Caspian Journal of Surgery
e-ISSN 3115 - 9087
(2026) vol 2: (1)

Review Article

Surgical Site Infections: A Silent Public Health Concern in Surgery

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Background: Surgical site infections (SSIs) represent a significant category of healthcare-associated infections, contributing to increased morbidity, prolonged hospitalisation, and substantial economic burdens.

Aim: This review aims to synthesise current evidence regarding the definition, classification, and risk factors of SSIs, while identifying common pathogens-including multidrug-resistant organisms-and outlining established principles for their management and prevention. Particular emphasis is placed on global guidelines intended to mitigate infection-related morbidity.

Key Findings: SSIs are defined as infections occurring within 30 days post-surgery and are categorised as superficial incisional, deep incisional, or organ/space. Identified risk factors include patient-related variables (e.g., smoking, obesity, advanced age) and procedure-related factors (e.g., prolonged operative time, implant usage, and surgical contamination). *Staphylococcus aureus*, including methicillin-resistant *S. aureus* (MRSA), remains a predominant pathogen. Management strategies necessitate surgical exploration, meticulous microbiological sampling, and targeted antimicrobial therapy. Prevention protocols are structured according to evidence-based recommendations established by the World Health Organization (WHO).

Conclusion: Future clinical and research priorities must focus on enhancing post-discharge surveillance, the rigorous validation of risk-stratification tools, and the conduction of high-quality trials evaluating advanced wound dressings and negative-pressure therapy. A multidisciplinary, integrated approach remains essential to optimising patient outcomes in surgical settings.

Keywords: Surgical site infections (SSIs); Surgery; Infection; Microorganism; Multi-drug resistant; Antimicrobial resistance.

Received:
December14, 2025
Revised:
January20, 2026
Accepted:
January27, 2026
Published on:
March11, 2026

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Introduction

Definition, Prevalence, and Classification of SSI: Surgical site infection (SSI), a frequent postoperative complication, is defined as an infection involving the skin, subcutaneous tissue, or adjacent organs and spaces resulting from a surgical procedure and occurring within 30 days of the operation (1). According to the Centers for Disease Control and Prevention (CDC) surveillance data regarding healthcare-associated infections (HAIs), approximately 110,800 SSIs occurred following inpatient surgeries in 2015 (2). Current reports indicate that SSIs account for 20% of all HAIs and are associated with a more than two-fold increase in mortality risk, with 75% of these deaths being directly attributable to the infection itself (3). Furthermore, SSIs represent the most costly category of HAIs, with an estimated annual economic burden of $3.3 billion; they also prolong hospital stays by

an average of 10 days and significantly increase total hospitalization costs (4).

In accordance with CDC criteria, SSIs are classified into three categories (5).

Superficial incisional SSI: Involves only the skin and subcutaneous tissue, typically presenting with purulent drainage from the superficial incision.

Deep incisional SSI: Involves deeper soft tissues, such as the fascia and muscle layers, associated with purulent drainage from the deep incision.

Organ/space SSI: Involves any anatomical structure-organ or space-other than the incision site that was manipulated during the surgical procedure (6).

All aforementioned categories are diagnosed within 30 days post-surgery, or up to 90 days if an implant is involved (5).

Risk Factors and Aetiological Agents

To effectively mitigate the incidence of SSIs, risk factors are broadly categorised into patient-related (intrinsic) (Figure. 1-A) and procedure-related (extrinsic) factors (Figure. 1-B) (7). Patient-related factors encompass host-specific characteristics—such as comorbidities, immune status, nutritional condition, and lifestyle habits—that increase susceptibility to infection independently of the surgical procedure (8). For instance, patients with diabetes mellitus are at a significantly higher risk due to impaired tissue perfusion, compromised wound healing, and a greater predisposition to preoperative colonization, all of which contribute to elevated rates of postoperative complications (90.

Conversely, procedure-related (extrinsic) factors are associated with surgical practices and perioperative conditions. While these infections typically manifest within 30 days, certain deep-seated infections may occur up to 90 days following surgery, particularly in procedures involving prosthetic implants (7). The relative contribution of intrinsic versus extrinsic factors often varies significantly depending on the specific nature and complexity of the surgery performed (5).

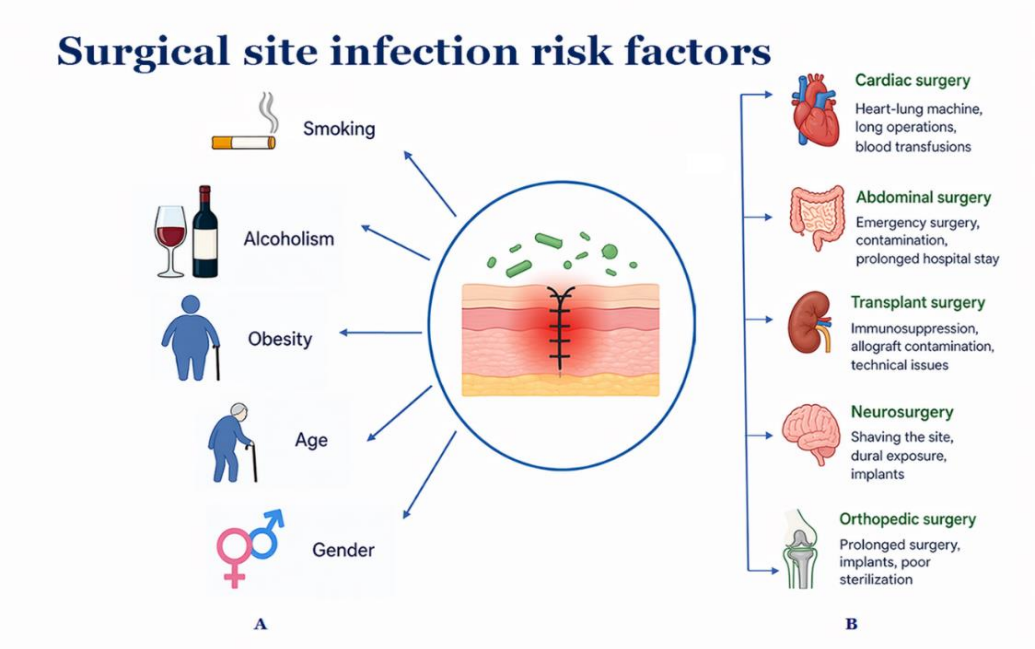

Fig. 1 Patient-related risk factors for Surgical Site Infections (SSIs) include smoking, alcoholism, and obesity (A), all of which impair wound healing and immune function. Smoking reduces tissue oxygen delivery, alcoholism causes malnutrition and weakens immunity, and obesity complicates wound closure and increases infection risk. Age and gender are also relevant intrinsic factors; older patients often have reduced immunity and a higher burden of comorbidities. Procedure-related factors include aspects of the surgical process such as operative technique, duration of surgery, and perioperative conditions (B) all of which directly influence microbial exposure and the likelihood of wound contamination.

Beyond these risk factors, understanding the microbiological aetiology of SSIs is fundamental to developing effective prevention and management strategies. SSIs are most frequently caused by the patient's own endogenous flora (1). The predominant pathogens identified in healthcare-associated SSIs include *Staphylococcus aureus*, *Enterococcus* spp., *Pseudomonas aeruginosa*, *Escherichia coli*, and other members of the *Enterobacteriaceae* family (5). Whilst monomicrobial infections are typical, polymicrobial infections account for more than 20% of cases and are significantly associated with prolonged hospitalization, increased healthcare costs, and elevated rates of morbidity and mortality (10-11).

The distribution of pathogens varies according to the anatomical site and the nature of the surgical procedure. In surgeries involving implants or grafts-such as orthopedic, cardiac, vascular, neurosurgical, and breast procedures-*S. aureus* (including methicillin-resistant strains, MRSA) and coagulase-negative staphylococci (CoNS) are the most frequently isolated organisms. In clean surgeries, *Enterobacteriaceae* account for approximately one-quarter of SSIs, increasing to over 50% in clean-contaminated procedures (12). Abdominal surgeries are typically associated with Gram-negative bacteria and anaerobes, whereas gastro-duodenal procedures often involve *Streptococcus* spp. Urogenital surgeries are predominantly linked to Gram-negative organisms, while obstetric and gynecological procedures commonly involve enterococci, Group B hemolytic streptococci, and anaerobes (13).

The clinical burden of SSIs is further exacerbated by the emergence of multidrug-resistant (MDR) organisms, including MRSA and extended-spectrum beta-lactamase (ESBL)-producing *Enterobacteriaceae (14)*. A significant proportion of isolates originates from abdominal sites; *S. aureus* (39.4%) remains the most common pathogen at surgical sites, likely due to surface contamination from skin and environmental sources leading to nosocomial infections. The presence of coliforms (14.3%), *Proteus mirabilis* (14.3%), *E. coli* (10.7%), and *Enterobacter* spp. (7.1%) may result from wound contamination by the patient's own endogenous flora, as *E. coli* and coliforms are primary inhabitants of the gastrointestinal tract (6).

In addition to summarising the definitions, risk factors, and aetiological agents of SSIs, this review aims to achieve three complementary objectives. First, it critically evaluates the evidence supporting current preventive strategies, including antiseptic bathing, the use of antimicrobial-coated materials, and negative-pressure wound therapy. Second, it explores emerging-albeit less established-interventions, such as the use of probiotics. Third, it identifies persistent knowledge gaps, particularly regarding post-discharge surveillance, the validation of clinical risk-assessment tools, and the requirement for high-quality clinical trials to advance SSI research and improve surgical outcomes.

Drug Sensitivity Patterns of Bacteria Isolated from SSIs

Commonly utilized preoperative antibiotics include gentamicin, penicillin, amoxicillin, ampicillin, and metronidazole, largely owing to their long-standing availability, cost-effectiveness, and ease of accessibility.[15] Understanding the prevalent pathogens and their current antimicrobial susceptibility profiles is critical for the effective management of SSIs (1). Antimicrobial resistance (AMR) significantly escalates complications, treatment expenses, and the duration of hospital stays associated with SSIs (16). Given the high incidence of positive bacterial cultures, stringent infection control measures are imperative to curtail the dissemination of resistant organisms (6).

As previously noted, multidrug resistance was observed in several key organisms, including *S. aureus*, *P. aeruginosa*, and *P. mirabilis* (6). *S. aureus* demonstrated favorable sensitivity to gentamicin, ciprofloxacin, and methicillin, yet exhibited high resistance to ampicillin and erythromycin. The elevated frequency of *S. aureus* infections is attributable to both endogenous sources (e.g., nasal carriage) and environmental contamination of surgical instruments, as disruption of the skin barrier facilitates bacterial translocation to the surgical site.[6] Resistance in MRSA is primarily mediated by the *mecA* gene, which encodes the PBP-2a protein, possessing a low affinity for beta-lactam antibiotics. Additional resistance mechanisms include the production of staphylococcal penicillinase and other enzymes capable of deactivating antibiotics. The presence of mobile genetic elements, such as plasmids, may also contribute to resistance (6). Beyond these genetic factors, *S. aureus* resistance is amplified by the irrational use of antibiotics, over-the-counter sales without prescriptions, the circulation of substandard drug formulations, and the availability of banned products in

certain markets. Consequently, MRSA infections precipitate substantial treatment costs, increased morbidity, and prolonged hospitalization (6).

Susceptibility testing indicated that the majority of Gram-negative isolates were sensitive to gentamicin, ceftazidime, and ciprofloxacin, but resistant to ampicillin, amoxicillin, and chloramphenicol (6). *P. aeruginosa* exhibited sensitivity to gentamicin and ceftazidime but displayed resistance to ciprofloxacin. Resistance to chloramphenicol reached 100%, and only 12.5% of *P. mirabilis* isolates demonstrated sensitivity to amoxicillin. This resistance pattern is likely influenced by factors such as prolonged antibiotic use, oral administration affecting absorption, and frequent prophylactic administration. Notably, ceftazidime and ciprofloxacin, both third-generation cephalosporins, are relatively expensive and less readily available in many healthcare settings (6). In developing countries, resistance rates ranging from 50% to 100% have been reported for commonly used antibiotics like ampicillin, gentamicin, and cephalosporins among *S. aureus*, *E. coli*, and *P. aeruginosa (17)*. Resistance to oxacillin, erythromycin, and clindamycin in *S. aureus* typically ranges from 10% to 60%, whereas resistance to vancomycin, amikacin, piperacillin-tazobactam, and imipenem generally remains below 25% (5). Another study investigating septic postoperative wounds reported the isolation of pathogenic bacteria from 58.5% of specimens. The predominant isolates identified were *S. aureus* (45.1%), coliforms (16.9%), *P. mirabilis* (11.3%), *P. aeruginosa* (9.9%), *Klebsiella pneumoniae* (7.0%), and *Enterobacter* spp. (2.8%) (6).

In summary, gentamicin, ciprofloxacin, and ceftazidime are recommended for the treatment of SSI over ampicillin and amoxicillin. The establishment of national surveillance programs for antibiotic-resistant organisms is urgently needed to guide empirical and targeted therapeutic strategies (6).

Management and prevention of SSI

Surgical management of an SSI is indicated immediately upon diagnosis. Clinical criteria for surgical exploration include the presence of fluid collection in association with systemic or local signs of infection. Diagnostic samples (swab or deep-tissue biopsy) should be obtained for microbiological culture and sensitivity testing prior to the initiation of targeted antimicrobial therapy. The surgical approach is contingent upon the severity of the infection, the involvement of prosthetic materials, and the patient's overall physiological status (18). Current global guidelines for the prevention of SSIs are summarized in Table 1.

Table 1 Key WHO-recommended interventions for the prevention of SSI adapted from the 2016 Global Guidelines. Abbreviation: SSI, surgical site infection; WHO, World Health Organization

Antibiotic therapy

When antimicrobial therapy is indicated for the management of an SSI, clinical decision-making must integrate multiple variables: microbiological culture results, the anatomical site of infection, prior antimicrobial exposure, local resistance patterns, the patient's overall physiological status, and the preferred route of administration. Whenever the patient's clinical stability permits, microbiological sampling should be performed prior to the initiation of empirical therapy to guide targeted treatment (19).

The efficacy of systemic antimicrobial therapy (intravenous or oral) is contingent upon achieving sufficient concentrations at the site of infection. However, skin penetration is frequently suboptimal for many common agents. For instance, most β\betaβ-lactam

antibiotics achieve ≤50%\le50\%≤50% of their serum concentration within skin tissues. Conversely, agents such as meropenem, aztreonam, and fluoroquinolones demonstrate superior tissue penetration; azithromycin exhibits particularly high tissue access, achieving supra-serum levels. Other agents exhibit varying profiles: macrolides primarily concentrate intracellularly, whereas fusidic acid and rifampicin demonstrate poor skin penetration, with the latter achieving only 20% of serum levels. Trimethoprim-sulfamethoxazole achieves concentrations approximately 40–50% of serum levels, and doxycycline demonstrates penetration of approximately 50% (20).

Methodologies for measuring tissue concentration significantly influence these findings. Whilst historical studies utilized blister-based methods-which may lack representative accuracy-modern investigations employing micro dialysis have refined our understanding. Micro dialysis studies indicate that meropenem and doripenem achieve approximately 60% penetration in muscle and subcutaneous tissue; in contrast, ertapenem demonstrates restricted penetration, reaching only 5–10% of plasma area under the curve (AUC). Lipopeptides (daptomycin) and glycopeptides (vancomycin) have shown poor skin penetration via micro dialysis, whereas oxazolidinones (linezolid, tedizolid) and glycylcyclines (tigecycline) achieve tissue concentrations at or above plasma levels. [21] These pharmacological data are critical for SSI management, as suboptimal tissue concentrations not only risk treatment failure but also promote the emergence and dissemination of resistant bacterial strains. Consequently, maximizing tolerated doses is generally recommended, provided the therapeutic index allows for such escalation (with aminoglycosides representing a notable exception requiring cautious dosing). Whether utilizing aggressive, meningitis-level dosing regimens is justified to overcome poor tissue penetration in SSIs remains a subject of ongoing clinical debate.

Topical antibiotics have historically been considered to compensate for poor systemic tissue penetration; however, their contribution to the global rise in antimicrobial resistance remains a significant concern.[22] Systemic agents should be strictly reserved for surgical prophylaxis and the treatment of severe infections in high-risk patients. Whilst topical agents retain utility in specific fields such as ophthalmology, their routine use in general wound management should be discouraged due to the potential for adverse effects and the selection of resistant organisms. Antimicrobial Stewardship Programs (ASPs) are essential to minimize unnecessary prescribing, prevent the use of excessively broad-spectrum regimens, and discourage antibiotic administration for non-infected wounds. The integration of robust infection control measures with comprehensive antimicrobial stewardship is vital to reducing the prevalence of resistant pathogens (23).

Antiseptics bathing

Preoperative antiseptic bathing, typically utilizing chlorhexidine gluconate (CHG), has traditionally been recommended as a strategy to reduce the skin microbial burden and prevent surgical site infections (SSIs). CHG exhibits broad-spectrum activity, including efficacy against resistant organisms, by disrupting cell membrane integrity and increasing permeability. As previously established, SSIs contribute significantly to increased morbidity, mortality, prolonged hospitalization, and substantial economic burdens (24).

Although antiseptic bathing has served as a cornerstone of preoperative infection prevention, the evidence supporting its independent efficacy remains nuanced and subject to debate. The clinical rationale is intuitive: reducing the bacterial load on the skin should, in theory, decrease the risk of SSI. However, high-quality clinical trials and subsequent meta-analyses have consistently demonstrated that preoperative showering or bathing with CHG does not produce a statistically significant reduction in SSI rates when compared with placebo or plain soap. For instance, a meta-analysis of randomized controlled trials concluded that bathing with 4% CHG did not confer a significant reduction in SSI incidence, highlighting limited independent efficacy (25).

Conversely, specific contexts yield divergent findings. A retrospective study in a high-risk population—neonates undergoing surgery-reported a significantly lower SSI rate utilizing a “CHG double-cleansing” protocol (0% vs. 22.6% with iodine, P=0.029P=0.029) with no documented adverse effects.[24] Furthermore, a recent comprehensive meta-analysis of 32 randomized controlled trials (RCTs) indicated that CHG was significantly superior to povidone-iodine in preventing SSIs; however, this observed benefit was primarily driven by clean-contaminated procedures and a reduction in superficial

incisional infections rather than deep-seated or organ/space SSIs (26).

Critically, a distinction must be made between whole-body preoperative bathing and the distinct, mandatory step of preoperative surgical site skin preparation, the latter of which maintains robust and well-established clinical support. Given the currently conflicting evidence base, international guidelines-including those issued by the World Health Organization (WHO) and updated CDC recommendations-have shifted away from prescriptive mandates. Current consensus suggests that CHG bathing should not be abandoned but rather integrated as a component of a multimodal SSI prevention bundle, alongside appropriate surgical skin preparation and judicious antimicrobial prophylaxis (27). The potential clinical utility of CHG bathing in vulnerable subgroups, such as neonates or patients with specific comorbidities, requires further prospective validation.

Probiotics

Surgical procedures often induce alterations in gut microbiota, increase mucosal permeability, and compromise intestinal barrier function, thereby contributing to immune suppression, systemic inflammation, and an elevated risk of postoperative infections and sepsis (28). Whilst standard preventive strategies-including mechanical bowel preparation and perioperative antimicrobial prophylaxis-remain the cornerstone of care, probiotics have emerged as a potential adjunct for mitigating these complications (29).

Clinical investigations suggest that perioperative probiotic supplementation may improve outcomes, particularly in patients undergoing major upper abdominal surgery. Sugawara et al. reported that the administration of symbiotic in hepatobiliary surgery significantly reduced markers of systemic inflammation (e.g., IL-6, white blood cell count, and C-reactive protein), increased the abundance of beneficial Bifidobacterium species, and decreased the incidence of postoperative infections ($P<0.05P<0.05$) (27). Comparable benefits have been observed in gastric resection, liver transplantation, and pylorus-preserving pancreatoduodenectomy, where probiotic use was associated with reduced antibiotic requirements and high patient tolerance (31). Notably, in cases of living-donor liver transplantation, sepsis rates declined significantly from 24% to 4% following the implementation of a probiotic regimen (30) A comprehensive umbrella meta-analysis of 11 studies, involving over 11,500 patients undergoing colorectal surgery, concluded that probiotic administration significantly reduced the incidence of SSIs with high certainty of evidence.[32] These findings position perioperative probiotic supplementation as an effective, safe, and increasingly evidence-based strategy for infection prevention in abdominal surgery.

In the context of obstructive jaundice-a condition characterized by impaired bile flow that disrupts gut microbiota, weakens mucosal barriers, and promotes bacterial translocation-Yao et al. demonstrated that perioperative probiotics successfully restored gut microbial homeostasis, strengthened the intestinal barrier, and reduced postoperative levels of C-reactive protein, IL-6, and endotoxins, ultimately resulting in fewer infectious complications (33). Nevertheless, further large-scale, prospective studies are required to establish optimal dosing and clinical protocols (33).

The modulation of the gut microbiome via perioperative probiotics exerts its protective effects through the competitive exclusion of pathogens, maintenance of intestinal barrier integrity, and the systematic modulation of the host immune response. These immunomodulatory effects are consistent with our previous in vitro evidence, which demonstrated that probiotics modulate inflammatory responses, inhibit biofilm formation, and interfere with the virulence of pathogenic bacteria in oral microbiota models (34). Furthermore, in a cohort study of 200 patients undergoing colorectal surgery, those receiving pre- and postoperative probiotics exhibited improved early gastrointestinal function and shorter hospital stays. Although the reduction in SSI rates in this study did not reach statistical significance due to the limited sample size, the overall improvements in gastrointestinal motility and patient-reported quality of life underscore the potential clinical benefits of this intervention (35).

Future prospective

The accurate determination of surgical site infection (SSI) rates is contingent upon the use of clear, objective diagnostic criteria. Current understanding of both true infection rates and the subsequent post-discharge economic burden remains constrained, underscoring an urgent requirement for enhanced SSI surveillance via standardized methodologies. Risk-stratification tools must

be rigorously validated and applied in a comprehensive manner, accounting for the complex interplay between patient-specific and procedure-related factors rather than evaluating variables in isolation. Whilst SSI prevention "care bundles" have demonstrated efficacy, and adherence monitoring is essential, high-quality evidence supporting several individual interventions remains limited, necessitating further robust clinical trials (36).

Advanced Preventive Technologies

Prophylactic negative-pressure wound therapy (NPWT), specifically closed-incision NPWT (ciNPWT), has gained prominence as a strategy for preventing SSIs in high-risk incisions. This therapy involves the application of a vacuum-assisted dressing to a closed incision to facilitate the removal of exudate, mitigate oedema, and stabilise wound edges. A randomised controlled trial (RCT) assessing incisional NPWT following major lower-limb amputations reported a statistically significant reduction in SSI incidence (16% in the NPWT group versus 51% with standard dressings, P=0.003P=0.003) (37). Another investigation focused on ventral hernia repair observed a lower, albeit not statistically significant, SSI incidence in the ciNPWT cohort (4% versus 12%) (38).

Consequently, while the most compelling evidence currently supports ciNPWT for specific high-risk procedures, it represents a promising adjunctive tool for select patient populations. Broader clinical application awaits further high-quality trials to establish universal efficacy.

Furthermore, antimicrobial-coated materials-including sutures, surgical meshes, and wound dressings-may mitigate SSI risk by the local release of agents such as triclosan or silver ions, which inhibit bacterial colonization and biofilm formation without inducing systemic toxicity (39). A recent second-order meta-analysis demonstrated a significant reduction in SSI rates associated with the use of antimicrobial-coated sutures (40).This is corroborated by an updated meta-analysis of 35 studies, which confirmed a reduction in SSI risk for antimicrobial sutures within RCT settings (41). Whilst evidence suggests that triclosan-coated sutures can significantly lower SSI rates across various surgical disciplines (42). future research must define optimal agents, specific indications, and cost-effectiveness. Despite these promising data, the quality of current evidence is graded as moderate, though it supports the use of these materials as a valuable adjunct in SSI prevention.

Finally, regarding management, early and accurate detection of SSIs is imperative and necessitates a multi-disciplinary, evidence-based approach. Antimicrobial therapy must be guided by microbiological culture results, comprehensive clinical evaluation, and local resistance patterns. Whilst digital photography may assist in diagnostic documentation, it remains inherently subjective; conversely, emerging technologies such as infrared thermography show potential for detecting subtle, infection-related temperature variations (43).

Conclusion

In summary, SSIs impose a substantial burden on both patients and healthcare systems, driven by complex interactions between host-related and procedure-related risk factors, diverse microbial aetiologias, and the escalating challenge of antimicrobial resistance. Effective management necessitates early, reliable diagnosis, timely surgical intervention when indicated, and targeted antibiotic therapy informed by microbiological data and local resistance profiles. Given the suboptimal penetration of many antibiotics into subcutaneous tissues, clinicians should priorities agents with favorable pharmacokinetic profiles-such as oxazolidinones or fluoroquinolones-and consider the administration of maximal tolerated doses where appropriate. The routine use of topical antibiotics should be discouraged, reserved instead for specific superficial infections. Antimicrobial stewardship programs remain critical to minimize unnecessary broad-spectrum antibiotic exposure. Looking forward, this review emphasizes the urgent need for standardized, objective definitions of SSI, refined post-discharge surveillance, and fit-for-purpose risk-stratification tools. High-quality trials are essential to evaluate antiseptic dressings and emerging diagnostic technologies, such as infrared thermography. An integrated, multidisciplinary approach that effectively bridges theoretical frameworks with clinical practice is essential to minimize the incidence and impact of SSIs.

Declaration

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on

reasonable request.

Conflict of interest statement

The authors declare that there are no conflicts of interest related to this study.

Funding information

No funding was received for this study.

Author Contributions

Concept and design: MMA1, MMA2
Analysis and interpretation: MMA1, MMA2
Data collection: MMA1, MMA2
Writing the article: MMA1, MMA2
Critical revision: MMA1
Final approval: MMA1
Statistical analysis: Not applicable
Funding: None
Overall responsibility: MMA1

Acknowledgement

We would like to express our sincere gratitude to the Clinical Research Development Unit of Rohani Hospital, Babol University of Medical Sciences, for their invaluable support in the conduct of this study.

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