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Review Article

Surgical site infection prevention: best practices and new approaches

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ABSTRACT

Surgical site infections (SSIs) remain a significant challenge in surgical care, posing a substantial threat to postoperative morbidity and mortality. There are many risk factors that can cause SSIs, encompassing patient-related factors and healthcare team practices. The risk factors for SSIs include advanced age, diabetes, smoking, obesity, distant site infections, elevated biomarkers, low HDL levels, opioid addiction, immunosuppressive drug use, higher ASA grade, comorbidities, prolonged preoperative hospitalization, and antibiotic resistance. Preoperative, intraoperative, and postoperative precautions have all been used as part of comprehensive preventative efforts to reduce the incidence of SSIs. Furthermore, emerging technologies, such as artificial intelligence and machine learning, have demonstrated potential in enhancing SSI detection and prevention, offering promising advancements to further optimize surgical outcomes. This review aims to explore the current evidence, risk factors, and emerging strategies in SSI prevention. By understanding the multifactorial nature of SSIs and implementing comprehensive preventive measures, healthcare providers can significantly mitigate the burden of these infections, ultimately improving patient outcomes and the overall quality of surgical care.

Keywords: Surgical site infection, Antibiotics, Prevention, Antibiotic resistance

INTRODUCTION

Healthcare-associated infections are a leading cause of adverse events globally, posing significant challenges to patient safety. Among these, SSIs are particularly prevalent, occurring at the site of an incision, within deeper tissues, or involving organs and cavities. These infections typically arise within 30 to 90 days after surgery and are directly associated with surgical interventions.[1,2] SSI continues to be a major source of morbidity and mortality among surgical patients. Overall cumulative incidence of SSI was estimated to be 2.5%. The highest incidence was found in the African Region.[3] SSIs immensely affect mortality and morbidity rates, representing 77% of postoperative deaths.[4]

SSI is the most well-known complication of postoperative procedures, and it causes mental and physical suffering in patients with delayed recovery. SSI is associated with numerous detrimental effects leading to higher healthcare-related costs due to prolonged hospitalizations and added surgical costs. The intricate nature of the disease poses challenges to both medical and surgical management, resulting in elevated morbidity and mortality rates.[5-7]

SSIs are classified based on the depth of the infection inside the incision. Accordingly, it is either a superficial infection if the infection only affects the cutaneous and subcutaneous layer, a deep infection if it affects the muscles and fascia, or an extended infection if the infection reaches an organ or an interstitial space.[2] SSI are primarily endogenous, occurring when hospital- or community-acquired bacteria contaminate surgical sites or implanted medical devices. Common endogenous microorganisms include *Staphylococcus aureus*, coagulase-negative *Staphylococci*, *Enterococcus*, and *Escherichia coli*. SSI can be exogenous, in which the microorganisms are transmitted to the body from the surrounding environments, usually in environments where sterilization is not optimal. Exogenous sources of SSI include the surgical team, operating room environment, and tools used during surgery. Medical implants can also be colonized by pathogens, leading to infections in dental, respiratory, or urinary tracts. Exogenous sources include cerebrospinal fluid shunt infections, which can occur during surgery or through blood infection.[2,8,9]

SSIs are largely preventable, and effective prevention strategies can significantly reduce patient morbidity and healthcare burden. By successfully mitigating SSIs, healthcare teams can minimize the length of hospital stays, lower treatment costs, and reduce the need for extensive postoperative care.[10]

Over the years, several evidence-based guidelines have been developed to reduce the incidence of SSIs. These guidelines encompass preoperative, intraoperative, and postoperative measures aimed at minimizing infection risks. The prevention and management of infections throughout the surgical pathway should consistently prioritize collaboration among all healthcare professionals, ensuring the extensive dissemination of best practices and the sharing of knowledge. Emerging and innovative approaches are also being explored to enhance SSI prevention. These include advanced surgical techniques, antimicrobial-coated implants and sutures, and the use of artificial intelligence and machine learning for risk prediction and real-time monitoring.

This review aims to synthesize the current evidence, risk factors, and emerging strategies in SSI prevention. By understanding the multifactorial nature of SSIs and implementing comprehensive preventive measures, healthcare providers can significantly mitigate the burden of these infections, ultimately improving patient outcomes and the overall quality of surgical care.

LITERATURE SEARCH

This narrative review is based on a comprehensive literature search conducted on 18 December 2024 in the DynaMed, ScienceDirect, PubMed, Wiley Library, Spine journal, MDPI, Oxford academic, journal of parenteral and enteral nutrition, BMC, journal of the American college of surgeons, and Cochrane databases. Utilizing medical subject headings and relevant keywords, the search aimed to identify studies discussing the best measures taken to prevent SSIs and the expected future approaches. Supplemental searches, including reference searches, manual searches, and Google Scholar searches, were conducted to identify additional relevant studies. No filters were applied regarding publication year, patient demographics, language, or type of publication, ensuring a broad exploration of the available studies.

DISCUSSION

Clinical presentation and classification of SSI

SSIs typically present with a range of clinical signs and symptoms, depending on the severity and depth of the infection. Common symptoms include localized redness (erythema), warmth, swelling (induration), and pain at the surgical incision site. Also, purulent wound drainage and separation of the wound may happen. Majority cases have systemic signs of infection such as fever and leukocytosis. Delayed wound healing or the appearance of necrotic tissue around the incision site may also indicate infection. These symptoms vary depending on the host's immunity and health conditions, the surgical site, and the time passed after the surgery.[11,12]

The centers for disease control and prevention classifies wounds into four categories based on cleanliness and the presence of infection. Class I refers to clean, non-inflamed, closed wounds without the involvement of any organ systems. Class II includes clean-contaminated wounds involving systems such as the respiratory, gastrointestinal, or urinary tract; these wounds are considered clean-contaminated as they do not exhibit infection or contamination. Class III involves contaminated wounds where there is a breach in sterile technique during surgery or spillage from the gastrointestinal tract, often leading to inflamed incisions. Finally, Class IV represents infected wounds, typically resulting from non-sterile operating conditions.[10]

Preoperative, intraoperative, and postoperative risk factors

Several factors can increase a patient's risk of developing an SSI. These include advanced age, as elderly patients are particularly vulnerable due to a decline in immune function, and diabetes, which predisposes individuals to infections because of impaired wound healing and hyperglycemia. Lifestyle factors such as smoking and obesity also contribute to SSI risk, with obesity associated with an increased amount of adipose tissue in the body that can impede immune response. The presence of infections at distant sites unrelated to the surgical field further elevates the likelihood of SSIs. Additionally, elevated blood biomarkers, such as C-reactive protein levels, blood urea levels, erythrocyte sedimentation rate, and low high-density lipoprotein levels, have been linked to increased susceptibility. Other contributing factors include opioid addiction, which impairs immunity and healing.[2,13,14]

Additional factors influencing SSI risk are the use of immunosuppressive drugs, a higher American Society of Anesthesiologists grade (used to assess a patient's health prior to surgery), and the presence of comorbidities, where patients suffer from more than one chronic condition. Prolonged preoperative hospitalization, particularly for eight days or more, has been shown to increase SSI risk up to tenfold. Furthermore, the presence of antibiotic-resistant organisms poses a significant challenge in managing and preventing SSIs.[15-17]

Risk factors extend beyond patient-related issues; they also encompass various elements influenced by healthcare teams, including surgical scrubbing prior to the procedure, skin disinfection before surgery, patient preparation and hair removal, administration of appropriate prophylactic antibiotics, ventilation of the operating room, sterilization of instruments, prevention of contamination at the surgical site, maintenance of hemostasis, regulation of blood sugar levels, oxygen saturation, and body temperature, as well as avoidance of tissue trauma.[2,15]

Traditionally, postoperative factors have been regarded as having a relatively minimal impact on the development of SSIs. Microorganisms in blood cultures, respiratory insufficiency, and ICU stay were independent risk factors for the development of SSIs. Additionally, lack of patient adherence to the post-operative instructions regarding the surgery, medication, and how to deal with the wound, in addition to the inappropriate care of the wound, can lead to an SSI.[2]

Established best practices for SSI prevention

Preoperative measures

Staphylococcus aureus, the most common microorganism causing SSIs, is an endogenous bacterium associated with nosocomial infections, and its identification through nasal screening or polymerase chain reaction testing followed by decolonization is pivotal for prevention.[18,19] Preoperative nasal decolonization is performed with mupirocin topical antibiotic ointment when *S. auruses* presence is identified. Endogenous colonization of *S. aureus* has been associated with a two-to-nine times higher risk of SSI.[20] Patients colonized with *S. aureus* should undergo decolonization with intranasal mupirocin, either with or without a chlorhexidine bath, prior to the surgery, majorly in cardiothoracic and orthopedic surgeries.[21]

Preoperative bathing or showering with an antiseptic skin cleanser is a widely recognized practice aimed at reducing skin bacterial load, thereby lowering the risk of SSIs.[19]

Doctors administer prophylactic antibiotics to patients before surgery to maintain a safe and clean wound and to reduce the risk of infection, whether intraoperative or postoperative.[15,22] Introducing surgical prophylactic antibiotics is recommended in class II (clean-contaminated), III (contaminated), and IV (infected) wounds.[19] SSIs represent 1.3 to 2.9% of class I wounds, 2.4-7.7% of class II wounds, 6.4-15.2% of class III wounds, and 7.7-40% of class IV wounds.[15] These data show us the importance of prophylactic antibiotics as an established perioperative routine.

The prophylactic antibiotic is chosen according to the type and site of the surgery and which spectrum of microorganisms it covers.[15] Doctors determine the dose based on age, health status, and type of the operation. The timing of administration of the antibiotic depends on its type and pharmacological properties. The most used prophylactic antibiotics are cephalosporins and they are introduced to the patient 1 hour before surgery so they peak during the surgery while the incision is still open.[15]

Antibiotic resistance is another factor that faces doctors when trying to follow the guidelines and administer prophylactic antibiotics. The most common antibiotic-resistant strain is methicillin-resistant *Staphylococcus aureus* (MRSA). Screening patients for MRSA colonization is essential. If found, a broader-spectrum antibiotic that is efficient against this strain is chosen. Vancomycin is the recommended medication in this instance.[19] If the patient has multidrug-resistant organisms (MDR-Os), the doctors tend to base their decision on the type of prophylactic agent they want to administer on the health status of the patient, the site of surgery, the type of procedure, and whether the patient is receiving other antimicrobial agents.[19]

Intraoperative measures

Hair removal is a routine practice prior to surgery, where hair is removed from the surgical site to minimize the risk of infection. Judith Tanner and Kate Melen reviewed 19 studies and found that there were 17 more SSIs per 1000 patients who removed hair with razors in comparison with patients who didn't remove hair.[23] According to their findings, hair removal with clippers and cream may not significantly impact SSIs, while razor removal likely increases infection risks.

For surgical skin preparation, a mixture of alcohol and chlorhexidine gluconate (CHG-alcohol) is advised in order to avoid SSI. There is disagreement over the CHG compound's concentration for SSI prevention, despite the fact that more than 1% CHG-alcohol is advised to avoid catheter-related bloodstream infections.[24] However, a recent meta-analysis highlighted the effectiveness of alcohol-based CHG solutions with a concentration of 0.5% or higher for surgical skin preparation in preventing SSIs. The study demonstrated that the risk ratios (RRs) of SSIs for 0.5% and 2.0% CHG-alcohol solutions were significantly lower compared to povidone-iodine. Specifically, the RR for 0.5% CHG-alcohol was 0.71 (95% CI: 0.52-0.97), while the RR for 2.0% CHG-alcohol was 0.52 (95% CI: 0.31-0.86). These findings emphasize the superior efficacy of alcohol-based CHG solutions with a concentration of 0.5% or higher in reducing SSIs, reinforcing their recommendation as an optimal choice for surgical skin preparation.[25]

Other important intraoperative measures include the provision of supplemental oxygen to maintain hemoglobin saturation levels of 95% or higher. Although this measure is commonly practiced, a meta-analysis of seven randomized clinical trials found no significant difference in SSI rates between patients who received perioperative oxygen (continued for two hours postoperatively) and those who did not.[22] The use of antimicrobial sutures, impregnated with broad-spectrum antibiotics, is another effective strategy. These specialized sutures have been shown to reduce SSIs by 30-33%, making them a valuable tool in preventing postoperative infections.[26] Additionally, maintaining optimal intraoperative conditions, including temperature, air circulation, and sterility, is imperative for preventing wound infections.

Postoperative measures

Postoperative wound infections can be reduced by using appropriate scrubbing techniques and double gloving. During the post-operative wound assessment, healthcare professionals evaluate for indicators such as fever, hematoma, seroma, wound edge separation, and the presence of purulent discharge. If wound infection is suspected, active management should be considered, including culture and sensitivity tests, antibiotic therapy, and tissue removal.

Postoperative measures to prevent surgical SSIs include careful management of surgical drains, which should be used sparingly due to limited evidence of their efficacy and potential to hinder patient mobility. Various strategies, such as antibiotic irrigation, topical antimicrobial gels, antibiotic-impregnated sutures, and antiseptic dressings, have been explored, but definitive evidence of their effectiveness remains lacking. Delayed primary closure, often used in contaminated cases, has not shown significant clinical benefits according to meta-analyses.[27]

For severely infected wounds, prophylactic negative-pressure wound therapy (NPWT) may be useful in preventing SSI.[28] Tailored antibiotic selection based on the surgical procedure and common pathogens is critical. While the choice of surgical dressings for closed incisions does not significantly impact SSI rates, prophylactic wound protectors, particularly in laparoscopic, laparotomic, and orthopedic procedures, have shown promise in reducing infection risk.

As previously mentioned, antibiotic resistance is a challenge that faces doctors in their attempts to administer prophylactic antibiotics, especially since 50% of the cases have staphylococcus aureus-resistant strains.[15] Risk factors for antibiotic resistance include prior hospitalization, prior antibiotic treatments, and preoperative infections. This urges doctors to responsibly use antibiotics to prevent development of resistance. CDC recommends administration of prophylactic antibiotics perioperatively and intraoperatively every 3 hours (in long-standing surgeries) to reduce SSI but doesn't recommend administering them after surgery.[29] MDR-Os are emerging as significant cause of SSIs. Antibiotic misuse and the development of MDR-Os can only be decreased by using antibiotics under cultural guidance.[30]

Emerging and innovative approaches in SSI prevention

The prevention of SSIs has seen significant advancements with the introduction of emerging and innovative approaches. The best way to avoid infections linked to medical implants is with coatings based on antibiotics; however, this decade will see a breakthrough in the optimization of medicines' controlled release. Polymers demonstrate remarkable potential in implant coatings by enhancing biocompatibility and enabling the controlled release of antimicrobial agents.[31] Another approach is the innovations in the dressings of the wound, and it plays a pivotal role in preventing the infection of the wound and accelerating its healing.

Wound healing and prevention of SSI have been enhanced through various dressings and coatings, such as hydrogels and affinity-based drug delivery polymers. Hydrogels balance wound moisture, absorb exudates, and deliver drugs, while affinity-based polymers release antibiotics using cyclodextrin to inhibit bacteria and prevent infection.[32,33] Another promising approach to mitigate SSI risks is antimicrobial-coated sutures. Sutures coated with triclosan can be used to mitigate the severity of these infections.[34]

Phage treatment is a potential remedy for bacterial infections that persist because antibiotic resistance poses a threat to world health. It exhibits few side effects, guaranteeing treatment safety. Enzybiotics derived from phage endolysins have strong antibacterial properties, and genetically modified phages provide improved specificity and effectiveness in the treatment of bacterial infections.[35] Negative pressure wound therapy (NPWT) is an emerging therapeutic technique that applies sub-atmospheric pressure to a wound to decrease the amount of fluid in case of edema, shrink the wound, and bring its edges together, which accelerates wound healing and decreases (Figure 1). Compared to the standard dressing group, the NPWT group had lower risks of both needing surgical wound revision and having SSIs.[36,37] In addition to accelerated wound healing, negative pressure wound therapy reduces the risk for SSI besides decreasing wound dehiscence and seroma.[29]

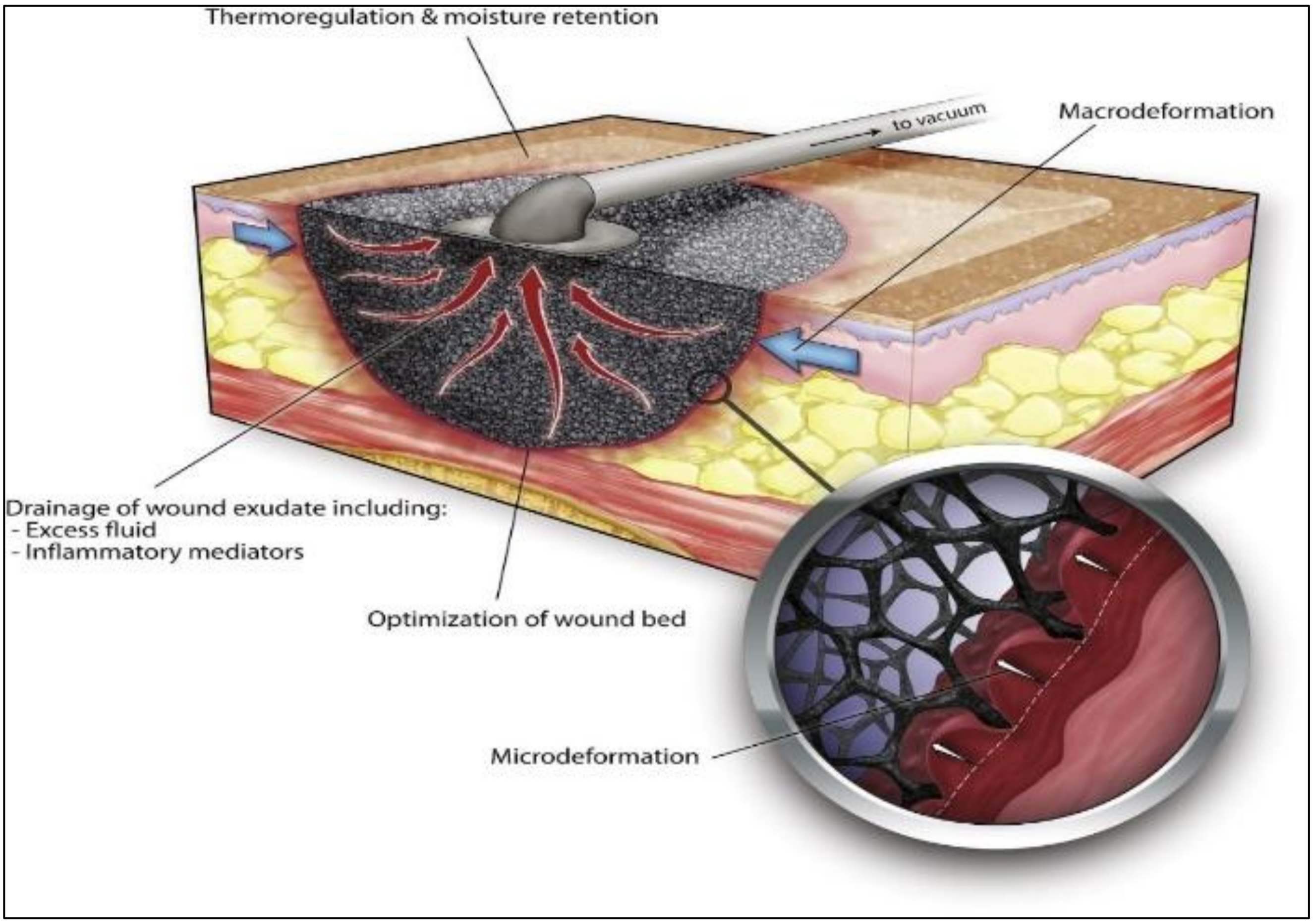

Figure 1: Mechanism and effect of negative pressure wound therapy on the wound-healing process.[36]

Infection surveillance and AI tools

The integration of advanced technologies into healthcare systems has emerged as a promising strategy to support efforts in preventing SSIs.

Postoperative infection surveillance, microorganism detection, and patient adherence to postoperative instructions have been significantly enhanced through technological tools such as machine learning (ML), e-health platforms, smartphones and tablets, and electronic health records. Among these, ML is the most widely implemented technology in SSI prevention.

These innovations offer numerous benefits, including continuous patient monitoring, empowering patients with a sense of control over their health, reducing the workload of healthcare professionals, decreasing the costs associated with SSI diagnosis and treatment, and providing patients with a personalized healthcare experience.[38]

A systematic review conducted by Baddal et al which included 162 studies, highlighted the application of ML and AI in healthcare settings. The review revealed that ML models were particularly useful in intensive care units, where they monitored patients, predicted clinical outcomes postoperatively, and detected infections in real-time. Such predictive capabilities allowed healthcare teams to make informed clinical decisions based on accurate prognostic data.[39] Notably, the university of iowa hospitals and clinics demonstrated a remarkable 74% reduction in SSIs using ML models.[40] Figure 2 illustrates the role of machine learning in detecting infections and predicting the occurrence of hospital acquired infection (HAI) Despite these advances, several limitations hinder the widespread adoption of these technologies. Vulnerable and geriatric patients often face challenges in utilizing these tools, while healthcare providers may lack adequate training to operate the systems or educate patients on their use. Furthermore, patient privacy and data security remain critical concerns in the implementation of AI-driven solutions.[38]

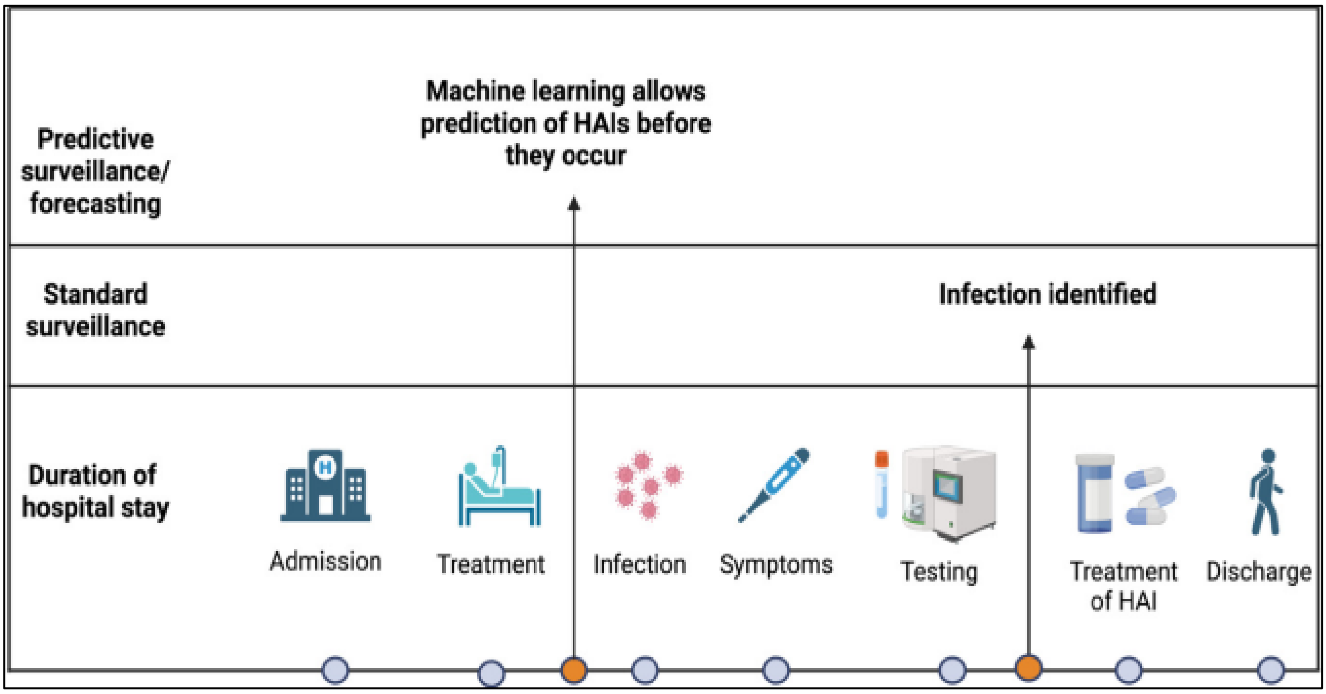

Figure 2: The role of machine learning in detecting infections and predicting the occurrence of HAI.[39]

CONCLUSION

SSI prevention is a top priority goal for health care organizations since it contributes to increased morbidity, mortality, longer hospital stays, and higher hospital expenses. However, effective prevention strategies can substantially mitigate these adverse outcomes. Comprehensive approaches that include preoperative, intraoperative, and postoperative measures have demonstrated success in reducing the risk of SSIs. Best practices and the incorporation of AI tools like ML are effective for infection control.

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