Surgical Site Infections: Risk Factors, Prevention, and Management — A Synthesis of Evidence

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Abstract

Surgical site infections (SSIs) remain one of the most common healthcare-associated infections and are a significant cause of postoperative morbidity, prolonged hospitalization, increased healthcare costs, and mortality worldwide. This review synthesizes current evidence regarding the epidemiology, risk factors, prevention strategies, management approaches, and future directions for SSIs. The available literature indicates that the development of SSIs is multifactorial, involving patient-related factors such as obesity, diabetes mellitus, smoking, malnutrition, anemia, and comorbidities; procedure-related factors including prolonged operative time, emergency surgery, wound contamination, and surgical complexity; as well as healthcare system-related factors such as adherence to infection prevention protocols and surveillance practices. Effective prevention requires a comprehensive perioperative approach encompassing preoperative patient optimization, timely and appropriate antibiotic prophylaxis, meticulous surgical technique, intraoperative infection control measures, and structured postoperative surveillance. Once an SSI develops, early diagnosis using standardized classification systems, multidisciplinary management, culture-guided antimicrobial therapy, and appropriate surgical intervention are essential for improving clinical outcomes. Although international guidelines have substantially improved infection prevention practices, important evidence gaps remain regarding the effectiveness of certain adjunctive intraoperative interventions and the implementation of standardized prevention programs across diverse healthcare settings. Future research should focus on procedure-specific preventive strategies, risk prediction models, antimicrobial stewardship, and strengthening surveillance systems to reduce the global burden of SSIs. Overall, sustained adherence to evidence-based guidelines, combined with patient optimization and continuous quality improvement initiatives, remains fundamental to minimizing the incidence and impact of surgical site infections.

Keywords: Surgical Site Infection (SSI); Healthcare-Associated Infection; Risk Factors; Infection Prevention; Antibiotic Prophylaxis; Perioperative Care; Wound Management; Infection Control; Antimicrobial Stewardship; Postoperative Complications; Surveillance; General Surgery.

1. Introduction

Surgical site infections (SSIs) remain a leading cause of postoperative morbidity, prolonged hospital stay, and increased healthcare costs across diverse settings. This review synthesizes evidence on (1) risk factors for SSIs, (2) prevention strategies at preoperative, intraoperative, and postoperative stages, and (3) management considerations. Across the sources, risk is multifactorial, spanning patient characteristics, procedural factors, and hospital/system-level determinants. Prevention success hinges on adherence to established guidelines, timely and appropriate perioperative prophylaxis, optimization of modifiable patient factors, and robust surveillance with feedback. Where evidence diverges (e.g., irrigation solutions, prophylaxis timing, or device-related risks), we highlight nuances and areas requiring further clarification.

2. Overview of Surgical site infections (SSIs)

Surgical site infections (SSIs) are among the most common healthcare-associated infections, occurring at or near the surgical incision within a specified postoperative period. According to the Centers for Disease Control and Prevention (CDC), SSIs are defined as infections that develop within 30 days after surgery or within 90 days when an implant is placed. These infections are classified into three categories: superficial incisional, deep incisional, and organ/space infections, depending on the depth and anatomical location involved (Fry, 2013; Li et al., 2018; Stryja et al., 2020). SSIs represent a major global healthcare challenge because they are associated with prolonged hospital stays, increased healthcare costs, greater morbidity, and higher mortality rates. To address this burden, several international organizations, including the World Health Organization (WHO), the CDC, the American College of Surgeons (ACS), the Surgical Infection Society (SIS), and the Society for Healthcare Epidemiology of America (SHEA) in collaboration with the Infectious Diseases Society of America (IDSA), have developed comprehensive evidence-based guidelines aimed at preventing SSIs throughout the perioperative period (Hebballi et al., 2024; Mueller et al., 2022; Rosa et al., 2023; Stryja et al., 2020).

3. Risk Factors for Surgical Site Infections

The development of SSIs is influenced by a combination of patient-related, procedure-related, and healthcare system-related factors. Patient-related factors include obesity, diabetes mellitus, smoking, poor nutritional status, anemia, advanced age, multiple comorbidities, and higher American Society of Anesthesiologists (ASA) physical status scores. These conditions impair immune function and wound healing, thereby increasing susceptibility to postoperative infections (Badeso, 2022; Kebede et al., 2024; Li et al., 2018; Matsuda et al., 2023; Pereira et al., 2023). Large-scale studies conducted among trauma and oncology patients have similarly demonstrated that metabolic disorders and chronic illnesses significantly increase the risk of SSIs and contribute to poorer postoperative outcomes (Fry, 2013; Matsuda et al., 2023).

Procedure-related factors also play a crucial role in SSI development. Operations with prolonged duration, emergency surgical procedures, contaminated or dirty wound classifications, and technically complex surgeries such as spinal surgery, pancreaticoduodenectomy, esophageal resection, colorectal surgery, cardiac surgery, and orthopedic procedures have consistently been associated with higher infection rates. The likelihood of SSIs further increases when organ-space contamination or extensive intraperitoneal involvement occurs during surgery (Fry, 2013; Ikegwuonu et al., 2024; Matsuda et al., 2023; Stryja et al., 2020; Yamamoto et al., 2020).

Hospital- and system-level factors are equally important determinants of SSI occurrence. Effective infection surveillance systems, strict adherence to infection prevention protocols, hospital infrastructure, surgical volume, academic affiliation, and institutional safety practices all influence SSI incidence. Studies have consistently demonstrated that hospitals implementing continuous surveillance and regular feedback mechanisms achieve lower SSI rates through improved compliance with evidence-based infection control practices (Fry, 2013; Malheiro et al., 2021; Stryja et al., 2020).

The reported incidence of SSIs varies considerably depending on the type of surgery and healthcare setting. In trauma surgery, deep SSIs have been reported as relatively uncommon, with an incidence of approximately 0.05%; however, they are associated with significant morbidity and adverse clinical outcomes. Conversely, complex gastrointestinal procedures such as pancreaticoduodenectomy have reported SSI rates as high as 18.4% in multicenter studies

(Matsuda et al., 2023; Stryja et al., 2020; Yamamoto et al., 2020). Similarly, studies conducted in low- and middle-income countries demonstrate considerable variation in SSI prevalence. For example, the prevalence of postoperative SSIs was reported as 9.2% in Bale Zone general hospitals in Ethiopia, whereas studies from Rwanda documented a prevalence of 30.6%, highlighting the influence of healthcare resources, surveillance quality, and infection prevention practices (Badeso, 2022; Niyomugabo et al., 2024). In spine surgery, shortages of cefazolin and the use of alternative prophylactic antibiotics have been associated with increased rates of reoperation for deep SSIs, emphasizing the importance of appropriate antibiotic prophylaxis (Nakarai et al., 2021). Among obstetric patients undergoing cesarean delivery, SSI prevalence has been reported to range between 3% and 15% across different geographical regions, reflecting variations in perioperative care standards, antibiotic prophylaxis, and infection control practices (Badeso, 2022; Bizuayew et al., 2021; Kebede et al., 2024; Mueller et al., 2022).

4. Prevention of Surgical Site Infections

The prevention of SSIs requires a comprehensive, evidence-based approach that spans the preoperative, intraoperative, and postoperative phases of patient care. During the preoperative period, adherence to internationally recognized guidelines issued by organizations such as the WHO, CDC, National Healthcare Safety Network (NHSN), ACS, and SIS forms the foundation of effective SSI prevention. Consistent implementation of these recommendations has been associated with significant reductions in infection rates across various healthcare settings (Hebballi et al., 2024; Mueller et al., 2022; Rosa et al., 2023; Stryja et al., 2020).

Preoperative patient optimization is an essential strategy for reducing SSI risk. Appropriate management of diabetes through glycemic control, correction of anemia, nutritional optimization, smoking cessation, and treatment of other modifiable comorbidities contribute significantly to improved surgical outcomes and reduced postoperative infections (Kebede et al., 2024; Matsuda et al., 2023). Proper skin preparation, careful wound cleansing, and administration of prophylactic antibiotics within the recommended time frame before incision are also fundamental components of SSI prevention. Numerous studies have demonstrated that delayed or inappropriate antibiotic prophylaxis substantially increases the risk of postoperative infections (Fry, 2013; Matsuda et al., 2023; Rosenberger et al., 2011).

During the intraoperative period, timely administration of prophylactic antibiotics remains one of the most effective preventive measures. Selection of antibiotics according to established guidelines, combined with appropriate timing and dosage, significantly reduces SSI incidence. Research has shown that shortages of first-line antibiotics such as cefazolin and substitution with broader-spectrum agents may lead to increased SSI rates, particularly in spinal surgery, emphasizing the importance of antibiotic stewardship (Mueller et al., 2022; Nakarai et al., 2021; Rosenberger et al., 2011). Intraoperative wound irrigation has also been investigated as a preventive strategy. Clinical trials comparing gentamicin-saline irrigation with normal saline have reported inconsistent findings, with some studies suggesting lower infection rates using antibiotic irrigation, although these differences often fail to reach statistical significance. These findings indicate that wound irrigation alone is unlikely to prevent SSIs without comprehensive infection prevention strategies addressing patient risk factors and surgical technique. Additional interventions, including peritoneal irrigation using oxidizing solutions, are currently being evaluated through protocols such as the PAISI trial, representing an emerging area of research aimed at reducing organ-space infections (Mueller et al., 2022). Furthermore, systematic reviews have found insufficient evidence to support the superiority of any particular postoperative wound dressing for SSI prevention, suggesting that dressing selection should be individualized based on patient and surgical characteristics while remaining integrated within standardized wound care protocols (Stryja et al., 2020).

Postoperative prevention focuses primarily on surveillance, early diagnosis, and prompt management of infections. Continuous SSI surveillance programs, coupled with regular feedback to surgical teams, have consistently demonstrated reductions in infection rates through improved compliance with preventive measures (Li et al., 2018; Stryja et al., 2020). Early recognition of postoperative infections, followed by prompt microbiological evaluation, appropriate antimicrobial therapy, and multidisciplinary management, is essential for minimizing complications and preventing recurrence (Hebballi et al., 2024; Rosa et al., 2023; Stryja et al., 2020). Since many SSIs become clinically apparent only after hospital discharge, structured post-discharge surveillance programs and comprehensive patient education regarding wound care and warning signs are increasingly recognized as critical components of modern SSI prevention

strategies, particularly following colorectal and abdominal surgeries (Fry, 2013; Li et al., 2018; Malheiro et al., 2021).

5. Management strategies for SSIs (clinical care after infection is established)

Accurate classification and diagnosis are essential for the effective management of surgical site infections (SSIs). Standardized diagnostic criteria established by the Centers for Disease Control and Prevention (CDC) and the National Nosocomial Infections Surveillance (NNIS) system provide a consistent framework for classifying SSIs as superficial incisional, deep incisional, or organ/space infections. This classification not only facilitates uniform reporting and surveillance but also determines the intensity of treatment and helps predict patient prognosis. Correct identification of the depth and extent of infection enables clinicians to select appropriate therapeutic interventions, ranging from local wound care for superficial infections to surgical drainage and prolonged antimicrobial therapy for deep or organ-space infections (Fry, 2013; Stryja et al., 2020).

The successful management of SSIs requires a multidisciplinary approach involving surgeons, infectious disease specialists, microbiologists, infection prevention teams, nursing staff, and critical care specialists when necessary. Collaboration among these healthcare professionals ensures timely microbiological investigations, appropriate selection of antimicrobial therapy, effective wound management, and informed decisions regarding surgical drainage or debridement. Current clinical guidelines strongly recommend involving microbiology services to guide culture-directed antibiotic therapy, optimize antimicrobial stewardship, and minimize the development of antimicrobial resistance while improving patient outcomes (Hebballi et al., 2024; Stryja et al., 2020).

Surgical site infections have significant clinical, economic, and healthcare consequences. Patients who develop SSIs frequently experience prolonged hospital stays, increased healthcare costs, higher rates of hospital readmission, and an increased need for additional surgical procedures such as wound debridement or reoperation. In specialized surgical fields, including spine and esophageal surgery, SSIs have been associated with delayed recovery, poorer functional outcomes, and, in oncological procedures, reduced long-term survival and compromised cancer-related outcomes. These adverse effects highlight the substantial burden

imposed by SSIs on both patients and healthcare systems and emphasize the critical importance of evidence-based prevention strategies, early diagnosis, and prompt multidisciplinary management to improve surgical outcomes and reduce healthcare expenditures (Matsuda et al., 2023; Willacy, 2021).

6. Gaps and Future Directions in the Evidence

Despite substantial advances in the prevention and management of surgical site infections (SSIs), several important gaps remain in the existing evidence. Considerable variability in SSI incidence has been reported across different surgical procedures, healthcare institutions, and geographical regions. These differences are influenced by variations in patient characteristics, surgical complexity, surveillance methodologies, diagnostic definitions, and adherence to infection prevention guidelines. Consequently, SSI prevention strategies should be tailored to local healthcare settings rather than relying solely on universal approaches. Context-specific interventions that consider institutional resources, patient populations, and regional healthcare practices are likely to be more effective in reducing SSI rates (Badeso, 2022; Fry, 2013; Malheiro et al., 2021).

Another area of uncertainty involves the effectiveness of several intraoperative adjunctive interventions. Techniques such as topical antibiotic wound irrigation, negative pressure wound therapy (NPWT), particularly following cesarean section, and other advanced wound management strategies have shown promising results in some studies. However, the available evidence remains inconsistent across different surgical specialties and patient populations. While certain investigations have demonstrated reductions in SSI incidence, others have reported minimal or no significant benefit. These conflicting findings indicate the need for large, high-quality, randomized controlled trials that evaluate these interventions in specific surgical procedures to establish clear clinical recommendations (Guo et al., 2021; Matsuda et al., 2023; Mueller et al., 2022).

Furthermore, evidence suggests that simply implementing surgical safety checklists or standardized documentation protocols may not be sufficient to reduce SSI rates. Although adherence to infection prevention guidelines is an important component of quality surgical care, several studies have found no consistent association between checklist compliance alone and

lower SSI incidence in certain clinical settings. These findings imply that successful SSI prevention requires comprehensive implementation programs that incorporate continuous staff education, multidisciplinary collaboration, organizational commitment, regular surveillance, performance feedback, and a strong institutional culture focused on patient safety and infection prevention. Therefore, future research should not only evaluate individual preventive interventions but also investigate system-level strategies that promote sustainable improvements in surgical quality and infection control (Pereira et al., 2023).

7. Practical Implications for Clinical Practice and Healthcare Policy

The prevention of surgical site infections (SSIs) requires sustained implementation of comprehensive, evidence-based infection prevention strategies throughout the entire perioperative continuum. Healthcare institutions should adopt and consistently follow internationally recognized guidelines developed by organizations such as the World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC), the American College of Surgeons (ACS), the Surgical Infection Society (SIS), and the Society for Healthcare Epidemiology of America (SHEA). While these guidelines provide standardized recommendations, their implementation should be adapted to local healthcare settings, available resources, patient populations, and institutional practices to maximize their effectiveness and sustainability (Hebballi et al., 2024; Mueller et al., 2022; Rosa et al., 2023; Stryja et al., 2020).

Healthcare systems should also prioritize comprehensive preoperative optimization programs aimed at addressing modifiable patient-related risk factors. Strategies such as effective diabetes management, weight reduction for obese patients, correction of anemia, nutritional support, and smoking cessation should be incorporated into routine preoperative care. The use of standardized preoperative risk assessment tools can help identify patients at high risk for developing SSIs, allowing healthcare providers to implement targeted preventive interventions before surgery. Such personalized risk-based approaches have the potential to improve surgical outcomes while reducing postoperative complications and healthcare costs (Badeso, 2022; Fry, 2013; Kebede et al., 2024).

Another critical priority is the implementation of robust perioperative antibiotic stewardship programs. Appropriate selection of prophylactic antibiotics, administration within the

recommended pre-incision time window, and avoidance of unnecessarily prolonged antibiotic therapy are essential to minimizing SSI risk while reducing the emergence of antimicrobial resistance. Healthcare organizations should also ensure reliable supply chains for first-line prophylactic antibiotics to prevent the need for broader-spectrum alternatives, which may contribute to increased resistance and less favorable clinical outcomes. Continuous monitoring of antibiotic prescribing practices and adherence to evidence-based protocols should form an integral part of institutional quality improvement initiatives (Nakarai et al., 2021; Rosenberger et al., 2011).

Finally, strengthening SSI surveillance systems is fundamental to improving patient safety and surgical quality. Comprehensive surveillance should extend from the preoperative period through hospitalization and continue after patient discharge, as many SSIs become clinically apparent only after patients leave the hospital. Regular collection, analysis, and reporting of SSI data should be accompanied by timely feedback to surgical teams, enabling continuous evaluation of preventive practices and early identification of areas requiring improvement. Benchmarking institutional performance against national and international standards can further support quality improvement initiatives, enhance accountability, and facilitate evidence-based policy development aimed at reducing the overall burden of surgical site infections (Fry, 2013; Malheiro et al., 2021; Stryja et al., 2020).

8. Conclusion

SSIs embody a multifactorial and context-dependent perioperative complication whose prevention requires a harmonized, evidence-based approach spanning preoperative optimization, intraoperative technique, and postoperative surveillance. The convergence of guidelines, patient-level risk modification, meticulous surgical practice, and robust surveillance is consistently associated with reductions in SSI burden, though heterogeneity remains across procedures and health systems. Ongoing research is needed to clarify the effectiveness of specific intraoperative adjuncts and to refine risk stratification models that can guide targeted prevention and management initiatives.

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