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Review

Surgical Site Infections: A Comprehensive Review

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Abstract: Surgical site infections are an important public health problem leading to increased morbidity and mortality and healthcare costs across the globe. The paper provides a systematic review of the epidemiology, classification, risk factors, microbiological aspects, treatment modalities, and prevention strategies of surgical site infections based on contemporary research and evidence-based practice protocols. Some of the more salient global concerns identified by surgical site infections have been antibiotic resistance and the contamination of surgical instruments, especially in resource-poor settings. These reports underscore the importance of preventive measures, such as appropriate preoperative interventions, strict use of aseptic technique, and appropriate antibiotic prophylaxis, in making the incidence of SSIs and patient outcomes improve better.

Keywords: surgical site infections; antibiotic resistance; *Staphylococcus aureus*; surgical instrument contamination; sterilization

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1. Introduction

Surgical site infections (SSIs) are infections that appear at the incision site of a surgery within 30 days of its execution or, after a year of in case implantation [1]. This type of infections gives major challenges to healthcare worldwide as it accounts for a significant percentage of the hospital-acquired infections and puts more risks and burden on the patients, infrastructure, and society at large [2]. To the surgical patients, majority of the nosocomial infection is ascribed to be the surgical site infections, and account for approximately 20% of total HAIs [3]. The global burden of SSIs is high, and their rate is higher in low- and middle-income countries because of various factors like limitations of resources, infrastructures, and the difficulties in implementing the infection control measures [2]. The growing menace of antimicrobial resistance compounds the SSI management difficulty, thus making infections tougher to treat and thus an impetus for implementing preventable measures and judicious use of antibiotics.

2. Epidemiology of SSIs

The incidence of SSIs varies from 1 to 30% for every surgical procedure type depending on patient-related factors [4]. Of the estimated 157,500 cases of SSIs reported in the US 2018, this went on to claim the life of approximately 8,205 people [5]. Deaths from SSIs amount for 11% of those found in ICUs, hence constituting one of the biggest cause of unplanned admissions for readmission into a health facility after surgery has taken place [6]. These patients are hospitalized longer than their counterparts without infections: 10 to 11 days in excess of those without infection [7]. Lengthy hospital stays naturally lead to elevated resource utilization, such as antibiotic treatment, wound care, and diagnostic testing, all of which raise healthcare costs [8].

An estimation of $3.3 billion is the annual economic burden of SSIs in the American healthcare system alone, and it is much higher worldwide [2]. direct costs, such as extended hospital stays, treatments, and diagnostic testing; and indirect costs, including loss of productivity due to long-term recovery and potential disability are included in this financial burden.

Beyond the economics, there are a variety of poor outcomes for patients with SSIs:

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- Higher risk of ICU admission
- Greater mortality risks (2 to 11 times greater)
- Increased risk of readmission into the hospital by five-fold
- Extended periods of recovery and even possible disability

The high morbidity, mortality, and economic implications of SSIs make prevention measures highly crucial to decrease the incidence of these infections and also enhance patient outcomes.

3. Classification of SSIs

SSIs are classified based on the location and depth of the infection. The three main classifications are:

3.1. Superficial Incisional SSIs

The most common kind of superficial incisional SSIs have been reported for more than 50% of the cases. These infections are merely confined to skin and adjacent subcutaneous tissues over or around the incision [6]. A diagnosis of superficial incisional SSI is one in which the patient will have met one or more of the criteria:

- Purulent discharge from the surgical site
- An organism isolated from a surgical site
- A clinical diagnosis of an SSI by the surgeon
- Intentional incision of the wound by the surgeon with at least one associated symptom such as swelling, erythema, pain, or warmth.

3.2. Deep Incisional SSIs

Deep incisional SSIs go deeper into the tissues below the incision site, to include muscles and fascia surrounding the surgical site. Arise where the infections are deeper than superficial SSIs and therefore, need extensive treatment.

3.3. Organ/Space SSIs

Organ/space SSIs are the rarest yet most serious type of SSI. They are infections beyond the skin, muscle and surrounding tissue directly involved in the procedure affecting organs, or spaces between the organs [9]. A drain placed in a body space or an organ discharges pus for an organ/space SSI or an organ/space abscess. The misguided approach to the diagnosis of life-threatening infections often requires extensive surgical intervention, or prolonged intravenous antibiotics, with long recovery times or with patients suffering debilitating illnesses.

4. Risk Factors for SSIs

Numerous factors can increase the risk of developing an SSI. These factors can be broadly categorized into three groups: patient-related, procedure-related, and external factors.

4.1. Patient-Related Factors

Individual patient characteristics have significant influences on susceptibility to SSI. Some of the important patient-related risk factors are:

- Age: Older adults more than 65 years old have an increased susceptibility to infection with advancing age, largely because of the associated immune dysfunction [10].
- Immunocompromised state: This is characterized by people having a low immune status like HIV/AIDS. People infected with such are highly exposed to SSIs, as their body fails to fight such infections, which is quite complex [11].
- Smoking: Smoking negatively affects the healing process in the body and increases resistance to infections; thus, such people tend to have a risk of experiencing SSIs and other secondary complications [11].

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- Obesity: Individuals with a higher body mass index and obesity have an increased chance of SSIs. These may be because of poor blood circulation and elevated tension on surgical wounds [11].
- Diabetes: Inadequately controlled diabetes is a risk factor for infection as it can make the immune system less efficient in fighting infections.
- Malnutrition: Poor nutrition compromises the immune system and prolongs the healing process of wounds, making a person susceptible to infections.
- Hypovolemia: Low blood volume prevents the tissues from getting sufficient oxygen and nutrients that fight infection, hence preventing it.
- Steroids: The use of steroids over a long period leads to suppression of the immune system, and hence makes an individual prone to infections.
- Previous infections: Infections elsewhere may spread to the surgical site leading to SSIs.
- Prolonged preoperative in-hospital stay: Longer stays before surgery increase the chances of exposure to nosocomially acquired infections [12].
- Poor preoperative skin antisepsis: Poor skin hygiene can double the bacterial load on the skin thus increasing the probability of contamination intra-operatively.

4.2. Procedure-Related Factors

The risk of SSIs is also affected by characteristics of the surgical procedure itself. Important procedure related risk factors are:

- Surgery type: Emergency and internal organ surgeries (clean-contaminated, contaminated and dirty wounds) have a higher SSI risk than clean surgeries, with infection risk increasing with contact with contaminated body sites and fluids [13].
- Duration of surgery: Longer surgical procedures increase the time the wound is exposed, increasing the risk of contamination.
- Open surgery: Open surgeries have larger incisions and greater tissue disruption, with a higher risk of SSIs than laparoscopic procedures.
- Use of drains: Surgical drains may offer a route for bacteria to enter the wound.
- Presence of foreign material: The presence of foreign materials, including implants and prostheses, increases the risk of infection.
- Improper hair removal: Shaving with a razor near the surgical site can cause irritation to the skin and increase the chance of infection; clippers are usually safer than razors [14].
- Hypothermia: Low body temperature during surgery can depress immune function and wound healing.
- Abnormal fluid collection: Hematomas and seromas can create an ideal environment for bacterial growth [15].

4.3. External Factors

Other than the patient and the surgery, there are other extrinsic factors that predispose to SSI risk. These factors include:

- Contamination of surgical site, equipment, or personnel: Poor sterilization or disinfection of instruments, the environment of surgery, or personnel members can introduce bacteria to the wound [16].
- Sharpness of surgical instrument: A dull surgical blade may hold biological materials even after sterilization, which may eventually lead to contamination and SSIs [9].
- Inadequate ventilation in the operating room: The lack of good ventilation in the operating room tends to increase the concentration of airborne bacteria, thus enhancing the possibility of wound contamination [11].
- Increased traffic in the operating room: High people traffic in and out of the operating room increases the possibilities of bringing in contaminants [10].

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Prevention of these risk factors through proper patient preparation, aseptic techniques, appropriate use of antibiotic prophylaxis, and meticulous wound care is important for reducing rates of SSI and improving overall patient outcome.

5. Microbiology of SSIs

SSIs are most commonly caused by bacteria though a variety of microorganisms may cause them. The type of surgery, the patient's current medical conditions, and more importantly, the local level of antibiotic resistance are very important in determining which organisms cause an SSI in a particular patient.

5.1. Common Bacterial Pathogens

The most frequently isolated bacteria in SSIs include:

- *Staphylococcus aureus* (including MRSA)
- *Staphylococcus epidermidis*
- *Streptococcus* species
- *Pseudomonas aeruginosa*
- *Escherichia coli*
- *Enterococcus faecalis*
- *Citrobacter freundii*
- *Bacillus cereus*

S. aureus, including the methicillin-resistant types, MRSA, is one of the most important pathogens in SSIs, particularly in cases related to the heart, breast, eyes, bones, and blood vessels. These microbes are not easily curable because they are resistant to most of the antibiotics applied [10].

Coagulase-negative staphylococci, such as Staphylococcus epidermidis, are normal skin flora, and such organisms cause the majority of SSIs that occur in clean surgical settings [10].

Gram-negative bacteria, particularly *Pseudomonas aeruginosa* and *Escherichia coli*, which also are commonly isolated in SSIs, especially within hospitals. Pseudomonas aeruginosa grows within moist environments. Moreover, it cannot easily be killed by antibiotic methods [12].

Another of the more dangerous pathogens is *Enterococcus faecalis*, whose antibiotic resistance trend is rising. This is a gut commensal that has recently emerged as a cause of SSIs, particularly in surgeries of the abdomen and pelvis.

Citrobacter freundii is an opportunistic pathogen causing the infections, which include SSIs mainly in hospitalized patients [12].

Usually, *Bacillus cereus* is implicated as an environmental contaminant, but increasingly it appears also to be a well-recognized source of nosocomial infection, including SSIs. In the Korle Bu Teaching Hospital study from Ghana, *Bacillus cereus* dominated the bacteria from the sterilized surgical instruments and the parts.

5.2. Surgical Instrument Contamination

Although with proper sterilization techniques, the surgical instrumentation can become contaminated during operation, which can lead to SSIs. It becomes contaminated in contact with the patient skin flora or intestinal microbes [11]. In SSIs outbreak due to contaminated surgical instruments, it is determined by studies that the patient's specimens, outer packaging, and even the instruments themselves carry skin flora like CoNS and *Bacillus* spp. On osteotomes contamination study, all tools tested were seen with bone contaminants, though this varied in amount with coatings [17]. These findings highlight proper sterilization techniques and possible risks associated with contaminated surgical instruments, especially in resource-poor settings where protocols might not be followed strictly.

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6. Treatment of SSIs

The treatment of SSIs depends on various factors, including the type and severity of the infection, the causative microorganisms, and the patient's overall health.

6.1. General Treatment Approaches

Generally, treatment of SSIs is a combination of different methods and the course of treatment is defined by the severity of infection type. Some generally included approaches are:

- Antibiotics: Most SSIs are treated with an antibiotic as the main form of therapy. The choice and type of antibiotic will depend on the suspected agent or identified agent of the infection, severity of illness and patient's medical history among others. If the wound discharges, the culture of pus can be done and sent for sensitivity test for details of etiologic bacteria and the best antibiotic [1,2]. The duration of treatment is according to the severity and response toward infection; usually, an antibiotic treatment requires at least a week's time. Patients can be started on intravenous antibiotics that can later be transitioned to oral antibiotics once the patient's condition improves. The patient should complete the dose of antibiotics prescribed even if the patient feels better because this will ensure that all the infection is eradicated and prevents the development of antibiotic resistance.
- Surgical therapy: Other than antibiotics, in the majority of cases presenting with an obvious collection of pus, necrosis of tissues, or the presence of a foreign body, the patient would require surgical therapy as an adjunct. Surgical management may include:
    - Open the wound: Such improved visualization, cleaning and draining of the infected site.
    - Debridement: The dead or infected tissues, which would stimulate their proliferation and healing, will have to be removed. Mechanical debridement is preferred but even possible with enzymatic agents, only if mechanical debridement would not be used for medical reasons.
    - Irrigation Sterile saline solution irrigates the area to remove bacteria and debris from it.
    - Abscess drainage: If an abscess is present, it must be drained to obtain clearance of an infection.
    - Dressing: Wound dressing with saline-soaked dressings to keep the wound moist and enhance healing.
- Wound care: The wound needs proper care in healing and prevention of its reoccurrence. This can include cleaning, dressing changes, and NPWT, also known as VAC dressings.
- Supportive care: The support cares basically focus on optimizing a patient's overall health and supporting a patient to recover. It encompasses care like pain relief, fluids and electrolyte maintenance, nutritional support.

6.2. Specific Treatment Considerations

- Specific treatment strategies may be adapted depending on the type of SSI and the etiologic microorganisms:
    - Superficial incisional SSIs: These infections can usually be managed with wound care and oral antibiotics.
    - Deep incisional SSIs: Such infections might require surgical debridement and intravenous antibiotics.
    - Organ/space SSIs: These infections typically require extensive surgical intervention, prolonged antibiotic therapy, and intensive care management.
- Management of SSIs caused by specific microorganisms:
    - Gram-positive bacteria: Some gram-positive pathogens include *Staphylococcus aureus*, including MRSA, and *Enterococcus* species. Therapeutic choices include:
        - β-Lactams: Cefazolin is the drug of choice for most SSIs. Nevertheless, other β-lactams like ceftaroline and ceftobiprole can be utilized for treating MRSA infections [16].

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    - Vancomycin: It is an alternative for patients who are allergic to β-lactams or in high MRSA-prevalence settings [14].
    - Daptomycin: This is a lipopeptide antibiotic with a high level of activity against MRSA and other gram-positive bacteria [18].
    - Lipoglycopeptides: Dalbavancin and oritavancin are two long-acting antibiotics which can be administered in single doses for some types of SSIs [3,11].
    - Linezolid: This is an oxazolidinone antibiotic with a wide spectrum of activity against MRSA and other resistant gram-positive bacteria.
- Gram-negative bacteria: Such pathogens include *Escherichia coli*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*. The choice of therapy includes:
    - Third-generation cephalosporins: SSIs due to susceptible gram-negative bacteria are commonly treated with third-generation cephalosporins; namely ceftriaxone and cefotaxime [19].
    - Carbapenems: Other broad-spectrum antibiotics comprise carbapenems like imipenem, meropenem, and doripenem that are active against many gram-negative bacteria. However, use should be limited to critical cases because carbapenems can favor the development of resistance [20].
    - β-Lactam/β-lactamase inhibitor combinations: These include ceftazidime-avibactam, ceftolozane-tazobactam, and meropenem-vaborbactam. These are effective against most resistant gram-negative bacteria [21].
    - Cefiderocol: This is a new siderophore cephalosporin that is active against a wide range of gram-negative bacteria, including carbapenem-resistant strains [20].
    - Tigecycline: This is a glycylcycline antibiotic that is active against most MDR gram-negative bacteria [20].
    - Colistin: This is an older antibiotic reserved for infections caused by MDR gram-negative bacteria that are resistant to other antibiotics [19].

Other considerations:

- Combination therapy: For infections caused by MDR bacteria or to boost the effectiveness of a particular antibiotic, antibiotics can be administered in combination.
- Duration of therapy: The duration of antibiotic therapy varies with the severity and type of SSI. Superficial SSIs may require only a few days of antibiotics, while deep or organ/space SSIs may require weeks or even months of treatment.

It is worth noting that the information contained herein is for general knowledge only and is not to be construed as medical advice. The particular treatment of an SSI is best determined by a qualified health care provider based on the specific circumstances of the individual patient.

7. Prevention of SSIs

Prevention is a priority in managing SSIs. The implementation of evidence-based practices and compliance with the guidelines are significantly effective for reducing incidence and improving outcomes for these infections. WHO has published guidelines that recommend 29 specific measures for preventing SSIs [22]. The strategies for prevention are diverse and include preoperative interventions, intraoperative measures, and postoperative care.

7.1. Preoperative Interventions

Preoperative interventions seek to optimize the patient's health, decrease the patient's microbial burden, and achieve a clean surgical environment. Key preoperative interventions include:

- Optimizing Patient Health [23]
    - Smoking cessation: Patients who smoke are significantly at risk of SSIs. Quitting smoking a few weeks prior to surgery can greatly improve wound healing and reduce infection risk.

  - Weight management: Patients who are overweight or obese are at higher risk for SSIs. If possible, maintaining a healthy weight before surgery improves outcomes.
  - Control of diabetes: Good blood glucose control is important to achieve optimal wound healing. Patients with diabetes should collaborate with their provider to optimize their management of blood glucose before surgery.
  - Pre-existing infections: Treatment of any pre-existing infections, such as urinary tract infections or skin infections, before surgery can reduce the risk of SSI development.
  - Medication review: Certain medications, like corticosteroids, can suppress the immune system and increase infection risk. Healthcare providers should review the patient's medication list and make adjustments if necessary.
- Reducing Microbial Burden [24]
  - Preoperative hygiene: Patients should shower or bathe with an antiseptic solution, such as chlorhexidine, the night before and/or the morning of surgery. This reduces the number of bacteria on the skin.
  - Hair removal: Hair removal, if required, must be done just before the surgery by clippers rather than shaving to reduce the irritation and micro-abrasions that may enhance infection.
  - Nasal decolonization: Nasal screening for Staphylococcus aureus (including MRSA) can be done for high-risk procedures such as cardiac and orthopedic surgery. Patients with positive results can be given intranasal mupirocin to decrease the bacterial colonization in the nose.
  - Oral hygiene: Proper oral hygiene and professional dental cleaning before surgery can reduce the SSIs, especially after abdominal surgery.
- Provision of a Clean Surgical Environment [25]
  - Antibiotic prophylaxis: Use of the appropriate antibiotics within 60 minutes before surgical incision is used to prevent SSIs through eliminating common pathogens that may cause infection in surgical wounds. Antibiotic selection depends on the type of surgery and risk factors of the patient involved.
  - Sterile technique: Maintaining a high standard of sterile technique by the surgical team would include proper hand hygiene, the use of gloves and gowns, proper manipulation of surgical instruments, to name a few.
  - Environmental control: Optimizing the conditions of the operating room, including appropriate ventilation and air filtration, can help reduce the concentration of airborne bacteria and thus reduce the risk of wound contamination.

7.2. Intraoperative Measures

Intraoperative measures include maintaining a sterile surgical field and reducing the time of surgery.

- Adherence to strict sterile technique: The sterile field must be maintained throughout the procedure. This includes proper hand hygiene, surgical attire, and aseptic handling of instruments and materials.
- Reducing surgical time: The longer the surgical time, the higher the risk of infection. Efficient surgical techniques and careful planning can reduce surgical time.
- Proper tissue handling: Gentle tissue handling minimizes trauma and reduces the risk of infection.
- Hemostasis control: Effective hemostasis prevents the accumulation of blood and serum, which can act as a medium for bacterial growth.
- Wound closure techniques: Proper wound closure techniques, including the right kind of suture material and tension, promotes optimal wound healing and minimizes the risk of infection.

7.3. Postoperative Care

Postoperative care is also important for the prevention of SSIs and wound healing.

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- Care of the wound: Regular cleaning, dressing change, and observation for signs of infection comprise proper wound care.
- Management of pain: Effective pain management fosters patient comfort and ambulation, thus helping with wound healing.
- Early ambulation: As appropriate, early ambulation enhances blood circulation to reduce the occurrence of complications.
- Patient education: Educating patients about proper wound care and signs of infection empowers them to participate in their recovery and seek medical attention if necessary.

Following these comprehensive preventative measures can significantly contribute to a safer surgical experience and improved patient outcomes. Healthcare professionals play a vital role in educating patients about these measures and ensuring their consistent implementation.

8. Global Implications of SSIs

The burden of SSIs is particularly pronounced in resource-limited settings, where factors such as limited access to healthcare, inadequate infrastructure, and challenges in implementing infection control measures contribute to higher infection rates.

8.1. SSI Rates in Low- and Middle-Income Countries

In low- and middle-income countries, the incidence of SSIs is significantly higher, at 11% of surgical patients experiencing infections. In Africa, the rate climbs to 20% for women who undergo caesarean sections [26]. These disparities are probably due to several factors:

- Lack of resources and infrastructure: The lack of adequate healthcare infrastructure, including access to sterile supplies, clean water, and trained healthcare personnel, increases the rate of infection.
- Challenges of implementing the infection control measures: Least resources and minimal training can prevent the implementation of clear infection control protocols.
- Higher prevalence of underlying medical conditions: Malnutrition, HIV/AIDS, and other underlying medical conditions increase susceptibility to infections.

8.2. Antimicrobial Resistance

SSIs are part of the rising danger of antibiotic-resistant bacteria, an international health issue. When infections rise, so does the demand for antibiotics, making the inevitable selection between susceptible and resistant bacteria, and increasing the difficulty in curing those infections [27]. The occurrence and spread of antimicrobial resistance strengthen the case for:

- Prudent use of antibiotics: Providing antibiotics only when necessary and ensuring a patient takes the full course so that resistance does not take place.
- Antimicrobial stewardship programs: Hospital-based programs focused on antimicrobial use as well as the prevention of the spread of resistance.
- Infection prevention and control: Preventing infections at the outset reduces the use of antibiotics and conserves their efficacy.

8.3. Surgical Instrument Contamination

Sterilization of surgical instruments is the key for preventing SSIs, especially in resource-limited settings. However, with sterilization protocols in place, instrumentation can get contaminated during the procedure itself, and the presence of bacterial contamination has been seen even after sterilization as reported by some studies. This means:

- Stringent cleaning, disinfection, and sterilization process: Sterility can be ensured only by following all the strict protocols of the reprocessing of instruments.

- Regular maintenance and quality control: Monitoring the effectiveness of sterilization processes and ensuring equipment is properly maintained is very important.
- Training and education: It is important that healthcare personnel be provided with the proper training on sterilization techniques and infection control measures.

It calls for a multifaceted approach that involves strengthening the infection control infrastructure, judicious use of antibiotics, optimization of patient care, and strict adherence to sterilization protocols. Research, education, and international collaboration are also needed to continue to develop and implement effective preventive strategies and to mitigate the impact of antimicrobial resistance.

9. Research and Future Directions

Further research is required in SSIs to improve the prevention and treatment strategies. Some of the current and future research areas include:

- New prevention methods: New antiseptic solutions, new wound dressings, and surgical techniques that are effective in preventing infections.
- New treatments: The development of new antibiotics and alternative treatment modalities, such as antimicrobial photodynamic therapy and phage therapy, to combat antibiotic resistance.
- Emerging pathogens and resistance: new pathogens being discovered and the continued spread of antibiotic resistance to guide prevention and treatments efforts better.
- Instrument contamination: Developing instruments with better surface properties, research into new methods of sterilization that do not contaminate the instruments.
- Standardization of guidelines and best practice: Standardize guidelines and best practice in prevention and management of SSI especially in resource-poor settings.
- International cooperation and knowledge sharing: Facilitate collaboration and knowledge sharing among researchers, clinicians, and healthcare organizations worldwide for further progress in the fight against SSI.

The thematic outline given by the sources provides a comprehensive framework for better understanding complexities in surgical site infections. A thematic outline may further facilitate research, education, or clinical practice guideline. We can reduce the burden of SSI and foster better patient outcomes worldwide with filled knowledge gaps and translation of the findings to clinical practice.

10. Conclusions

The prevalence of surgical site infections is significant complications from surgery, which pose an ever-increasing threat to patients' health and healthcare systems in general. Knowledge of epidemiology, classification, risk factors, microbiology, treatment, and prevention of SSIs will vary greatly contribute to the proper management of infections for health care professionals and hence improve outcomes for patients. A multifaceted approach including patient education, preoperative optimization, strict adherence to sterile techniques, appropriate antibiotic prophylaxis, and meticulous wound care helps reduce SSI rates. Global burden in the context of SSIs, and more importantly in resource-limited settings, requires a concerted effort in strengthening infection control infrastructure, judicious use of antibiotics, and evidence-based preventive strategies. Continued research, innovation, and international collaboration will advance the understanding of SSIs, the development of novel prevention and treatment strategies, and combat the effects of antimicrobial resistance.

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