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Surgical site infections: etiology, risk factors, and preventive measures – a literature review

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Abstract

Background. Surgical site infections (SSIs) are a leading cause of postoperative complications, affecting up to 11% of surgical patients globally. They result from microbial contamination of wounds and are influenced by patient health, surgical technique, and healthcare conditions.

Aim. To evaluate current knowledge on surgical site infections, including epidemiology, risk factors, pathogenesis, diagnostic approaches, treatment, preventive strategies.

Material and Methods. A comprehensive literature review was conducted using the PubMed database, focusing on English-language studies, more than 70% of the articles referenced were published between 2015 and 2025. Studies were selected based on relevance to epidemiology, pathogenesis, risk factors, diagnosis, and treatment.

Results. Studies show that longer surgeries, poor antisepsis, obesity, and uncontrolled blood sugar increase SSI risk. Rates are highest in low- and middle-income countries. Preventive strategies like timely antibiotics, antiseptic protocols, and negative pressure wound therapy help reduce incidence, though misuse of antibiotics and resistant organisms remain major challenges.

Conclusion. SSIs remain a significant health burden despite preventive advances. Tackling them requires strict infection control, better diagnostic tools, and responsible antibiotic use. Future efforts should focus on biofilm-targeting therapies, risk prediction models, expanding minimally invasive surgery to improve outcomes worldwide.

Keywords: surgical site infections, infection control, surgical wound management, antimicrobial resistance, biofilm formation.

Pooperacinės žaizdos infekcijos: etiologija, rizikos veiksniai ir prevencinės priemonės – literatūros apžvalga

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Santrauka

Įvadas. Chirurginės žaizdos infekcijos (SSI) yra viena pagrindinių pooperacinių komplikacijų priežasčių, paveikiančių iki 11 % pacientų visame pasaulyje. Jos atsiranda dėl mikrobinio žaizdų užteršimo, kurį lemia paciento sveikatos būklė, chirurginė technika ir sveikatos priežiūros sąlygos.

Tyrimo tikslas. Atlikti išsamią pooperacinių infekcijų apžvalgą, vertinant naujausias žinias apie epidemiologiją, rizikos veiksnius, patogenezę, diagnostikos metodus, gydymo galimybes ir prevencijos strategijas.

Medžiaga ir metodai. Išsamiai išanalizuota mokslinė literatūra, pasitelkus PubMed duomenų bazę. Į analizę įtraukti tik anglų kalba publikuoti tyrimai, daugiau nei 70% literatūros šaltinių paskelbti 2015–2025 m. Atrinkti tyrimai buvo vertinami pagal jų svarbą epidemiologijos, patogenezės, rizikos veiksnių, diagnostikos ir gydymo sričiai.

Rezultatai. Ilgesnės operacijos, prasta antiseptika, nutukimas, nekontroliuojamas cukraus kiekis kraujyje didina SSI riziką. Didžiausi rodikliai yra mažų ir vidutinių pajamų šalyse. Prevencinės strategijos, tokios kaip laiku skiriami antibiotikai, antiseptikos protokolai ir neigiamo slėgio žaizdų terapija, padeda sumažinti sergamumą, nors piktnaudžiavimas antibiotikais ir atsparūs organizmai tebėra didelės problemos.

Išvados. Nepaisant pažangos prevencijos srityje, su sveikatos priežiūra susijusios infekcijos tebėra didelė našta. Norint jų sumažinti, reikia griežtos infekcijų kontrolės, geresnių diagnostikos priemonių, racionalaus antibiotikų vartojimo. Ateityje daugiausia dėmesio turėtų būti skiriama į bioplėvelę nukreiptiems gydymo būdams, rizikos prognozavimo modeliams, minimaliai invazinės chirurgijos plėtrai, siekiant pagerinti rezultatus visame pasaulyje.

Raktažodžiai: chirurginės infekcijos, infekcijų kontrolė, chirurginių žaizdų tvarkymas, atsparumas antimikrobinėms medžiagoms, bioplėvelės susidarymas.

1. Introduction

Healthcare-associated infections remain a major global challenge, undermining patient safety and burdening healthcare systems. Among these, surgical site infections (SSIs) are among the most frequent and serious complications following operative procedures. They significantly contribute to postoperative morbidity, extended hospital stays, and increased healthcare costs worldwide (1).

SSIs result from microbial contamination of a surgical wound during or after a procedure and are influenced by factors such as environmental sterility, operative technique, and patient condition. They are classified based on the depth and site of infection: superficial incisional, involving the skin and subcutaneous tissue; deep incisional, affecting deeper soft tissues such as muscle and fascia; and organ/space infections, involving internal organs or anatomical spaces manipulated during surgery (2). According to the Centers for Disease Control and Prevention (CDC), an SSI is defined as an infection occurring within 30 days of a surgical procedure, or within one year if an implant or prosthetic material was placed (3).

The clinical significance of SSIs extends beyond the immediate infection. Particularly challenging are wounds healing by secondary intention, which are slower to resolve and more prone to complications. These cases demand a focused approach to wound care, early identification of risk factors, and implementation of modern evidence-based prevention strategies (4).

2. Methods

A comprehensive literature review was conducted using the PubMed database to identify relevant studies on surgical site infections, epidemiology, risk factors, pathogenesis, diagnostic approaches, treatment options, and preventive strategies. The search strategy employed a combination of keywords, including "Surgical site infections", "Postoperative infection", "Infection control", "Surgical wound management", "Postoperative Complications", "Antimicrobial Resistance". In total, 43 articles were included in the review based on their compliance with the established inclusion criteria.

Inclusion criteria:

- To ensure the inclusion of recent and up-to-date findings, at least 70% of the articles referenced were published between 2015 and 2025.
- Publications written in English.
- Peer-reviewed original research articles, systematic reviews, meta-analyses, and clinical guidelines.
- Studies focused on the epidemiology, risk factors, pathogenesis, diagnosis, treatment, or prevention of surgical site infections.
- Studies involving human subjects.

Exclusion criteria:

- Articles published in languages other than English.
- Articles lacking accessible full text.

The application of additional filters allowed for the inclusion of studies addressing epidemiology, risk factors, pathogenesis, diagnosis, treatment, and prevention of surgical site infections. Following the application of the predefined inclusion and exclusion criteria, a selection of the most relevant studies was made. This systematic approach ensures a thorough and up-to-date evaluation of the current knowledge and advancements in the management of surgical site infections.

3. Results

3.1 Epidemiology and risk factors

Surgical site infections continue to be a global health concern, with incidence rates significantly varying by region, healthcare infrastructure, surgical specialty, and patient-related factors. A comprehensive meta-analysis involving 57 studies and nearly 489,000 patients found that the pooled 30-day incidence of SSIs was approximately 11%, with notable variation by anatomical site and urgency of the procedure. Duration of surgery was independently associated with increased infection risk (5). Similar findings by Allegranzi and othersin a WHO-sponsored review noted an increased risk in procedures exceeding two hours, particularly in emergency surgeries (6).

Risk factors for SSIs are commonly categorized as patient-related and procedure-related. Patient-based factors include age, poor nutritional status, diabetes mellitus, smoking, obesity, immune suppression, and prolonged hospital stay before surgery, which may compromise wound healing or systemic immunity (7,8). Procedural risk factors include improper antisepsis, inadequate antimicrobial prophylaxis, longer surgery duration, poor wound classification, suboptimal surgical technique, and use of foreign materials (7). Material selection during surgery also influences infection risk. Multifilament and non-absorbable sutures are more prone to bacterial colonization and biofilm formation compared to monofilament and absorbable options. Sutures act as potential reservoirs for pathogens, especially in cases involving implants, further emphasizing the need for antimicrobial or coated suture technologies (9,10).

Environmental and institutional factors—such as operating room ventilation, sterilization practices, and surgical team adherence to hygiene protocols—play a pivotal role in SSI prevention. High surgical staff turnover and suboptimal infection control policies further exacerbate the risk in under-resourced settings (6).

3.2 Pathogenesis and microbiota

The development of surgical site infections is a multifactorial process involving microbial colonization, host immune response, and environmental exposure during or after surgery. Most SSIs originate from the patient’s endogenous microbiota—primarily from the skin, gastrointestinal tract, or mucosal surfaces—which gain access to the surgical wound either during the procedure or in the immediate postoperative period (11). The spectrum of pathogens isolated from SSIs depends largely on the type of surgical procedure, anatomical location, and healthcare setting. Based on contemporary surveillance data from the National Healthcare Safety Network, the most frequently identified pathogens include Staphylococcus aureus (both methicillin-sensitive and methicillin-resistant), Escherichia coli, Enterococcus faecalis, Pseudomonas aeruginosa, and coagulase-negative staphylococci (12). Alarmingly, only 23% of the pathogens were sensitive to the prophylactic antibiotics administered preoperatively, reflecting the growing challenge of antimicrobial resistance. The increasing emergence of multidrug-resistant organisms, including MRSA and vancomycin-resistant S. aureus, has further complicated SSI management, often necessitating broad-spectrum or targeted antimicrobial therapy (13).

The prevalence of Methicillin-resistant *Staphylococcus aureus* (MRSA) in surgical site infections varies significantly depending on region, hospital practices, and national healthcare infrastructure. In countries like the United States and parts of Europe, MRSA accounts for 10–20% of SSIs, while in lower-resource settings such as Pakistan, Ukraine, it can exceed 30–40% due to inadequate infection control and inconsistent antibiotic protocols (14,15). MRSA-related SSIs are most commonly reported in orthopedic, abdominal, and trauma surgeries, particularly in adults. In contrast, MRSA prevalence in pediatric surgical patients is generally low, especially in cardiac and general surgeries, where structured infection prevention bundles and preoperative screening are routinely applied (16). This suggests that targeted interventions in pediatric settings are effective in keeping MRSA SSI rates minimal.

A significant portion of infections, particularly chronic and relapsing ones, are now understood to be associated with biofilm formation. Biofilms are complex microbial communities embedded within an extracellular polymeric matrix composed of polysaccharides, proteins, lipids, and extracellular DNA. These structures adhere to both biological tissues and medical devices, such as catheters, sutures, and implants (17). Biofilm-associated bacteria exhibit markedly enhanced resistance to antimicrobial agents—up to 1000 times more than planktonic cells—due to impaired antibiotic penetration, metabolic dormancy of cells, and the presence of specialized persister phenotypes (18). Biofilm formation follows a multi-phase process: initial adhesion, microcolony formation, maturation, and dispersion. The final phase is critical, as detached cells from mature biofilms can colonize new sites, potentially leading to systemic infection (19). Notably, biofilms also promote horizontal gene transfer, facilitating the spread of resistance traits among bacterial populations in the wound bed (20). Consequently, traditional antimicrobial therapy is often ineffective, and removal of infected implants or debridement becomes necessary in chronic SSI cases.

Understanding the microbial ecology of surgical wounds and the molecular mechanisms of biofilm formation is therefore essential for developing more effective prevention and treatment approaches.

3.3 Diagnosis of surgical site infections

Diagnosing surgical site infections requires a multifaceted approach integrating clinical judgment, physical examination, imaging, and laboratory findings. Common clinical features include localized erythema, warmth, edema, incisional pain, and purulent discharge (21). Deeper infections may manifest with systemic signs such as fever, malaise, leukocytosis, and elevated inflammatory markers (22). Organ-space infections, which may initially lack cutaneous signs, often require imaging for detection and confirmation. The physical examination should be comprehensive and ideally in person, with all dressings removed to assess wound characteristics such as fluctuance, necrosis, or ischemia. Sterile probing may reveal dead spaces or fluid pockets suggestive of deeper involvement (23).

Imaging modalities are invaluable for diagnosing deep or organ/space SSIs. Ultrasound is useful for detecting abscesses, guiding aspiration, and identifying fluid collections. X-rays may reveal gas in soft tissues or suggest osteomyelitis. Computed tomography (CT) provides rapid evaluation of fluid collections and necrotic changes, while magnetic resonance imaging (MRI) is superior for detecting fascial and muscular involvement, especially in suspected necrotizing soft tissue infections (24,25). MRI is considered the gold standard in differentiating cellulitis from necrotizing fasciitis when clinical signs are inconclusive.

Laboratory diagnostics support clinical suspicion but should not delay intervention. Elevated white blood cell counts, C-reactive protein (CRP), and procalcitonin are common findings, especially in systemic or deep infections. CRP levels on postoperative day 3–4 have demonstrated utility in predicting SSIs, with elevated levels correlating with increased infection risk (26).

Microbiological confirmation, when possible, is critical for guiding therapy. Superficial wound swabs may be contaminated by skin flora and are generally less reliable. Deep tissue cultures, obtained via aspiration or biopsy, yield higher diagnostic accuracy and are especially important in suspected multidrug-resistant infections. Blood cultures are reserved for patients with systemic symptoms or suspected bacteremia (27). For patients with necrotizing infections—such as Fournier gangrene—rapid surgical exploration remains the cornerstone of diagnosis, with imaging and labs serving a supportive role.

Finally, several risk stratification tools aid in predicting SSI likelihood, including the National Nosocomial Infection Surveillance index and procedure-specific scores like the Surgical Site Infection Risk Score. Although useful, many tools omit nuanced patient and surgery-specific factors, limiting their predictive power (28).

3.4 Prevention of surgical site infections

The prevention of surgical site infections requires a multifaceted strategy encompassing preoperative, intraoperative, and postoperative interventions, each tailored to address specific modifiable risk factors.

3.4.1 Preoperative measures

Preoperative strategies are critical to minimizing microbial contamination at the time of incision. Hair removal, if necessary, should be performed using electric clippers rather than razors to reduce microscopic skin trauma and subsequent bacterial entry. This should be done as close to the time of surgery as possible and outside the operating room (29). Glycemic control is equally important; perioperative hyperglycemia, even in non-diabetic patients, significantly increases SSI risk. Current recommendations suggest maintaining intraoperative glucose levels below 10 mmol/l, with tighter control (≤8,33 mmol/l) showing additional benefit without added mortality, although hypoglycemia risk remains a concern (30).

Nutritional status also plays a crucial role, as malnutrition impairs immune function, delays wound healing and increases the likelihood of chronic wound formation. Studies confirm that patients with adequate nutrition experience faster healing and shorter hospital stays (30). Obesity (BMI >30) presents another major risk factor, impairing tissue oxygenation and reducing the effectiveness of antimicrobial prophylaxis due to altered drug distribution and metabolic demands (21). Antimicrobial prophylaxis—typically with first- or second-generation cephalosporins—should be administered intravenously 30 to 60 minutes before incision.

3.4.2 Intraoperative measures

During surgery, strict adherence to aseptic techniques is vital. Skin antisepsis using chlorhexidine gluconate (CHG)-alcohol solutions has demonstrated superior efficacy over povidone-iodine in reducing bacterial load and SSI incidence, though combining these agents may further improve outcomes (31). Surgical site irrigation with sterile saline, maintenance of normothermia, and minimization of intraoperative contamination (e.g., through wound protectors and antimicrobial-coated sutures) have all been shown to significantly reduce infection rates (32). Antibiotic prophylaxis should not extend beyond 24 hours postoperatively, as prolonged use offers no added benefit, increases C. difficile risk, and contributes to antimicrobial resistance (30).

3.4.3 Postoperative Measures

Postoperatively, the focus shifts to wound care and early complication detection. Non-touch techniques and the use of sterile saline for wound cleansing are the gold standard in immediate postoperative care. After 48 hours, patients can typically begin showering with soap, but topical antimicrobials are generally discouraged unless clinically indicated, as they do not significantly reduce SSI risk (33). Dressing materials also influence outcomes—recent meta-analyses suggest that VE-silicone and mupirocin-impregnated dressings may be superior to conventional dressings in reducing infection incidence (34). Negative-pressure wound therapy (NPWT) is another adjunct shown to reduce postoperative wound complications, particularly in high-risk or contaminated surgeries (32).

3.5 Treatment of surgical site infections

The treatment of surgical site infections involves a multifaceted approach encompassing empirical and targeted antibiotic therapy, surgical wound management, and adjunctive interventions like NPWT. Empirical antibiotic therapy is crucial in the early management of SSIs, particularly in cases of systemic involvement such as sepsis. Studies show that timely empiric antibiotic administration—preferably within the first hour—can significantly reduce mortality in septic shock and severe infections (35). Once culture and sensitivity data become available, targeted antibiotic therapy should be initiated to minimize the risk of resistance and optimize outcomes (36).

Surgical site care is fundamental, especially in purulent or deep infections. Superficial infections may require simple drainage and debridement, while deep incisional or organ/space infections necessitate thorough drainage, removal of necrotic tissue, and sometimes hardware or suture removal (3).

In more complex or chronic cases, Negative Pressure Wound Therapy (NPWT) has emerged as a valuable tool. It enhances local perfusion, promotes angiogenesis, and accelerates granulation tissue formation. A systematic review of studies, including randomized controlled trials and cohort analyses, reported a reduction in infection rates, serohematoma formation, and reoperation rates with NPWT, particularly in high-risk surgical wounds (37,38). However, NPWT must be preceded by surgical debridement and appropriate antibiotic coverage for optimal efficacy and safety.

Antimicrobial resistance poses a growing challenge in SSI management. Methicillin-resistant Staphylococcus aureus remains a leading cause of SSIs, particularly in hospital settings. Empirical treatment for complicated SSIs often includes vancomycin, linezolid, or daptomycin, while outpatient cases involving community-acquired MRSA (CA-MRSA) can be managed with clindamycin, doxycycline, or trimethoprim-sulfamethoxazole (39). Resistance patterns also influence therapy for streptococcal infections; although macrolide resistance is rising, β-lactams like penicillin remain effective against group A Streptococcus (36). In life-threatening infections such as necrotizing fasciitis caused by S. pyogenes, high-dose penicillin combined with clindamycin remains the treatment of choice.

3.6 Outcomes, complications, and future directions in surgical site infections

Surgical site infections remain a significant burden on patients and healthcare systems, leading to serious clinical and economic consequences. Studies show that methicillin-resistant *Staphylococcus aureus* -associated SSIs following colorectal surgery can extend hospital stays by nearly 20 days (40). Tuon and others also reported a mortality rate of 5.4% due to SSIs related to orthopedic trauma, highlighting the severity of such infections (41). Beyond mortality, SSIs are major contributors to hospital readmissions and reoperations, particularly in procedures involving prosthetic implants or secondary wound healing (42).

Long-term complications can include persistent purulent discharge, abscess or hematoma formation, and chronic wound inflammation, which impair quality of life and increase dependency on healthcare resources. Chronic wounds, including those evolving from poorly managed SSIs, often remain trapped in the inflammatory phase of healing (43).

4. Conclusion

Surgical site infections remain a major complication in surgical care, driven by a complex interplay of microbial, patient-related, procedural, and environmental factors. Their impact is particularly severe in low-resource settings, where infrastructure and perioperative practices are often suboptimal. SSIs prolong hospitalization, increase costs, worsen outcomes, and are further complicated by the rise of antimicrobial resistance—especially from MRSA and other multidrug-resistant pathogens. While standard treatments like timely antibiotics, debridement, and wound care remain essential, newer strategies—such as antimicrobial-coated materials, negative pressure wound therapy, and risk prediction tools—show promise. Moving forward, prevention must focus on evidence-based protocols, improved diagnostics, and responsible antimicrobial use. Integrating innovations like anti-biofilm therapies and precision medicine may further reduce SSI incidence and improve surgical outcomes globally.

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