization
DM
Chronic liver disease or CHF
Steroid use
Smoking
Anemia with hematocrit <35
Obesity (BMI > 30 kg/m^2)
Low serum albumin <35 g/L
Neuromuscular disorders[a]
Revision surgeries

Abbreviations: SSI, surgical site infection; DM, diabetes mellitus; CHF, congestive heart failure; BMI, body mass index.
[a]Diagnosis of neuromuscular disorders increases the risk of SSIs in pediatric age group.

SSIs in pediatric patients following spinal fusion was 8.3% in revisions and 3.3% in primary surgeries ($P = .057$).

Risk Categorization

There is evidence supporting the premise that comorbidities are associated with an increased risk of SSIs both in the adult and pediatric populations.[15-23] However, there are no risk categorization systems to help surgeons determine which patients need to be approached as high risk for SSI after spine procedures based on their comorbidities. The authors propose including the patients with key independent risk factors in high-risk category for developing SSI after spine surgery (Table 1).

Optimization of Modifiable Risk factors

Smoking Cessation. Smoking is one of the modifiable risk factors that significantly increases the risk of SSIs after spinal surgery.[32] Smoking has been shown to have a detrimental effect on tissue oxygenation, which impairs the reparative processes of wound healing and the neutrophil defense against pathogenic microorganisms.[33-38] In a randomized controlled trial with 78 healthy subjects who were exposed to a standard incisional wound near the sacrum, Sorensen et al[39] demonstrated that the wound infection rate in smokers was 12%, compared with 2% in those who had never smoked ($P < .05$). Wound infections were significantly fewer in abstinent smokers compared with continuous smokers after 4, 8, and 12 weeks. Hence, smoking cessation at least 4 weeks before surgery is critically important to decreasing the risk of infection in spine patients.

Preoperative Glycemic Management. High blood glucose has been shown to impair blood B lymphocyte function[40] and attenuate the angiogenic capability of endothelial cells, which would eventually decrease tissues' healing potential.[41] There is further evidence that directly links hyperglycemia to postoperative SSIs such as inhibition of keratinocyte and fibroblast migration, inhibition of wound healing, and increased biofilm formation by microorganisms such as *Staphylococcus aureus* and *Staphylococcus epidermidis* in a concentration-dependent manner.[42,43] Hence, tight glycemic control may decrease the risk of postoperative SSIs by minimizing the negative effects of hyperglycemia on immune status and the healing capacity of the surgical wounds. Cancienne et al[44] reported that patients who underwent single-level lumbar decompression with perioperative hemoglobin (Hb) A1C level of 7.5% or above had a significantly higher risk for deep infection compared with patients below this threshold (odds ratio: 2.9; 95% CI: 1.8-4.9; $P < .0001$). Hikata et al[45] investigated 345 patients who underwent posterior instrumented thoracic and lumbar spinal arthrodesis. In this series, of the 36 patients with DM, 16.7% developed postoperative SSI. Among the 309 patients without DM, only 3.2% developed SSI ($P = .0005$). Although the perioperative serum glucose level did not differ between DM patients who did and those who did not develop SSI, the perioperative HbA1C value was significantly higher in diabetic patients who developed SSI (7.6% vs 6.9%, $P = .006$). Based on available evidence, it could be suggested that HbA1C level should be lowered below 7.0% preoperatively to minimize the risk of SSIs in spine patients with DM.

Screening and Eradication of S aureus. *Staphylococcus aureus* is recognized as the most commonly encountered microorganism in patients with SSIs after spine surgery. The pooled average contribution of *S aureus* infections to spinal SSIs was calculated to be as high as 49.3%.[9] There are 2 important reasons why *S aureus* is the most commonly isolated pathogen in patients with SSIs. First, it is a part of normal flora of the body, frequently found in the nose, respiratory tract, and on the skin. Second, *S aureus* has many virulence factors that make this microorganism capable of causing infections. These virulence factors include surface proteins that promote attachment to host proteins or formation of biofilms and the ability to secrete proteins, toxins, and enzymes to protect itself from the host's immune response and to convert the host tissue into nutrients required for bacterial growth. Kim et al[46] studied 7019 patients who underwent preoperative screening using nasal swabs for *S aureus* before elective orthopedic surgeries, including arthroplasty, spine surgery, and sports medicine procedures. The patients who tested positive for *S aureus* were managed with intranasal 2% mupirocin ointment twice daily for 5 days and a shower wash with 2% chlorhexidine once daily for 5 days. In their series, the percentages of the patients who were found to be carriers for methicillin-sensitive and methicillin-resistant *S aureus* (MSSA and MRSA) were 22.6% and 4.4%, respectively. A significantly higher rate of SSI was observed among MRSA carriers compared with noncarriers (0.97% vs 0.14%, $P = .0162$). The rate of SSI among MSSA carriers (0.19%) was also higher than that of noncarriers ($P = .709$). The screening and treatment program was associated with an overall 59% reduction in the rate of SSIs compared with that during the period preceding the start of the screening program. In a prospective observational study, Rao et al[47] reported similar results with significantly lower SSIs ($P = .016$) in patients who were screened and treated for *S aureus* colonization compared with the control group.

Based on current evidence, it is justifiable to suggest routine preoperative *S aureus* screening with nasal swabs, as well as eradication using mupirocin ointment and chlorhexidine baths, before spinal procedures.

Preoperative Antiseptic Showers and Antiseptic Dressings. Chlorhexidine is an antiseptic that dissociates and releases positively charged chlorhexidine cation at physiologic pH. The binding of this cationic molecule to negatively charged bacterial cell walls results in bactericidal effects via disruption of the bacterial cell wall and membrane. Edmiston et al[48] demonstrated that a standardized preadmission shower regimen that includes 118 mL of aqueous chlorhexidine gluconate (CHG) 4% per shower, a minimum of 2 sequential showers, and a 1-minute pause before rinsing results in maximal skin surface concentrations of CHG that are sufficient to inhibit or kill Gram-positive or Gram-negative surgical wound pathogens. However, meta-analysis of prospective controlled trials suggested no significant benefit of whole-body preoperative bathing with CHG for prevention of SSIs.[49,50] Most studies included in these meta-analysis reports omitted the details of CHG concentrations or application protocols.[49,50]

As an alternative to CHG showers, CHG no-rinse cloth application to the surgical site (the night before and morning of surgery) has been suggested as an effective method of preventing SSIs in orthopedic surgical patients.[51,52] These reports compared the addition of CHG no-rinse cloth protocols with standard in-hospital skin preparation only that consisted of antiseptic painting of the surgical site following induction of anesthesia and positioning of the patient on the operating table. Hence, current evidence does not support any superiority of CHG dressings over CHG showers in the prevention of SSIs.

Intraoperative Preventive Measures

Intravenous Antibiotics

Intraoperative IV antibiotic prophylaxis has been proven to be a safe and efficacious means of reducing the risk of SSIs after spine surgery.[53,54] Although the superiority of one antibiotic agent or dosing regimen over another has not been clearly demonstrated,[53] administration of a broad-spectrum antibiotic covering *S aureus*, such as cefazolin, 30 minutes before skin incision with redosing every 4 hours during longer surgeries, has become common practice in spine surgery.[14] Evidence suggests that skeletal muscle concentration of cefazolin peaks within 30 to 60 minutes after the first IV dose.[55] Hence, it seems reasonable to initiate parenteral prophylaxis with cefazolin within 1 hour before skin incision. In patients who are allergic to penicillin or cefazolin, clindamycin can be used as a safe alternative. To further investigate the association between the prophylaxis timing and the occurrence of SSIs, Steinberg et al[56] studied 109 patients with SSIs. When antibiotics requiring long infusion rates (vancomycin and fluoroquinolones) were excluded, the infection risk following administration of antibiotic within 30 minutes prior to incision was 1.6%, compared with an infection risk of 2.4% associated with administration 31 to 60 minutes prior to incision (OR: 1.74; 95% CI: 0.98-3.04). Intraoperative redosing also appeared to reduce SSI risk in operations lasting longer than 4 hours (OR of 3.08 with no redosing; 95% CI: 0.74-12.90). Further studies with large patient numbers are needed to support the conclusions of Steinberg et al.[56]

Another point worth discussing is whether the duration of IV antibiotic administration should be extended until the drain is removed in patients after spinal procedures. It has been shown that wound drains can be colonized with pathogenic microorganisms, and retrograde migration of skin flora along the drain is common.[57] Wound drains are often left in place for over 24 hours due to the likelihood of high output for an extended period of time following spinal surgery. In practice, it is common for spine surgeons to continue IV antibiotics as long as the drain is in place postoperatively. However, in a prospective randomized study, Takemoto et al[58] showed that continuing perioperative administration of antibiotics for the entire time a drain is in place after spinal surgery did not decrease the rate of SSIs. Hence, we recommend limiting the use of perioperative antibiotic prophylaxis to 24 hours and avoiding the use of broader spectrum antimicrobials unless there are clear indications of a need to prevent resistance development.

Skin Preparation

Intraoperative skin preparation before the surgical incision is the standard of care in any transcutaneous surgical procedure that aims to minimize direct inoculation of the wound with the skin flora.[59] The most commonly used solutions for intraoperative skin antisepsis include CHG and povidone-iodine with or without isopropyl alcohol. Darouiche et al[60] compared the efficacy of CHG-alcohol scrub with povidone-iodine (no alcohol) in a prospective randomized trial including 849 patients undergoing clean-contaminated surgery (ie, colorectal, small intestinal, gastroesophageal, biliary, thoracic, gynecologic, or urologic operations). The overall rate of SSI was significantly lower in the CHG-alcohol group than in the povidone-iodine group (9.5% vs 16.1%, respectively; $P = .004$). Savage et al[61] compared CHG-alcohol (Chloraprep—2% chlorhexidine gluconate and 70% isopropyl alcohol; Enturia, El Paso, Texas) with iodine-alcohol (Duraprep—0.7% available iodine and 74% isopropyl alcohol; 3M Healthcare, St Paul, Minnesota) in a prospective randomized study including 100 patients undergoing elective lumbar spine surgery. There was no difference in the rate of positive skin culture between the CHG-alcohol and iodine-alcohol groups (0/50 vs 3/50, respectively; $P = .24$) after skin preparation and after wound closure (17/50 vs 16/50, respectively; $P = .22$). Based on these studies, it can be speculated that combining CHG or povidone-iodine with alcohol offers better skin antisepsis than using either solution without the addition of alcohol. A previously published meta-analysis did not find sufficient high-level evidence to recommend the combined application of CHG-alcohol and povidone-iodine-alcohol over the use of these solutions in

Figure 1. Image from a long thoracic posterior spinal instrumentation and fusion case. Wound irrigation using 3 liters of normal saline was performed before closure. (Courtesy of Danny Tunmire, RN, BSN, CNOR, CRNFA, University of Alabama at Birmingham, Department of Orthopaedic Surgery, Birmingham, AL, USA.)

isolation.[62] However, in a randomized controlled trial including 407 patients undergoing elective spine surgery, Patrick et al[63] showed significantly lower viable bacteria after skin disinfection with sequential application of povidone-iodine-alcohol and CHG-alcohol compared with application of only povidone-iodine-alcohol twice. It should be noted that the study demonstrated bacterial viability as the outcome measure and the clinical implications of positive culture results in terms of risk for SSIs remain to be studied.

Wound Irrigation

SSIs typically result from contamination of the surgical site during the interval between the skin incision and wound closure.[64] Savage et al[61] demonstrated a significant increase in positive culture results taken from the surgical site after wound closure compared with the rate following skin preparation (33% vs 3%, respectively; $P < .0001$). Hence, intraoperative irrigation of the surgical site before wound closure is believed to be effective in the prevention of bacterial colonization and may reduce the risk of SSIs (Figure 1). Nevertheless, evidence to date is not sufficient to establish consensus and suggest guidelines regarding surgical wound irrigation practices in spine surgery. In a retrospective series of 223 patients after spine surgery, Watanabe et al[15] reported 14 SSIs. Mean saline irrigation over 2000 mL/h showed a strong association with the prevention of SSI (OR: 0.08).

Povidone-iodine (PVP-I) is an antiseptic solution composed of polyvinylpyrrolidone (povidone, PVP) and elemental iodine. Iodine molecules released from PVP-I penetrate and destroy the cell wall of microorganisms, and they impair vital events such as protein synthesis by forming complexes with amino acids and unsaturated fatty acids. Chang et al[65] investigated the use of PVP-I solution for wound irrigation in a series with 244 patients undergoing primary posterior lumbosacral instrumented fusion. The wound irrigation in the study group ($N = 120$) was performed with 0.35% PVP-I followed by normal saline solution, and in the control group ($N = 124$) with normal saline only. The infection rate was significantly lower in the study group, with no difference in fusion rate, wound healing, or clinical outcomes. In a prospective randomized trial with 414 patients undergoing spinal procedures including decompression, discectomy, tumor excision, and pedicle screw fixation, Cheng et al[66] used 0.35% PVP-I in 208 patients. The infection rate was significantly lower in the PVP-I group ($P = .0072$). Despite these encouraging results, concerns exist regarding potential negative effects of PVP-I on tissues at the cellular level. In vitro and animal studies indicate cytotoxic effects of PVP-I (at 0.35% or lower concentrations) on osteoblasts and neuronal tissues.[67,68] Therefore, wound irrigation with PVP-I solutions needs to be studied further before recommendations for or against its use in spine surgery can be justified.

Theoretically, CHG can be considered an alternative to saline or PVP-I for intraoperative wound irrigation,[69] but current literature does not provide any evidence regarding the use of CHG wound irrigation in spine surgery.

Intrawound Vancomycin Powder

The application of local vancomycin in powder form within the surgical wound as an adjunct to parenteral antibiotics to decrease the risk of SSI has gained widespread popularity among spine surgeons (Figure 2). Intrawound vancomycin powder appears to be a promising option for additional antibiotic prophylaxis due to its low cost, extensive availability, ease of application, good safety profile, and perception of effectiveness.[70]

Vancomycin inhibits the synthesis of the peptidoglycan layer in the bacterial cell wall and causes the bacteria to lyse. Vancomycin is very effective against most commonly isolated pathogens in SSIs such as Gram-positive rods and cocci, including MRSA and multidrug-resistant *S epidermidis*.[71] Due to its poor oral bioavailability, vancomycin is administered intravenously and distributed to the tissues through the systemic circulation. However, the distribution of any IV antibiotics in a surgical wound can be limited by factors such as hematoma and soft tissue damage around the wound, obesity, and diabetes.[72] Thus, intrawound application of vancomycin can help in achieving minimum inhibitory concentrations (MIC) for common microorganisms in a surgical wound for

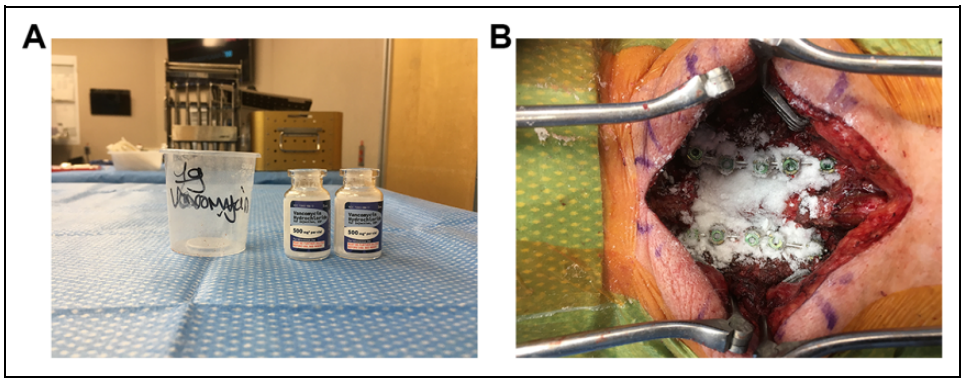

Figure 2. Images from a posterior spinal instrumentation and fusion between the level of cervical two to six with laminectomies from cervical three to five. (A) Two vials of vancomycin (500 mg per vial) were opened. (B) One gram of vancomycin powder was applied throughout the hardware bilaterally.

an extended period of time without exposing other tissues to potentially toxic effects of IV administration. Armaghani et al[73] measured daily postoperative vancomycin levels in serum and drain outputs in pediatric patients after spinal deformity correction. All patients received prophylactic IV cefazolin perioperatively and 1 gram of vancomycin powder applied into the surgical wound before closure. The mean serum vancomycin levels were 2.5 μg/mL, 1.9 μg/mL, and 1.1 μg/mL on postoperative day 0 (POD 0: immediately after the operation), POD 1, and POD 2, respectively. The mean vancomycin levels in drain output were 403 μg/mL, 251 μg/mL, and 115 μg/mL on POD 0, 1, and 2, respectively. Intrawound application of vancomycin powder produced local levels well above the MIC for common wound pathogens (2-4 μg/mL) and serum levels below the toxicity threshold (25 μg/mL).

There is growing evidence suggesting that intrawound application of vancomycin powder may be effective in decreasing the risk for SSIs after spinal surgery.[74-77] Strom et al[74] reported that the rate of infection after posterior cervical fusion fell from 10.9% to 2.5% ($P = .0384$) following the introduction of vancomycin powder. In a multicenter prospective study with 2056 patients, Devin et al[76] demonstrated that the risk of SSI was higher in patients in whom intrawound vancomycin powder was not used ($P < .001$). Khan et al[77] performed a meta-analysis of spinal SSI and vancomycin powder including 9 retrospective cohort studies and 1 randomized controlled trial. There were 2574 cases and 106 infections (4.1%) in the control group, in which vancomycin powder was not used, and 2518 cases and 33 infections (1.3%) in the treatment group, in which the patients received intrawound vancomycin (absolute risk reduction = 2.8%). The patients who had instrumented spinal operations had a reduced risk of SSI with vancomycin powder ($P = .023$) compared with those who had noninstrumented spinal operations ($P = .226$). It is plausible to expect that the reduction in the incidence of SSIs after spine surgery associated with intrawound application of vancomycin powder would also reduce the infection-related costs.[78,79] Godil et al[79] reported that the use of intrawound vancomycin powder can lead to cost savings of $438 165 per 100 spinal fusions performed.

Contrary to many prior studies, some retrospective reports with a limited number of patients did not show a significant reduction in SSI risk with vancomycin powder.[80,81] Furthermore, concerns regarding potentially negative in vitro effects of vancomycin powder on dural cells or osteoblasts[82,83] have not been supported by in vivo animal experiments or clinical studies.[16,84]

Another point worth mentioning is the potential impact of widespread use of intrawound vancomycin on creating vancomycin-resistant organisms or microbial selection. Although development of vancomycin-resistant pathogens is a reasonable concern, evidence to date does not show an increase in SSIs caused by such pathogens in patients who received intrawound vancomycin.[85] Chotai et al[85] studied 2802 patients of whom 1215 received intrawound vancomycin powder during index spine surgery while the rest did not receive it. There was a significantly lower rate of deep SSIs in the vancomycin powder group compared with the control group (1.6% vs 2.5%, $P = .02$). None of the patients who had intrawound vancomycin and subsequently developed *S aureus* SSI demonstrated pathogens with resistance to vancomycin. Grabel et al[86] reported 115 SSIs after 5909 elective spinal procedures. Intrawound vancomycin powder was used in 42 and not used in 73 of the infected cases. The culture results revealed 23.8% polymicrobial and 16.7% Gram-negative growth in the vancomycin group compared with 9.6% ($P = .039$) and 4.1% ($P = .021$) in the no-vancomycin group, respectively. Although this study showed a higher prevalence of polymicrobial and Gram-negative culture results in patients that ultimately developed postoperative SSIs, there was no sufficient data in terms of patient comorbidities such as diabetes that might be a predisposing factor for Gram-negative or polymicrobial SSIs. For this reason, spine surgeons occasionally prefer applying intrawound vancomycin along with tazocin powder to cover both Gram-positive and Gram-negative microorganisms.

Based on high level evidence regarding the safety and effectiveness of intrawound vancomycin, we suggest routine application of vancomycin powder both in adult (1 g) and pediatric (0.5 g) patients undergoing instrumented posterior spinal procedures to decrease the risk of spinal SSIs. We note that the literature does not include any reports to suggest an alternative intrawound antibiotic for patients who are allergic to vancomycin. However, there is evidence supporting the local use of daptomycin-loaded polymethylmethacrylate beads in patients with periprosthetic joint infections, and prosthetic vascular graft infections.[87,88] Hence, it can be speculated that daptomycin powder will emerge in the near future as an alternative intrawound antibiotic for patients who are allergic to vancomycin.

Intraoperative Oxygenation and Body Temperature Regulation

Tissue perfusion and oxygenation are vitally important determinants of tissue viability, resistance to infection, and wound healing after surgery. Hence, in addition to adequate perfusion to the surgical wound, the fraction of inspired oxygen (FiO_2) administered intraoperatively has been suggested as a modifiable risk factor for SSI after spinal surgery.[89] In a case-control study, Maragakis et al[89] found that 68% of the patients with SSIs after spinal procedures received less than 50% FiO_2 intraoperatively compared with 34% of the patients who did not develop SSIs. The authors suggested that FiO_2 less than 50% is an independent, modifiable risk factor for SSI after spinal surgery. Supporting these findings for intraoperative oxygenation, Inanmaz et al[90] underlined the importance of tissue oxygenation during the postoperative period in a study including 42 patients after neuromuscular scoliosis surgery. The infection rate in patients who received hyperbaric oxygen therapy (5 sessions/week for 6 weeks) was lower compared with those who did not receive such therapy (5.5% vs 16.6%). Interestingly, in a retrospective study including 4498 patients, Wanta et al[91] compared 1250 patients with SSIs with 3248 control patients who did not develop SSIs after vascular, general, orthopedic, neurologic, and spine surgeries. The authors could not demonstrate any decrease in SSIs with increased intraoperative FiO_2. Furthermore, higher intraoperative FiO_2 exposure was associated with higher odds of SSI in the neurological and spine populations. These authors speculated that unfavorable consequences of hyperoxia such as free radical–induced cellular damage and apoptosis might have mitigated any benefit of increased tissue oxygenation in clean wounds. Therefore, keeping in mind that the normal FiO_2 in air is 21%, it may be advisable not to increase the FiO_2 to levels far beyond 50% in patients undergoing surgeries under general anesthesia.

The biological and physiologic cascades in the human body are optimized for a narrow temperature range around 36.5°C to 37.5°C. Because the use of general anesthesia inhibits the body's thermoregulatory responses, perioperative hypothermia is not an uncommon condition for patients undergoing lengthy spinal surgeries. Hypothermia increases total oxygen consumption, induces coagulopathy, and alters the functions of the immune system.[92] As a result, hypothermia may increase the risk of SSIs after spine surgery. There is evidence in favor of perioperative active warming to decrease the risk of SSIs.[93,94] Tsuchida et al[95] showed that severe (<35°C) and late-nadir (<36°C occurring after 2 hours of anesthesia induction) hypothermia were associated with a greater incidence of SSIs after prolonged gastroenterological surgery. In a case-control study, Brown et al[96] could not demonstrate a significant association between intraoperative hypothermia and SSIs in patients with clean surgical wounds. The main limitations of this study were retrospective data gathering and lack of homogeneity in the complexity of the surgical procedures between the groups.

Based on current evidence, it would be most reasonable to suggest keeping the FiO_2 at 50% and the body temperature between 36.5°C and 37.5°C throughout spinal procedures for optimal results.

Postoperative Preventive Measures

Silver-Impregnated Dressings

The antibacterial activity of silver against both Gram-positive and Gram-negative pathogens has long been known and has found a variety of applications because its toxicity to human cells is considerably lower than to bacteria.[97,98] Although the exact mechanisms by which silver exerts its antimicrobial effects are yet to be fully elucidated, proposed mechanisms of action include alteration of the bacterial cell wall and/or cell membrane structure, inhibition of DNA replication and respiratory activity with modification of intracellular ATP levels.[98] Silver-impregnated wound dressings containing slow-release silver ions have been used to decrease the risk of wound infections after surgery (Figure 3).[99] Epstein et al[99] compared silver-impregnated dressing with regular dressing (iodine- or alcohol-based swab and dry 4 × 4 gauze) in patients undergoing lumbar laminectomies with instrumented fusion. There were 11 superficial and 3 deep wound infections in the regular dressing group. None of the patients in the silver dressing group developed superficial or deep wound infections. In a meta-analysis of 9 randomized controlled trials with a total of 2196 patients (1141 patients in the silver-containing-dressing group vs 1055 patients in the control group), Li et al[100] found that silver-containing dressing was not associated with lower incidence of SSI after colorectal surgery, vascular surgery, fracture surgery, or caesarian delivery.

Although current evidence is not conclusive, the routine use of silver-impregnated wound dressings after posterior spine surgery is commonly practiced in many health centers across North America.

Closed Incision Negative-Pressure Wound Therapy

The use of closed incision negative-pressure (CI-NPWT) has been advocated by researchers because this therapy has a

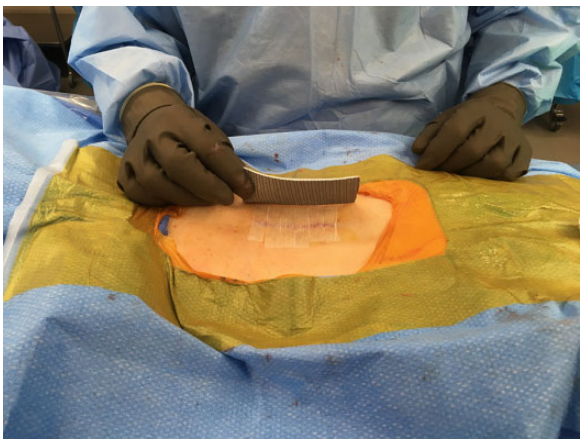

Figure 3. Demonstrates application of silver-impregnated pad after wound closure.

positive impact on wound healing by diminishing the tensile forces and edema, enhancing the removal of exudate, and increasing the blood and lymphatic flow around the wound.[101] In a retrospective case-control study including 160 patients undergoing long-segment thoracolumbar spine fusions, Adogwa et al[102] compared the group that received CI-NPWT (N = 46) with controls who did not receive CI-NPWT (N = 114). There was a 50% decrease in the incidence of wound dehiscence in the CI-NPWT group compared with controls (6.38% vs 12.28%, respectively; $P = .02$). The incidence of postoperative SSIs was significantly lower in the CI-NPWT group compared with the control group (10.63% vs 14.91%, respectively; $P = .04$). Liu et al[103] investigated the effects of CI-NPWT in a meta-analysis including 1295 patients from 5 randomized, quasi-randomized, and controlled clinical studies who underwent lumbar spinal surgeries. Although more patients in the control group contracted postoperative fever than did those in the CI-NPWT group, there was no significant difference between the 2 groups in terms of the incidence of wound infection.

Current evidence does not include sufficient high-level evidence defining the specific indications for using CI-NPWT routinely in spine patients. Even so, it has been adapted by many spine surgeons as a safe and effective means of wound management in patients with increased risk of SSIs after spinal procedures.

Dressing Change

Despite tremendous advances in sterile and surgical techniques for reducing the risk of SSIs in spine surgery, there are no guidelines or consensus regarding the ideal timing of dressing change postoperatively. There are differences between institutions and even among spine surgeons from the same institution on how to manage the dressing after spine surgery. In general, dressing change is performed after 2 days postoperatively. Nevertheless, it has also been advocated that the sterile dressings applied in the operating room after spinal surgeries may serve as a barrier to bacterial inoculation and reduce the risk of SSIs. Bains et al[104] reported a decrease in the incidence of SSIs after the institutional adoption of a new "dressing change" protocol. Over a 15-year period, a total of 8631 instrumented spine fusions were performed. There were 2473 cases performed during the preprotocol period (1999-2004), during which the dressing change was performed mostly on postoperative day 2. The number of cases performed after the adoption of the new "no dressing change for 5 days after surgery" protocol was 6158 (2005-2013). Overall, after adoption of the new dressing-change protocol, the incidence of SSIs decreased from 3.9% (97/2473) to 0.93% (57/6158) ($P < .0001$). The authors suggested that "dressing changes in the immediate postoperative period are not necessary" and that leaving the original postoperative surgical dressing in place for 5 days may lead to decreased SSIs. It must be noted that the study was performed retrospectively and that the improvement in sterilization techniques and infection prevention measures during the last decade might have confounded the results.

Although scientific evidence that supports the adoption of new dressing change protocols after spine surgery is lacking, it is reasonable not to open a sterile surgical wound to be exposed to nosocomial pathogens during the immediate postoperative period unless the dressing is soaked with blood or serosanguinous discharge.

Table 2. Summary of the Currently Used Strategies for Prevention of SSIs in Spine Surgery.

	Preoperative	Intraoperative	Postoperative
Routine	*Staphylococcus aureus* screening and eradication	IV cefazolin	Silver-impregnated dressings[a]
	Chlorhexidine baths	Skin preparation: CHG-ETOH	
		Intrawound vancomycin powder[a]	
Selected cases	Tight glycemic regulation	Wound irrigation[a]	CI-NPWT[a]
	Weight reduction	Intrawound daptomycin[a]	
	Smoking cessation		

Abbreviations: SSI, surgical site infection; CHG-ETOH, chlorhexidine gluconate–alcohol; CI-NPWT, closed incision negative pressure wound therapy.
[a]There is supportive evidence for the use of these strategies in instrumented posterior spinal procedures.

Summary and Recommendations From the Authors

SSIs after spine surgeries may severely affect clinical outcomes and be an economic burden for the health care systems. Evidence to date indicates several potential independent risk factors that may increase the likelihood of postoperative SSIs, including obesity, DM, smoking, alcohol abuse, steroid use,

neuromuscular disorders, anemia (adult hematocrit < 35), *S aureus* colonization, and chronic diseases such as liver failure or CHF. Current strategies for preventing postoperative infections in spine surgery can be summarized under 3 categories: preoperative, intraoperative, and postoperative preventive measures. In addition to routinely used preventive measures, it is advisable to consider additional precautions based on patient and procedure characteristics as well as independent risk factors (Table 2).

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