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Surgical Site Infections in General Surgery: Risk Factors, Antibiotic Prophylaxis and Evidence-Based Prevention Strategies

Dr. P. Dhivyaprasath[1]*, Jayashree T[2], Gayathri M[2], Grace S[2], Janani B S[2]

[1]Assistant professor, Department of Pharmacy Practice, Swamy Vivekanandha College of Pharmacy, Elayampalayam, Tiruchengode, Namakkal 637205
[2]V[th] Pharm d Students, Department of Pharmacy Practice, Swamy Vivekanandha College of Pharmacy, Elayampalayam, Tiruchengode, Namakkal 637205

ABSTRACT

One of the most common and avoidable side effects of general surgery is still surgical site infections (SSIs), which have a substantial impact on postoperative morbidity, extended hospital stays, higher medical expenses, and mortality. This narrative review synthesizes current knowledge on the epidemiology, categorization, pathophysiology, microbiology, risk factors, and prevention methods for SSIs. The frequency of SSI varies globally, ranging from 2-3% in high-income settings to around 8-10% in low- and middle-income countries. The largest risk is associated with treatments including colon surgery, emergency laparotomy, and contaminated or unclean wounds. SSIs occur from a complex interplay of endogenous flora, foreign contamination, compromised host defenses, tissue damage, and biofilm formation. Patient-related factors (diabetes, obesity, age extremes, malnutrition, immunosuppression), surgery-related factors (prolonged duration, poor technique, wound class, implants), and hospital-environmental factors (OR traffic, inadequate sterilization, ventilation) all raise infection risk. Antibiotic prophylaxis when appropriately selected, timed, and redosed remains a cornerstone of prevention, but non-antibiotic strategies such as glycemic control, smoking cessation, CHG bathing, optimal intraoperative asepsis, normothermia, and postoperative wound care are equally essential. When regularly used, evidence-based bundles that are advised by the CDC, WHO, and SHEA/APIC dramatically lower SSI rates. Emerging technologies including antimicrobial-coated sutures, negative-pressure wound therapy, AI-based risk prediction models, and microbiome-targeted interventions offer promising advances, particularly in high-risk surgical populations. Strengthening multidisciplinary collaboration, improving adherence to guidelines, and enhancing institutional quality-improvement practices are critical to reducing the global burden of SSIs and improving surgical outcomes.

INTRODUCTION

Surgical site infections (SSIs) remain a significant complication in general surgery, contributing to increased patient morbidity, prolonged hospitalisation, higher healthcare costs and, in some cases, mortality. For patients undergoing procedures in the general surgical setting, the incidence of SSIs is estimated to be in the range of approximately 0.5% to 3% of cases, although rates may be higher depending on the patient population and operative context. [1] The development of an SSI is multifactorial. Host-related risk factors (such as diabetes, obesity, malnutrition, immunosuppression), operative factors (prolonged surgery, contaminated wounds, foreign implants), and microbial factors (endogenous flora, contamination during surgery) all play major roles. [2] Importantly, prophylactic antibiotic administration-when properly selected, timed and dosed-is a cornerstone of prevention. However, antibiotic prophylaxis alone is insufficient: a bundle of evidence-based preventive strategies (skin antisepsis, hair removal techniques, normothermia, glycaemic control, surgical technique, wound care) is required to achieve meaningful reductions in SSI risk.[1] [3][4]In the era of increasing antimicrobial resistance and heightened focus on antimicrobial stewardship, the optimal strategies for prophylactic antibiotics - including agent choice, timing, duration, intra-operative redosing and tailoring to patient and surgical risk -remain critically important. At the same time, non-antibiotic preventive measures must be emphasised to reduce SSI incidence sustainably. Surgical site infections (SSIs) continue to represent a significant burden in general surgical practice. Although modern advances in surgical technique, antisepsis, and perioperative care have reduced their incidence, SSIs still affect approximately 0.5 % to 3 % of all surgical procedures in developed settings, and considerably higher rates in some settings or high-risk groups .These infections are not only associated with increased patient morbidity and prolonged hospital stays -for example patients with an SSI may remain hospitalised 7-11 additional days compared with those without -but also impose substantial financial and resource burdens on healthcare systems.

The pathogenesis of SSIs is multifactorial, typically involving the inoculation of bacteria (often endogenous flora such as Staphylococcus aureus) into the surgical wound at the time of the procedure, followed by local factors (wound contamination, tissue damage, foreign material) and host factors (immune competence, comorbidities, nutrition) that determine the progression to infection[1]From a practical standpoint, risk factors may be grouped into intrinsic patient-related factors (e.g., advanced age, comorbid conditions such as diabetes mellitus or obesity, malnutrition, immunosuppression) and extrinsic procedure- or environment-related factors (e.g., wound classification [clean vs contaminated], operative time, surgical approach, intraoperative hypothermia, blood loss) as well as institutional factors (sterilisation practices, operating-room traffic, instrument contamination) that compound risk.[5]Preoperative antibiotic prophylaxis remains a cornerstone of SSI prevention in general surgery. Evidence supports that proper antibiotic selection, timing (ideally within 60 minutes before incision for many agents), appropriate dose and redosing when required (especially for prolonged operations or major blood loss) significantly reduce SSI risk. For example, in a prospective cohort study of general surgery patients, adherence to prophylaxis protocol dramatically impacted SSI rates (odds ratio around 0.5 when prophylaxis was correctly administered) while delays of two hours or more before incision significantly increased risk (OR ~5.3).[6]While much of the evidence for SSI prevention derives from elective general surgery in high-income settings, global data highlight that rates of SSI remain considerably higher in low- and middle-income countries - owing to constrained resources, infrastructure limitations, and challenges in implementing standardized infection-control practices.[7]

EPIDEMIOLOGY

Surgical site infection (SSI) remains one of the most frequent healthcare-associated infections and a leading cause of postoperative morbidity in general surgery.[1]

Global incidence and regional variation

Reported SSI incidence varies widely by region and study methodology; pooled global estimates from recent meta-analyses place the overall incidence in the low single digits (≈2–3%), while rates in many low- and middle-income countries (LMICs) are substantially higher (often >8–10%). For example, a 2023 systematic review found an overall pooled SSI incidence of **2.5%** (95% CI 1.6–3.7%), with markedly higher rates in the African WHO region (≈7.2%).[9] Differences between high-income and low-income settings reflect not only patient and procedure mix (more emergency/contaminated cases in some regions) but also variation in surveillance quality, perioperative infrastructure, and adherence to infection-prevention practices .[10]

Procedure-specific risk (general-surgery focus)

SSI risk is procedure dependent. Colorectal surgery consistently reports the highest SSI rates among routine general-surgery procedures (commonly **10–30%** in published series), driven by heavy bowel microbial burden and frequent contamination. [5]

Emergency laparotomy, operations for perforated viscera, and contaminated/dirty abdominal procedures are also associated with substantially higher SSI incidence compared with elective, clean procedures (hernia repair, uncomplicated laparoscopic cholecystectomy), which typically report much lower rates (<2–5%). [5][12]

Microbiology and antimicrobial resistance trends

Common SSI pathogens include **Staphylococcus aureus** (including MRSA), *Enterococcus* spp., and Gram-negative bacilli such as *E. coli*, *Klebsiella* and *Pseudomonas*. Surveillance and recent reviews report increasing proportions of multidrug-resistant organisms (including MRSA and ESBL-producers) among SSI isolates, complicating empirical therapy and emphasising the need for antibiotic stewardship. [1][13]

Morbidity, mortality and economic burden

SSIs prolong hospital stay (on average **7–11 extra days**), increase readmissions and reoperations, and raise direct treatment costs substantially; deep and organ/space infections carry higher morbidity and measurable attributable mortality. These impacts make SSI incidence a key quality metric for surgical services. [1][2]

CLASSIFICATION

Classification Of Surgical Site Infections According To Cdc/Nhsn Criteria

Surgical site infections (SSIs) are among the most frequent healthcare-associated infections and serve as a critical measure of surgical quality and patient safety. To ensure uniformity in diagnosis, surveillance, and reporting, several classification systems have been developed; however, the most widely adopted is the Centers for Disease Control and Prevention (CDC) and National Healthcare Safety Network (NHSN) system(table1). This classification is based on the depth of tissue involvement and the anatomical location of the infection, allowing consistent comparison of outcomes across institutions and aiding in the development of targeted prevention strategies. According to CDC/NHSN criteria, SSIs are broadly categorized into superficial incisional, deep incisional, and organ/space infections.

Table 1: Classification of Surgical Site Infections According to CDC/NHSN Criteria

SSI Category	Anatomical Involvement	Diagnostic Time Frame	Key Diagnostic Criteria	Clinical Impact
Superficial Incisional SSI	Skin and subcutaneous tissue	≤ 30 days after surgery	Purulent discharge, localized inflammatory signs, positive culture from superficial incision, surgeon diagnosis	Low severity, increased wound care demand
Deep Incisional SSI	Fascial and muscular layers	≤ 30 days if no implant; ≤ 1 year if implant placed	Purulent drainage from deep incision, dehiscence with fever/pain, deep abscess confirmed surgically or radiologically	Higher morbidity, re-operation risk, longer hospital stay
Organ/Space SSI	Internal organs/spaces manipulated during surgery	≤ 30 days if no implant; ≤ 1 year if implant placed	Purulent drainage from drain into organ/space, positive culture, imaging/surgical confirmation of abscess/infection	Highest severity, risk of sepsis, mortality

This standardized CDC/NHSN classification offers a globally recognized framework for consistent surveillance and reporting of surgical site infections. By categorizing infections based on depth and anatomical extent, it aids early diagnosis, guides clinical management, and supports infection control and quality improvement in general surgery [18][2][4][3]

Classification Of Surgical Wounds Based On Contamination Level

Surgical wounds are classified according to the degree of microbial contamination at the time of the operation. This classification system, proposed by the Centers for Disease Control and Prevention (CDC) and adopted globally by the World Health Organization (WHO) and National Institute for Health and Care Excellence (NICE), serves as a predictor of surgical site infection (SSI) risk and guides the appropriate use of perioperative antibiotic prophylaxis. Based on intraoperative findings and the presence or absence of infection or inflammation, wounds are divided into four categories-clean, clean-contaminated, contaminated, and dirty/infected

Table 2: Classification of Surgical Wounds Based on Contamination Level

Wound Class	Definition / Description	Common Surgical Examples	Approximate SSI Risk
Class I – Clean	Uninfected operative wounds in which no inflammation is encountered and the respiratory, alimentary, genital, or urinary tracts are not entered. Primary closure is performed, and drains are not used.	**Hernia repair, thyroidectomy, mastectomy**	**Low (1–5%)**
Class II – Clean-Contaminated	**Operative wounds where the respiratory, alimentary, genital, or urinary tracts are entered under controlled conditions and without unusual contamination.**	**Cholecystectomy, hysterectomy, gastrectomy**	**Moderate (5–10%)**
Class III – Contaminated	**Open, fresh accidental wounds or operations with major breaks in sterile technique, gross spillage from the gastrointestinal tract, or acute non-purulent inflammation.**	**Penetrating abdominal trauma, perforated appendix without abscess**	**High (10–20%)**
Class IV – Dirty/Infected	**Old traumatic wounds with retained devitalized tissue or existing clinical infection or perforated viscera; organisms present before the procedure.**	**Abscess drainage, fecal peritonitis, gangrenous bowel resection**	**Very High (>40%)**

This wound classification framework helps estimate infection risk and guide appropriate antibiotic prophylaxis. Clean wounds have the lowest SSI risk, whereas dirty or infected wounds carry the highest due to existing contamination. Recognizing contamination levels supports effective prevention, aseptic technique, and evidence-based infection [14][2][3][4][5]

PATHOPHYIOLOGY

Surgical site infection begins when the surgical incision disrupts the skin barrier, allowing microorganisms from the patient's skin, environment, surgical instruments, or staff to contaminate the wound. The risk increases when tissue handling causes ischemia and reduced oxygen tension, which impair neutrophil function and weaken host defenses. Host factors such as age, diabetes, malnutrition, and immunosuppression further reduce the ability to clear bacteria. Once bacteria adhere to tissues or sutures, they multiply and may form biofilm, enabling immune evasion and persistent infection. Modern molecular studies show SSIs are often polymicrobial, including anaerobes and antibiotic-resistant organisms, leading to inflammation, pus formation, delayed healing, and progression from superficial to deep or organ-space infection.[14][7][8][10][11]

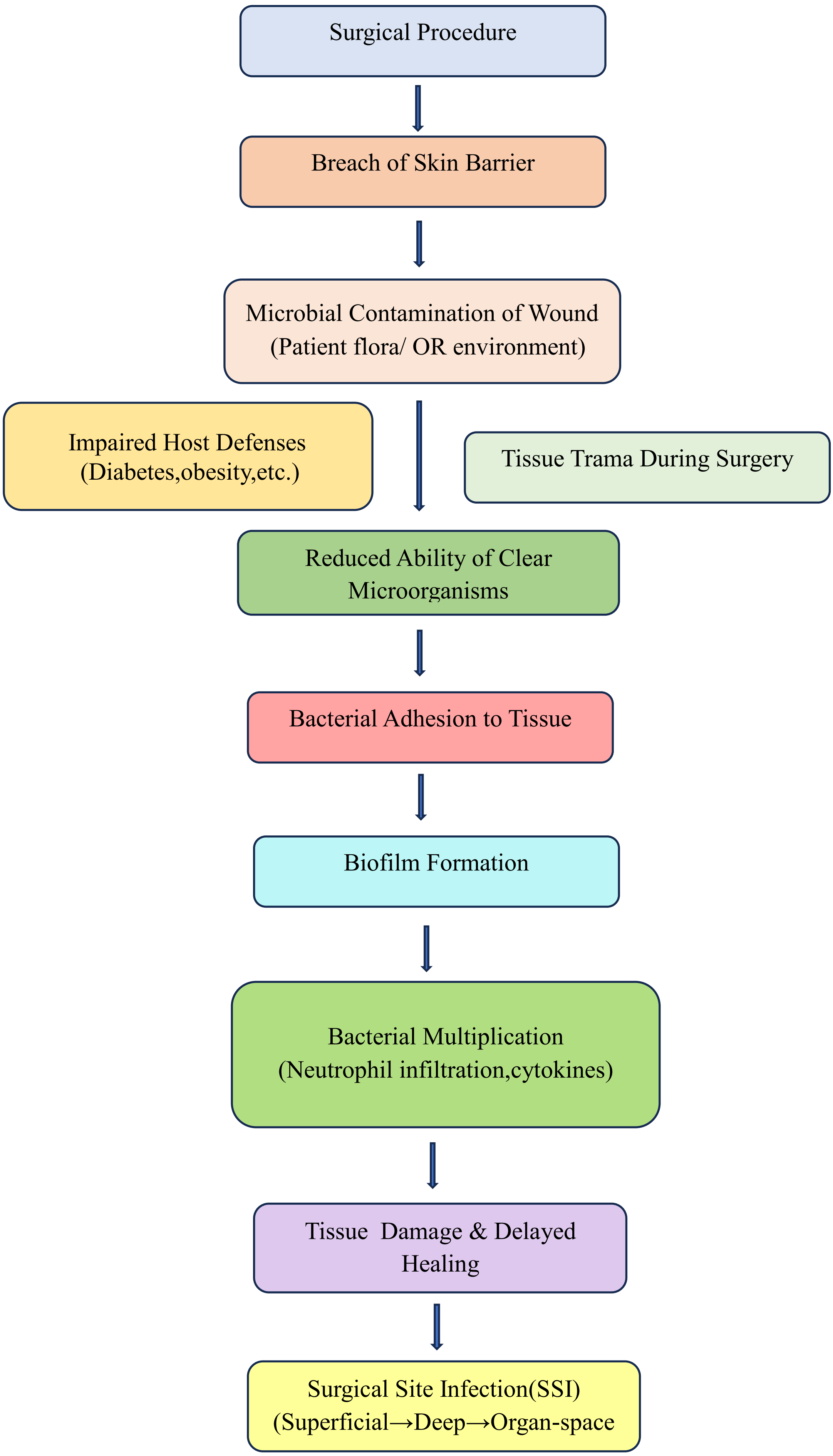
Surgical Procedure
Breach of Skin Barrier
Microbial Contamination of Wound
(Patient flora/ OR environment)
Impaired Host Defenses
(Diabetes,obesity,etc.)
Tissue Trama During Surgery
Reduced Ability of Clear Microorganisms
Bacterial Adhesion to Tissue
Biofilm Formation
Bacterial Multiplication
(Neutrophil infiltration,cytokines)
Tissue Damage & Delayed Healing
Surgical Site Infection(SSI)
(Superficial→Deep→Organ-space

FIG.1.The sequential mechanisms leading to SSI, beginning with microbial contamination of the surgical wound and progressing through impaired host defenses, tissue injury, and biofilm formation. The combined effect of these processes results in localized infection, delayed healing, and postoperative complications.

ETIOLOGY AND MICROBIOLOGY OF SSIS

Endogenous sources (skin, gastrointestinal flora)

The vast majority of SSI pathogens originate from the patient's own endogenous flora — particularly skin microbiota (e.g., Staphylococcus aureus, coagulase-negative staphylococci) and mucous membranes/viscera (e.g., gastrointestinal tract flora) present at the time of incision. A review of the microbiome of surgical wounds suggests that up to ~70–95% of SSIs may be attributable to organisms already present at the incision site (skin, nares) at the time of surgery (i.e., endogenous) rather than later contamination.[12]

In general-surgery and abdominal procedures where the gastrointestinal tract is entered, endogenous gut flora including Gram-negative bacilli (such as Escherichia coli) and anaerobes may seed the operative site when visceral content is opened or spillage occurs. [18]

The importance of endogenous sources emphasises the role of preoperative skin/nares decolonisation, bowel preparation (when applicable) and minimising tissue exposure to native flora.

Exogenous Contamination

Pathogens may also be introduced from exogenous sources such as the operating-room environment (airborne contamination), surgical team (hands/skin carriage), surgical instruments, dressings and implants. Exogenous flora are typically aerobic Gram-positive organisms (e.g., staphylococci, streptococci) but may include Gram-negatives in specific settings. The relative contribution of exogenous contamination is especially relevant in settings with breaks in sterile technique, high-traffic operating theatres, instrument contamination, or suboptimal environmental controls. A large proportion of SSIs therefore represent a failure to control both endogenous and exogenous sources.[14]

In procedures involving implants or prosthetic devices, exogenous contamination may be especially critical since foreign materials reduce the threshold of bacterial load needed to cause infection.

Common Pathogens & Resistance Patterns

MRSA (Methicillin-Resistant Staphylococcus aureus)

Staphylococcus aureus remains one of the most frequent SSI pathogens in general surgery. In several reports, about 10% or more of SSIs are caused by MRSA strains.[18]

An Italian position paper emphasises that MRSA is a "versatile and dangerous pathogen" in SSIs -combining virulence, resistance and survival fitness.

MRSA presence increases treatment complexity, cost, morbidity and may mandate broader empiric coverage or decolonisation strategies.

ESBL-producing Gram-negative bacteria (and other multidrug-resistant Gram-negatives)

The microbiologic spectrum of SSIs is shifting in many settings to include resistant Gram-negative organisms. For example, in a systematic review, ESBL-producing E. coli or Klebsiella spp were identified in up to ~50% of certain abdominal/colorectal SSI isolates. A prospective study in Ethiopia found that Gram-negative bacteria accounted for ~78% of SSI isolates, with E. coli being predominant; high rates of antibiotic resistance were observed. The presence of foreign material, longer operative time, and use of broad-spectrum antibiotics predispose to selection of resistant organisms. [18]

Biofilm Formation on Implants/Mesh

Biofilm formation on surgical implants, prostheses, mesh and foreign material is a key mechanism by which SSIs become chronic, hard to eradicate and resistant to treatment. Approximately **80%** of human SSIs (including chronic wound and implant-associated infections) are related to biofilm-forming bacteria. Biofilms are structured microbial communities attached to surfaces and encased in an extracellular polymeric substance (EPS) matrix, which protects bacteria from host immune response and antimicrobial agents. In the context of general surgery, mesh repair (e.g., hernia), vascular grafts, orthopedic implants and other prosthetics present a nidus for bacterial adhesion and biofilm formation. Bacteria in biofilms can exchange resistance genes (horizontal gene transfer), further complicating antibiotic therapy. Prevention strategies therefore must account for biofilm risk — such as use of implant coatings, careful aseptic technique when handling implants, limiting unnecessary foreign material, and early removal of drains or devices when possible. [17]

RISK FACTORS CONTRIBUTING TO SSIS

Patient-Related Factors

The patient's inherent state of health has a significant influence on SSI risk. A common comorbidity, diabetes mellitus impairs neutrophil activity and microvascular circulation, which hinders wound healing and makes a person more vulnerable to infection. Research shows that SSI rates in diabetic patients can be nearly twice as high as in non-diabetic patients, especially if there is insufficient glucose control during surgery. Obesity increases mechanical and physiological costs because it decreases tissue oxygenation, increases surgical complexity, and increases wound tension, all of which promote bacterial colonization. Due to compromised immune systems and delayed recovery, both in children and the elderly, age extremes raise the risk of infection. The body is unable to mount effective immune responses and repair tissue when hypoalbuminemia and other types of malnutrition are present. Host defenses are further weakened by immunosuppression brought on by illnesses (like HIV/AIDS) or drugs (like steroids and chemotherapy). Furthermore, smoking reduces leukocyte activity and causes vasoconstriction, which worsens tissue resistance and perfusion. Finally, surgical wounds may develop resistant bacteria as a result of pathogenic organisms like MRSA colonizing the skin or mucosa, circumventing the usual prophylactic measures. Immunosuppression caused by diseases like HIV/AIDS or medications like steroids and chemotherapy further impairs host defenses. Additionally, smoking induces vasoconstriction and lowers leukocyte activity, which exacerbates tissue resistance and perfusion. Finally, when pathogenic organisms like MRSA colonize the skin or mucosa, surgical wounds may develop resistant germs, evading the typical preventive measures.[18]

Diabetes Mellitus:

One of the main patient-related risk factors for SSIs has been repeatedly found to be diabetes mellitus. The body's first line of defense against perioperative bacterial invasion is weakened by hyperglycemia, which affects important immune processes, especially neutrophil chemotaxis, phagocytosis, and intracellular killing (Owens & Stoessel, 2008). Additionally, diabetes causes microvascular disease, which lowers oxygenation and local tissue perfusion-two factors necessary for wound healing. According to clinical research, diabetic patients are up to twice as likely to experience SSI as non-diabetics, particularly if their perioperative glucose control is inadequate.

Obesity:

Obesity further complicates the SSI narrative by combining structural and metabolic risks. Increased adipose tissue thickness creates a hypoxic wound environment due to poor vascularity, while excess tissue heightens mechanical tension on incisions, predisposing to dehiscence and seroma formation, both fertile grounds for bacterial growth. Morbid obesity is independently associated with increased SSI incidence across multiple surgical populations. Additionally, obesity commonly coexists with diabetes and immune dysregulation, compounding infection risk. [19]

Age:

Immunosenescence, which includes decreased neutrophil and macrophage activity, decreased T-cell proliferation, and impaired cytokine production, is a progressive reduction in immunological function that affects people at extremes of age, particularly the elderly. These modifications lead to decreased infection control and poorer wound healing. Neonates and newborns are also more susceptible to SSI due to their young immune systems and limited adaptive responses, which are characterized by decreased opsonization and antibody production.[6]

Nutrition:

Malnutrition weakens defenses against SSIs. Deficiencies in protein and micronutrients impair the production of collagen, fibroblast function, and antibodies, which negatively impacts the strength of wounds and immune competence. Higher SSI rates and worse surgical outcomes are consistently linked to hypoalbuminemia in clinical data. These trends are made worse by chronic nutritional deficiencies and alcoholism, which makes preoperative nutritional optimization necessary for high-risk patients.

Immunosuppression:

Whether caused by disease (e.g., HIV/AIDS, post-transplant) or medication (e.g., corticosteroids, chemotherapy), immunosuppression significantly hinders coordinated immune responses that are essential for removing perioperative contamination. Cellular immunity and neutrophil function dysregulation significantly increases vulnerability to opportunistic pathogens and slows wound healing, often leading to more severe or atypical SSIs.[19]

Smoking:

Nicotine-induced vasoconstriction and carbon monoxide-induced tissue hypoxia, which lower oxygen delivery and leukocyte activity, mediate smoking's harmful effects on wound healing and infection resistance. This promotes the growth of anaerobic bacteria and inhibits the production of collagen; smokers exhibit markedly higher rates of SSI and longer wound healing durations.[18]

Colonization Status:
A subtle but powerful risk for SSIs is preoperative colonization with pathogenic organisms, particularly Staphylococcus aureus, including methicillin-resistant strains (MRSA). During incision and implantation, colonized patients introduce resistant organisms, acting as reservoirs. MRSA colonization, which frequently eludes conventional prophylactic regimens and calls for specialized decolonization and antibiotic strategies, is responsible for up to 30% of SSIs in high-risk settings, according to studies.[7]

Surgery-Related Factors
The development of SSI is significantly influenced by surgical technique and procedural features. Longer surgical times, particularly longer than two hours, increase the risk of hypothermia and contamination as well as tissue exposure time, which in some studies nearly doubles the incidence of SSI. Tissue necrosis and bacterial colonization are decreased by careful surgical technique that emphasizes delicate tissue handling, sparing cautery use, and accurate hemostasis. A predictive framework is provided by the classification of wounds: clean wounds have the lowest infection rates, whereas contaminated and dirty wounds-which are frequently the result of emergency surgeries large spills carry much higher infection risks, occasionally surpassing 25–30%. By introducing foreign bodies that promote biofilm formation and shield bacteria from host defenses and antibiotics, the use of implants and surgical drains increases the persistence of infections and makes treatment more challenging.[33]

Duration of Procedure
One of the most frequently mentioned risk factors for SSIs is extended surgical duration. The risk of infection increases with each extra hour of surgery, sometimes doubling the likelihood of surgical site infections (SSI) for procedures longer than two hours. More chances for bacterial inoculation from the environment or endogenous flora are made possible by the longer duration. Prolonged surgery also results in hypothermia and tissue desiccation, which hinder wound healing and local immune responses. According to a comprehensive analysis, surgeries lasting more than two hours considerably increase the incidence of surgical site infections (SSI) for a variety of general surgical procedure.[18]

Surgical Technique & Tissue Handling
Extended surgery time is one of the risk factors for SSIs that is most commonly highlighted. The risk of infection rises with each additional hour of surgery, sometimes doubling the chance of surgical site infections (SSI) for procedures longer than two hours. The longer time increases the likelihood of endogenous flora or environmental bacterial infection. Long-term surgery also causes tissue desiccation and hypothermia, which impede local immune responses and wound healing. A thorough investigation found that the incidence of surgical site infections (SSI) for a range of general surgical procedures is significantly higher for surgeries that continue more than two hours.[33]

Wound Classification (Clean → Dirty)
A simple yet effective way to estimate the risk of SSI is still wound categorization. The system divides wounds into two categories: clean wounds, which are incisions that have not come into contact with the respiratory, gastrointestinal, or genitourinary tracts, and dirty wounds, which are polluted with purulent material or a gross infection. Clean wounds usually have infection rates below 2%, clean-contaminated and contaminated wounds have risks of 5–15%, and dirty wounds often have SSI rates above 25%. Antibiotic prophylaxis and risk stratification are guided by the classification. The occurrence of SSI is also noticeably higher in emergency procedures, which are frequently linked to contaminated or unclean wounds.[7]

Use of Implants & Drains
Wound classification is still a straightforward yet useful method of estimating the risk of SSI. The approach classifies wounds into two groups: filthy wounds, which are contaminated with purulent material or a severe infection, and clean wounds, which are incisions that have not come into contact with the respiratory, gastrointestinal, or genitourinary systems. Clean wounds typically have infection rates around 2%, clean-contaminated and contaminated wounds have risks between 5 and 15%, and dirty wounds frequently have SSI rates exceeding 25%, The classification serves as a reference for risk assessment and antibiotic prophylaxis. Additionally, SSI is much more common during emergency procedures, which are often associated with contaminated or dirty wounds.[18]

Hospital and Environmental Factors
An important context for SSI risk is provided by hospital infrastructure and environmental measures. Airborne microbiological contamination is significantly decreased by operating room sterility, which includes efficient ventilation systems with HEPA filtration and laminar airflow. Infection clusters, however, are largely caused by inadequate infrastructure and sterilization protocol violations, particularly in the Central Sterile Supply Department (CSSD). There is strong evidence that staff adherence to aseptic procedures, including as proper glove and gown donning, hand cleanliness, and reduced operating room traffic, can lower SSI rates. Additionally, extended hospital stays prior to surgery put patients at risk for multidrug-resistant organism colonization, which makes managing postoperative infections more difficult and increases the chance of SSI.[9]

Operating Room Sterility & Ventilation

Hospital infrastructure and environmental measures provide an important background for SSI risk. Operating room sterility, which incorporates effective ventilation systems with HEPA filtration and laminar airflow, dramatically reduces airborne microbial contamination. However, poor infrastructure and sterilization protocol violations-particularly in the Central Sterile Supply Department (CSSD)-are the main causes of infection outbreaks. There is compelling evidence that lowering SSI rates can be achieved by staff adhering to aseptic practices, including as wearing gloves and gowns correctly, washing their hands, and reducing operating room traffic. Long hospital stays before surgery further increase the risk of multidrug-resistant organism colonization, which complicates the management of postoperative infections and raises the risk of surgical site infections. Pathogenic germs are directly introduced when surgical instruments and surfaces are not thoroughly sterilized. Adherence to aseptic procedures, frequent audits, and stringent sterilization methods are crucial. Research has shown that infection outbreaks are strongly correlated with sterilization or environmental cleanliness violations, particularly in settings with low resources.[13]

Staff Practices

Inadequate sterilization of surgical equipment and surfaces results in the direct introduction of pathogenic germs. Strict sterilization techniques, regular audits, and adherence to aseptic processes are essential. Studies have demonstrated a substantial correlation between sterilization or environmental cleanliness violations and infection outbreaks, especially in low-resource environments.[18]

Preoperative Hospital Stay

Patients are more susceptible to nosocomial infections, including multidrug-resistant bacteria like MRSA and VRE, during prolonged preoperative hospital stays (Rezaei, 2025). Colonization is facilitated by longer stays, particularly when infection control measures are inadequate. Postoperative surgical site infections (SSIs) are more common in colonized individuals, especially if prior skin decolonization or screening procedures are not followed. Postoperative infections have been successfully decreased by initiatives to reduce preoperative hospital stays and enhance infection control during inpatient stays.[7]

Microbial Spectrum and Resistance Patterns

Coagulase-negative staphylococci, Staphylococcus aureus (including MRSA), and Gram-negative bacteria including Escherichia coli, Klebsiella pneumoniae, and Pseudomonas aeruginosa are the main causes of SSIs. Prophylaxis and therapy are challenged by growing antimicrobial resistance, especially in MRSA and extended-spectrum beta-lactamase (ESBL)-producing pathogens. This highlights the necessity for customized antibiotic stewardship and effective infection control methods. [21]

Interrelationship of Risk Factors

These factors frequently coexist and worsen each other, according to recent prospective studies. For instance, a diabetic obese patient undergoing extended emergency surgery in an operating room with poor ventilation and subpar staff practices faces a compounded risk, with SSIs approaching 30%. Strict infection control audits, improved surgical techniques, patient optimization, and environmental enhancements are all necessary for effective mitigation.[15]

ROLE OF ANTIBIOTIC PROPHYLAXIS IN SSI PREVENTION

Bacterial contamination of the surgical wound, which can happen during the procedure or in the early postoperative phase, leads to surgical site infections. By guaranteeing sufficient antimicrobial concentrations in serum and tissues at the moment of possible bacterial invasion, antibiotic prophylaxis seeks to stop this contamination from resulting in clinical infection (Owens & Stoessel, 2008). Prophylaxis has been demonstrated to lower the incidence of SSI by up to 50% in a variety of surgical procedures, including clean-contaminated surgeries (e.g., gastrointestinal, gynecological). Prophylaxis is equally important to avoid biofilm-associated illnesses in clean operations including implant implantation.[3]

Clinical and Economic Impact

By lowering SSI rates, appropriate prophylaxis reduces hospital stays, readmissions, and the need for expensive interventions like prolonged antibiotic medication or reoperations. On the other hand, improper prophylaxis-whether it be delayed, poorly selected, or used for an extended period of time-contributes to the rise in antimicrobial resistance and the burden on healthcare.[5]

Indications in clean vs clean-contaminated vs contaminated surgery

Clean Surgery

Clean procedures, such as hernia repair and thyroidectomy, entail incisions that do not reach the respiratory, gastrointestinal, or genitourinary tracts and are free of inflammation or infection. For regular clean procedures, prophylactic antibiotics are typically not recommended unless foreign bodies or prosthetic implants are placed.

Because biofilm formation and foreign body colonization enhance the risk of SSI, implant presence requires prophylaxis. In these situations, one preoperative dose is usually adequate.[4]

Clean-Contaminated Surgery

Colorectal resections, cholecystectomy, and hysterectomy are examples of clean-contaminated procedures that entail controlled entrance into tracts colonized by endogenous flora, such as the pulmonary, gastrointestinal, or genitourinary systems. For these treatments, antibiotic prophylaxis is highly recommended to avoid contamination by local bacteria. Cefazolin and metronidazole are commonly used in regimens to treat both aerobic and anaerobic bacteria. Research shows that proper prophylaxis significantly reduces surgical site infections (SSIs) in clean-contaminated operations when compared to no antibiotics.

Contaminated Surgery

Gross gastrointestinal spills, traumatic wounds, and procedures involving infected or inflamed tissue can all result in contaminated wounds. In this case, prophylaxis turns into therapeutic antibiotic treatment, which frequently calls for the administration of broad-spectrum medications both during and after surgery. Because of large bacterial loads and established tissue colonization, clean-contaminated criteria are insufficient on their alone. Aggressive source control, prolonged antibiotic courses, and culture-directed therapy are some infection control tactics.[5]

Choice of Antibiotics Based on Procedure: Detailed Information

The American Society of Health-System Pharmacists (ASHP) Clinical Practice Guidelines on Antimicrobial Prophylaxis in Surgery, which emphasize targeted spectrum of coverage, appropriate timing, dosing, safety, and stewardship to effectively prevent SSIs while minimizing harm and resistance, are among the authoritative clinical guidelines and evidence-based literature that support the overview of antibiotic selection criteria for surgical prophylaxis. Owens CD, Stoessel K. "Surgical site infections: epidemiology, microbiology and prevention.In order to maximize results, this often cited review emphasizes the significance of choosing antimicrobials with activity against anticipated pathogens, attaining sufficient tissue concentrations at the moment of incision, and employing the shortest effective period. "Assessment of Surgical Site Infections and Their Risk Factors in Abdominal Surgeries," Healthcare Bulletin, 2025. This recent study underscores tailoring antibiotic choice based on procedure-specific microbial profiles, patient factors, and resistance patterns**.**[2]"Factors Contributing to Surgical Site Infections: A Comprehensive Systematic Review," Clinical Practice, 2023, which reviews current best practices in antimicrobial selection emphasizing pharmacokinetics, safety, and ecological impact**.** Rezaei AR, "Surgical site infections: a comprehensive review," Journal of Trauma and Injury, 2025. This comprehensive review details the evidence-based approach to antibiotic prophylaxis including antibiotic selection and stewardship**.** [3]

Pathogen Coverage

Antibiotics that target the microorganisms most likely to infect the surgical site are necessary for effective prevention. Skin flora like coagulase-negative staphylococci and Staphylococcus aureus are common during clean procedures. Gram-negative bacilli and anaerobes must be covered in clean-contaminated operations involving the gastrointestinal or genitourinary tracts. Choosing agents with a restricted but suitable spectrum lowers the chance of developing resistance and helps avoid overusing broad-spectrum antibiotics.[4]

Pharmacokinetics and Tissue Penetration

At the time of incision and throughout the procedure, the antibiotic must reach effective concentrations in serum and tissues. Two crucial characteristics are sufficient half-life and quick absorption. For instance, the first-generation cephalosporin cefazolin has acceptable pharmacokinetics, strong tissue penetration, and a half-life that allows for intraoperative dosing every three to four hours if necessary. Medications that require extended infusion, like vancomycin, must be administered at specific times in order to remain effective.

Safety Profile

The potential of allergic reactions, toxicity, and unfavorable drug interactions are all included in safety concerns. First-generation cephalosporins are preferable medications in the majority of preventive situations because they are typically well tolerated and have a low frequency of side effects. For patients with allergies or those at risk for resistant organisms, alternatives like clindamycin or vancomycin are used; however, their use must be cautious due to their increased risk of adverse events.[4]

Minimal Impact on Normal Flora and Resistance

The colonization of opportunistic and resistant bacteria like Clostridium difficile can be avoided by using antibiotics that alter the patient's normal microbiome as little as possible. For this reason, narrow-spectrum antibiotics that are limited to the predicted pathogens are preferred over broad-spectrum ones. Stewardship guidelines govern the length and selection of prophylaxis because overuse and extended exposure to antibiotics raise the risk of resistance development.[3]

Cost-Effectiveness
Cost is a practical factor that affects the selection of antibiotics, particularly in environments with limited resources. Cefazolin is economical because it strikes a good balance between cost, safety, and efficacy. Shorter courses (single dose or less than 24 hours) lower drug use and antibiotic-related complication management costs, supporting both clinical efficacy and economic stewardship.[5]

Duration of Administration
There is evidence that the best prophylactic is a single preoperative dose or stopping the medication within 24 hours of operation. Long-term post-operative antibiotic courses enhance side effects and the selection of resistant organisms but do not further lower the incidence of SSI. Consequently, in contemporary surgical practice, short-duration prophylaxis is standard.[4]

Common Antibiotics by Procedure Type
Clean Procedures
Clean surgeries involve uninfected operative sites without exposure to endogenous flora surgery for the breasts, hernia repair). Preferred Agent: Because of its superior efficacy against certain Gram-negative bacteria as well as Gram-positive skin flora, such as Staphylococcus aureus, cefazolin is the first-line option. Alternatives: Clindamycin or vancomycin are options for patients with beta-lactam allergies or in environments where MRSA is prevalent (Owens & Stoessel, 2008). Justification: By focusing on skin flora, narrow spectrum reduces needless broad-spectrum usage and resistance. [16]

Procedures for Clean-Contaminated
These operations (such as cholecystectomy and colorectal resection) involve controlled entry into channels lined with mucous membranes, such as the gastrointestinal, genitourinary, or respiratory systems. To defend against aerobic Gram-negative bacteria and anaerobes, a combination of metronidazole and cefazolin is advised. Other options include the use of second-generation cephalosporins having anaerobic action, such as cefoxitin or cefotetan. Justification: Compared to clean surgery, mixed flora with aerobic and anaerobic organisms requires more extensive covering.[4]

Contaminated and Dirty Procedures
These include wounds that have been severely polluted, traumatized, or have an existing infection (such as an abscess or perforated colon). Ideal Routines: Until culture findings direct treatment, broad-spectrum antibiotics as piperacillin-tazobactam, carbapenems, or combination treatments are employed empirically. Justification: Due to the prevalence of multidrug-resistant pathogens and polymicrobial illnesses, extensive initial coverage is required. [5]

Orthopedic and Implant Surgeries
The risk of infection is increased during procedures involving implants, such as vascular grafts or joint replacements. Preferred Agent: Cefazolin is preferred because to its high bone penetration, acceptable pharmacokinetics, and efficacy against cutaneous flora. Alternatives: Vancomycin for those with allergies or MRSA colonization. Justification: Agents that are effective against common skin pathogens are needed to prevent biofilm-associated infections on implants. [20]

Timing: Pre-incision guidelines
Prophylactic antibiotics should be administered 60 minutes before to skin incision for the majority of agents in order to maximize their effectiveness, according to substantial data. This timing guarantees that at the crucial point of bacterial penetration, the antibiotic is at its highest concentrations in tissues. Numerous studies have supported this, such as the groundbreaking randomized trial by Classen et al. (1992), which showed that administration within a two-hour window prior to incision, particularly in the vicinity of 30 to 60 minutes prior, significantly lowers SSI rates compared to later administration.[6] In order to finish infusion before incision, administration of antibiotics with longer infusion periods, like vancomycin and fluoroquinolones, must begin within 120 minutes of the incision. It has been frequently demonstrated that postponing administration following incision increases the risk of SSI by leaving the wound vulnerable during first infection.[2] These insights have been refined by recent large cohort investigations, which show that the ideal administration window is roughly 10–25 minutes before to incision, where SSI rates are minimal. A higher risk of infection is associated with timing outside of this window, both earlier and later.[23] Operational coordination between the surgical and anesthesiology teams, integration into surgical safety checklists, and system-based reminders are necessary to guarantee accurate timing. These approaches have been successful in raising compliance and lowering the incidence of SSI .[24]

Redosing in prolonged procedures
Pharmacokinetic Justification
The half-lives of the most widely used preventive antibiotics, such cefazolin, are comparatively short—roughly 1.5 to 2 hours in healthy adults. Antibiotic concentrations drop below therapeutic thresholds during procedures that take longer than two half-lives (usually three to four hours), endangering the preventive effect. Similarly, regardless of the

length of the procedure, significant intraoperative blood loss (>1500 mL) can remove or redistribute medications, requiring redosing. Effective antimicrobial concentrations at the surgical site are determined by the drug's half-life, tissue penetration, and the dynamics of antibiotic clearance, all of which contribute to the pharmacokinetic rationale for antibiotic redosing during surgery.

Antibiotic Half-Life and Tissue Levels

An antibiotic's half-life (t½) is the amount of time needed for its plasma concentration to drop by half. The majority of preventive antibiotics have brief half-lives of 1.5 to 2 hours, including cefazolin, a first-generation cephalosporin that is frequently used in surgical prophylaxis. Ineffective prophylaxis results from concentrations falling below the minimum inhibitory concentration (MIC) of target pathogens throughout extended operations in the absence of redosing . [33]

Research has shown that to effectively prevent bacterial contamination and colonization, minimum serum and tissue concentrations above the MIC must be maintained throughout the bulk of the operating time. This is the rationale behind the suggestion to retake antibiotics after two half-lives .[24]

Impact of Blood Loss and Volume of Distribution

Even if the surgery takes less time, significant intraoperative blood loss lowers effective tissue concentrations by depleting circulating antibiotic levels through dilution and clearance mechanisms. In order to make up for the loss, patients with significant bleeding (>1500 mL) would need to take additional or earlier doses.[34] Under surgical stress, volume of distribution may change, changing pharmacokinetics and requiring dosage modifications based on patient characteristics such obesity or renal function.[4]

Supporting Clinical Evidence

These pharmacokinetic concepts are incorporated into recommendations for intraoperative redosing to maintain bactericidal concentrations in clinical practice guidelines such as those from ASHP. In observational and interventional studies, there is a correlation between higher SSIs and failure to redose during lengthy or high blood loss procedures.[22]

Clinical Evidence and Guidelines

In order to maintain safe antibiotic levels, surgical prophylactic guidelines strongly advise redosing:

The American Society of Health-System Pharmacists (ASHP) recommends intraoperative redosing when the duration of surgery exceeds two antibiotic half-lives or when excessive blood loss occurs. Multiple studies demonstrate that failing to redose appropriately during prolonged procedures significantly increases SSI risk. [23].For example, cefazolin should be redosed every 3 to 4 hours intraoperatively. For antibiotics with longer half-lives, dosing intervals may be adjusted accordingly.[24]

Discontinuation-avoiding prolonged use

Prophylactic antibiotics must be stopped promptly after surgery in order to avoid negative consequences and fight antibiotic resistance. Research indicates that prolonging prophylaxis after surgery for more than 24 hours does not lower surgical site infections (SSIs), but it does considerably raise hazards such medication toxicity, Clostridium difficile infections, and the emergence of resistant organisms. For the majority of procedures, prophylaxis should be stopped within 24 hours, according to recommendations from the CDC, WHO (2016), and reviews by Owens & Stoessel (2008). Long-term antibiotic courses are discouraged because they increase needless antibiotic exposure and resistance development while providing no further benefit in preventing SSI.[24]

PREOPERATIVE STRATEGIES

Preoperative Bathing and Nasal Decolonization

There is insufficient evidence to conclude that preoperative bathing with antiseptic compounds like chlorhexidine lowers SSIs in comparison to routine bathing. Nonetheless, preoperative chlorhexidine washing and nasal decontamination that targets Staphylococcus aureus carriers with intranasal mupirocin or povidone-iodine considerably lowers the incidence of SSI, particularly in orthopedic and cardiovascular procedures. By reducing the bacterial load at the primary colonization site, nasal decolonization stops pathogens from spreading to the surgical site. [25]

Glycemic Control

Because hyperglycemia significantly raises the risk of surgical site infections (SSIs), perioperative glycemic management is crucial. Research indicates that individuals with hyperglycemia are roughly twice as likely to experience infection, delayed wound healing, and poorer surgical results. Regardless of diabetes status, intensive glucose control has been shown to lower SSI rates, particularly in the early postoperative phase.[26]

Hair Removal Practices
Since the existence of hair is not definitely linked to an increased risk of SSI, hair removal should be avoided if at all possible. It is better to use depilatory creams or electric clippers instead of razors if hair removal is required for surgical exposure or dressing application. Razor shaving greatly raises the risk of SSI because tiny skin abrasions allow bacteria to enter. The timing of hair removal is also crucial; removing hair the day before surgery is linked to somewhat fewer infections than doing so just before .[27]

Smoking Cessation
Due to its negative effects on blood flow, oxygenation, and immunological function, which impede wound healing, smoking is a separate risk factor for SSIs. SSI rates are much higher among current tobacco users. Quitting smoking four weeks or more prior to surgery lowers mortality, postoperative infections, and wound problems. Tissue hypoxia and vasoconstriction brought on by nicotine and other tobacco byproducts hinder recovery and make tissues more vulnerable to infection. Smoking abstinence is therefore highly advised prior to surgery.[28] When combined with strong surgical technique and antimicrobial prophylaxis, these preoperative interventions form comprehensive SSI prevention bundles that enhance surgical outcomes.[29]

Intraoperative Strategies
Surgical Hand Preparation:
In order to reduce the risk of surgical site infections (SSIs), surgical hand preparation is a crucial step in infection control during surgery. The goal is to lower the bacterial counts on the surgical team's hands and forearms. The objective is to minimize resident flora and eliminate transitory germs while maintaining the integrity of the skin.

Methods of Surgical Hand Preparation
Surgical hand scrubbing (SHS) with antibacterial soap, such as povidone-iodine or chlorhexidine gluconate, has historically been the norm. SHS include using a sterile brush or sponge to scrub hands and forearms for two to five minutes, paying particular attention to nails, fingertips, and interdigital regions. Thorough cleaning and drying with sterile towels come next. This mechanical process uses the soap's antibacterial qualities to eliminate dirt and flora.[30]
Surgical hand rubbing (SHR) utilizing alcohol-based handrubs has become more popular in recent years. Rapid bactericidal effects, long-lasting antibacterial activity, and improved skin tolerance are all features of alcohol-based rubs. The method is rubbing the product all over the hands and forearms for one to three minutes until the hands are completely dry. According to WHO standards, SHR is preferred over traditional scrubbing in environments with low water quality or availability.[25]

Efficacy and Guidelines
SHR offers comparable or better microbial reduction than standard SHS, with improved adherence and shorter duration, according to numerous studies and systematic reviews. Maintaining the integrity of the skin on the hands and forearms is essential because damaged skin lowers the effectiveness of antibiotics and raises the risk of infection. Before preparing, it is advised to take off jewelry and artificial nails, wash your hands with non-medicated soap if they are obviously dirty, and keep your hands up. Although there is little data, regular hand rubs may be helpful for procedures that last more than two hours. The decision between SHS and SHR may be influenced by surgical circumstances, product availability, and institutional protocols.[29]

Normothermia and Oxygenation:
Surgical site infections (SSIs) can be avoided during surgery by maintaining normothermia and sufficient oxygenation.

Normothermia
During surgery, the term "normothermia" refers to keeping the patient's core body temperature between 36 and 37.5°C. The infusion of cold intravenous fluids, exposure to cool operating rooms, and anesthesia-induced vasodilation are major causes of intraoperative hypothermia.[30]

Vasoconstriction, decreased tissue oxygen delivery, weakened immunity, and delayed wound healing are all consequences of hypothermia that raise the risk of SSI. Active warming to maintain normothermia was shown in a landmark randomized controlled trial to lower SSI rates from 19% in hypothermic patients to 6% in normothermic patients after colorectal surgery. Maintaining the ambient OR temperature, warming intravenous fluids, and using forced-air warming blankets are examples of active warming techniques. Additionally, normothermia reduces heart problems and hospital stays.[31]

Oxygenation
During surgery, sufficient tissue oxygenation facilitates neutrophils' oxidative destruction of germs, which is essential for preventing infections. Some investigations have demonstrated that supplemental oxygen (usually 80% of inspired oxygen) during and for a few hours following surgery reduces surgical site infections. There is conflicting information, nevertheless, with some worries regarding oxygen poisoning and lung issues at extremely high FiO2. In

order to strengthen host defenses, it is generally agreed upon to maintain adequate oxygen delivery to surgical wounds (by optimizing breathing, hemoglobin, and cardiac output). Oxygenation needs to be adjusted for the surgical setting and patient risk.[32]

Aseptic Technique and Limiting Operating Room (OR) Traffic:

Aseptic Technique

In order to prevent microbiological contamination during surgery, aseptic technique entails a series of procedures to establish and preserve a sterile area. Sterile gowning and gloving, the use of surgical masks and caps, careful hand washing prior to putting on gloves, and sterile draping of the surgical site are important elements. Every equipment and implant needs to be disinfected, and handling them carefully reduces the chance that sterile barriers may be compromised. Additionally, sterile technique entails keeping sterile drapes in the right place, minimizing needless contact with sterile regions, and following instrument handling procedures. Hospital protocols and published recommendations encourage proper aseptic technique, which is essential for breaking the chain of infection.[33]

Limiting Operating Room Traffic

Airborne microbial contamination in the OR is increased by frequent door openings and excessive personnel movement. According to studies, every door opening might lead to an increase in bacterial load and particle counts since it disrupts airflow and introduces contaminants. Environmental contamination can be decreased by decreasing movement, limiting needless access and leave, and limiting the number of employees in the OR. Since high OR traffic is a known independent risk factor for SSIs, less traffic is correlated with lower SSI rates. Putting procedures in place to maximize OR staffing, scheduling, and communication aids in efficiently reducing traffic. Although OR ventilation systems are important, human variables must be controlled.[34]

Antiseptic Wound Irrigation

By lowering the bacterial burden, intraoperative wound irrigation with antiseptic treatments like diluted povidone-iodine or chlorhexidine right before wound closure dramatically lowers SSIs. Antiseptic irrigation lowers the risk of SSI by almost 40% as compared to no irrigation, according to systematic reviews that include 41 RCTs. Concerns about resistance make antibiotic irrigation less popular; saline irrigation by itself does not considerably lower SSIs when compared to no irrigation.[35]

Minimally Invasive Approach Advantages:

Laparoscopic and robotic procedures are examples of minimally invasive surgery (MIS), which entails fewer incisions, less tissue damage, and less exposure of interior structures. Due to fewer incisions, less blood loss, less dead space, and quicker recovery, MIS is linked to lower rates of SSI. By reducing tissue damage and contamination, the use of tubular retractors or endoscopic techniques may possibly lower postoperative infections.[36]

Postoperative Strategies

Incision Care Protocols

Maintaining a clean, dry wound environment and using aseptic dressing change techniques are essential components of proper postoperative incision care. Infection risk is decreased by avoiding needless manipulation and invasive procedures like routine wound packing unless clinically essential. Standard procedures include limiting exposure to possible pollutants and using sterile bandages.

It is crucial to regularly check for early indications of infection, such as redness, swelling, temperature, discharge, or worsening pain. According to some standards, wounds should be cleaned with saline, and topical antimicrobials should not be routinely applied to mostly closed wounds because their effectiveness is unknown. It has been demonstrated that replacing surgical gloves and tools prior to wound closure lowers the incidence of postoperative infections.[37]

Patient Education

Patients are empowered to actively participate in SSI prevention when they receive education on wound care, cleanliness, infection warning signals, and adherence to follow-up appointments. Research highlights the significance of educating patients about wound care, antibiotic use, infection risks, and when to consult a doctor after being discharged. Patient involvement increases early diagnosis of problems and promotes adherence to preventative actions. During hospital stays and after release, education should be given both orally and in written or multimedia formats.[38]

Early Identification and Management

When patients are educated about wound care, cleanliness, infection warning signs, and keeping follow-up appointments, they are more equipped to take an active role in preventing SSI. The need of teaching patients about wound care, antibiotic use, infection risks, and when to see a doctor after being released from the hospital is highlighted by research. Patient engagement encourages adherence to preventative measures and boosts early issue detection. Oral instruction as well as written or multimedia instruction should be provided both during hospital stays and after discharge.[39]

PREVENTIVE BUNDLES AND GUIDELINES

WHO Guidelines Summary

First published in 2016 and updated in 2018, the World Health Organization's Global Guidelines for the Prevention of Surgical Site Infection serve as the foundation for surgical site infection prevention. These recommendations include 29 specific suggestions and 28 systematic reviews of the available data. According to quality improvement initiatives and recent implementation studies, these guidelines continue to be the gold standard for SSI prevention strategies in preoperative, intraoperative, and postoperative surgical care.[40] According to the WHO guidelines, antimicrobial prophylaxis should be given within 120 minutes of the surgical incision, preferably within 60 minutes for optimal tissue concentrations. When it comes to skin antisepsis, alcohol-based solutions that contain chlorhexidine gluconate are the best choice. It is still best to give patients 80% of the oxygen they breathe in during general anesthesia with endotracheal intubation. If at all possible, this should be kept up for 2 to 6 hours after the surgery. Before surgery, patients should shower with soap, use clippers to remove hair if necessary, and use mupirocin to kill Staphylococcus aureus carriers' nasal bacteria.[41]

CDC & SHEA/APIC Recommendations

To assist acute-care hospitals in prioritizing and implementing SSI prevention initiatives, the 2022 Compendium update from the CDC/SHEA/IDSA/APIC/AHA/Joint Commission provides helpful recommendations in a framework that contrasts "essential practices" and "additional approaches." The 2023 peer-reviewed paper "Strategies to prevent surgical site infections in acute-care hospitals: 2022 update" is the most comprehensive update, classifying interventions into evidence-based tiers for hospital adoption. All acute-care hospitals should implement necessary protocols in accordance with these contemporary standards. Hospitals can try to further improve results by implementing additional strategies after basic measures have been successfully established.[42] These contemporary guidelines should be followed by all acute-care hospitals. Hospitals can try to improve outcomes by implementing additional strategies after basic measures have been successfully established.

The appropriate agent should be selected based on the technique and common infections, antimicrobial prophylactics should be started within an hour of the incision (30 minutes for vancomycin), and for most procedures, prophylactics should be discontinued within 24 hours of surgery.[43] A notable multisociety position paper from 2025 from SHEA, APIC, IDSA, and PIDS advocates for strengthening facility infection prevention and control programs by ensuring that they are a key part of operational structure, resourced with the appropriate leadership and expertise, and prioritized to address all potential infectious harms. This emphasizes that SSI prevention is not merely a clinical quality initiative but requires organizational commitment and adequate resource allocation.[44]

Use of Compliance Checklists and Bundle Implementation

The use of standardized SSI prevention packages in hospitals varies greatly, according to recent implementation studies. A systematic study published in 2025 found that although hospitals were putting audits and feedback mechanisms for complex infection control bundles into place, there were significant gaps in the consistent application of all bundle components. Of the 42 institutions analyzed, only 71% conducted yearly audits of intraoperative antibiotic prophylactic adherence, and compliance with the standard 48-hour postoperative wound dressing changes (audited by only 12% of hospitals) was especially low.[45] An 11-point SSI prevention bundle was used in emergency general surgery from November 2020 to February 2023 and proved to be very successful. Across all perioperative phases, the components of the bundle produced adjusted risk reductions of 48% for superficial incisional SSI, 68% for deep incisional SSI, and 55% for intra-abdominal infections. Intriguingly, bundle application was associated with a shorter median length of stay (8 vs. 13 days) despite longer operating hours, suggesting that the severity and complications of infections that do occur are reduced when preventative bundles are used.[46]

A 64 percent relative risk reduction in SSI at 30 days following surgery was observed in a randomized controlled trial of an SSI prevention bundle in gynecological surgery, which took place between January 2019 and May 2020 (9.5% in the intervention group vs. 25.8% in the control group; p=0.005). Comorbidities, older age, and other operational characteristics were among the subgroups that consistently demonstrated bundle effectiveness.[47] According to a 10-year implementation study that examined a 4-element bundle in 47 hospitals, compliance over that period was 67.1%, demonstrating that continuous quality improvement strategies may maintain compliance. Complete implementation was consistently hampered by institutional culture resistance to change (40 percent of hospitals) and a lack of frequent audits and feedback (33 percent of hospitals).[48]

Hospital-Based Quality Improvement Initiatives

To reduce SSI, modern quality improvement programs use systematic approaches. Multidisciplinary cooperation, standardized wound dressing procedures, and thorough nursing education were the key factors in a 2023 prospective before-and-after study of a pediatric cardiothoracic SSI prevention bundle that successfully decreased SSI rates from

5.71 per 100 cases (2014) to 0.80 per 100 cases (2022). This proves that consistent, ten-year quality improvement initiatives yield compounding gains.[49] Structured audit and feedback systems, electronic compliance monitoring, multidisciplinary team approaches with surgeons, nurses, anesthesiologists, and infection preventionists, regular training updates for all surgical staff, and surveillance systems that track patterns to support early intervention are all commonly used. The most successful programs include these elements in regular departmental meetings and mortality/morbidity conferences for continued accountability and visibility.[50] Preoperative, intraoperative, and postoperative planned interventions with predefined compliance indicators significantly decreased SSI rates, according to a 2025 implementation study of SSI prevention bundles in gynecological procedures that included quality control activities.[51]

CLINICAL AND ECONOMIC IMPACT

Increased Morbidity and Mortality

According to recent data, SSI mortality is still a significant problem. A 2025 study found that 75% of deaths directly related to SSIs are caused by the infection, and the fatality rate associated with SSIs is 3%. Moreover, SSIs are linked to 11% of deaths that occur in intensive care units. Deep SSI patients have particularly poor outcomes; their in-hospital mortality rate is 3.5 times higher than controls' (4.2% vs. 1.2%, $p<0.001$).[52] A 2024–2025 cross-sectional study of gastrointestinal surgery outcomes found that among 100 patients undergoing elective or emergency gastrointestinal surgery, superficial incisional infections (SSI) were the most common type (61.1%), followed by deep incisional (22.2%) and organ/space infections (16.7%). 11.1% of SSI cases required reoperation, and 5.6% of SSI patients died; these adverse outcomes were not observed in the non-SSI group. Compared to laparoscopic procedures, which had SSI rates of 10%, open surgical techniques had significantly higher rates (23.3%).[53] In 2024–2025, a multicenter surveillance study with 3,090 patients in India revealed that the incidence of SSI was 5.2% (95% CI: 4.5–6.1), with notable heterogeneity between sites (1.5% to 13.5%). The median length of stay was 7 days for non-infected patients and 17 days for SSI patients, indicating significant morbidity even among SSI survivors. This duration was identified as a significant risk factor, with an SSI rate of 2.3% for shorter procedures and 9.0% for surgeries exceeding 120 minutes.[54]

Surveillance for Hospital Readmissions & Prolonged Stay

Recent economic analyses have repeatedly demonstrated that SSI significantly lengthens hospital stays. According to a 2023–2024 analysis, the median length of stay for SSI patients is 11 days longer than expected. After accounting for index admissions, readmissions, and outpatient visits, the overall incremental length of stay per SSI is 7.8 days for Premier patients and 9.3 days for Medicare patients. The gastrointestinal surgery study showed that the mean hospital stays for SSI patients were 14.6 ± 4.2 days, whereas the mean hospital stays for non-infected patients were 7.4 ± 2.5 days ($p < 0.001$).[55] The effects of deep SSI are particularly persistent, as evidenced by the 81% hospital readmission rate among patients with deep SSI compared to matched controls.

SSI patients were hospitalized for an average of 8 days instead of 13 days in the usual care group when the emergency general surgery SSI prevention bundle was put into place. Despite the longer operating times for bundle patients, this represents a 38% decrease.[56] In these situations, readmission rates are significantly higher, with SSI patients five times more likely to be readmitted than patients without infection. Readmissions have serious financial consequences because they require more hospital beds, staff time, and medical supplies, and they divert resources from other patients.[57]

Cost Burden and Healthcare Resource Utilization

The financial strain on SSIs continues to increase. A comprehensive review of health economics in 2023–2024 found that the global economic costs of SSIs range from 1.47 to 19.1 billion Eurodollars. Additionally, there is a strong link between the costs associated with SSI and poor patient outcomes, readmissions, reoperations, and longer hospital stays. The study emphasized that the financial cost of SSI is particularly high in low- and middle-income countries (LMICs), which have a much higher prevalence of the condition but fewer management resources.[9] According to thorough cost evaluations, the estimated case costs for patients with SSI in European healthcare systems are approximately double those of patients without infection; estimates range from €19,008 for SSI patients to €9,040 for controls. Hospitalization costs for deep SSI average €9,016 while controls cost €5,409.

Total incremental costs per SSI, including all stages of care, are expected to be $18,626 for Medicare patients and $20,979 for Premier patients.[58] Recent research indicates that SSI prophylaxis is incredibly cost-effective. Since preventing a single SSI can save $5,000 to $20,000 or more in direct hospital expenses, evidence-based prevention strategies are economically justified even in settings with limited resources. It is estimated that by using evidence-based practices appropriately, 55% of SSIs could be prevented, greatly improving the healthcare system.[59] The additional financial burden extends to antibiotic consumption as well, since SSI patients require antibiotic medication for almost three times as long as control patients. Although the number of ER visits for SSI groups increases significantly after discharge, additional procedures for debridement, wound care, or device removal increase costs even more.[60]

FUTURE PERSPECTIVES

Antimicrobial-Coated Sutures

Recent meta-analyses and systematic reviews have provided compelling evidence for the use of triclosan-coated sutures in SSI prevention. In 2024, a comprehensive meta-analysis of 26 randomized controlled trials and 9 observational studies revealed that antimicrobial sutures significantly reduced the risk of SSIs (RCTs: OR 0.74; 95% CI: 0.63-0.87; OBS: OR 0.61; 95% CI: 0.48-0.76). Certain conclusions are constrained by moderate to low quality data, despite the notable consistency of findings across studies.[61] An updated systematic review and meta-analysis from 2025 specifically looked at 31 randomized clinical trials with 17,968 participants and found moderate-certainty evidence that triclosan-containing sutures reduced the risk of SSI (RR 0.75; 95% CI: 0.65-0.86). The trial sequential analysis demonstrated that the cumulative evidence surpassed the trial sequential monitoring barrier for benefit, indicating that there is sufficient evidence for a 15% relative risk reduction and that further trials are unlikely to alter the findings. Curiously, SSIs with both deep and superficial incisions demonstrated a greater protective effect than infections in organs or spaces.[62]

Triclosan-coated sutures were found to reduce postoperative wound infection rates by 24% (risk ratio 0.76; 95% CI: 0.67-0.87) in a 2023 meta-analysis of 29 randomized controlled publications. Surgical departments, oncological condition presence, and wound contamination class were the subgroups that showed the most positive effect, with abdominal surgery showing the biggest influence. According to a cost-effectiveness analysis, the extra cost of up to €12 per coated suture is fair considering the decrease in hospital expenses and postoperative wound infections.[63] According to a 2024 study, antimicrobial-coated sutures specifically for fascial closure in gastrointestinal surgery significantly decreased the risk ratio for incisional SSIs, reaching 0.79 (95% CI: 0.63-0.99). Studies on real-world uses continue to demonstrate their effectiveness; a retrospective analysis found that 99.3% of wounds closed with sutures coated in triclosan did not develop an infection.[64]

Negative-Pressure Wound Prophylaxis

The evidence in favor of negative-pressure wound therapy (NPWT) is still expanding, despite inconsistent results depending on the clinical setting. A 2025 systematic review of ten high-quality randomized controlled trials evaluating negative pressure wound therapy (NPWT) in abdominal and gastrointestinal surgeries found that NPWT significantly reduced SSI rates in high-risk populations by reducing seroma formation and wound dehiscence, particularly in contaminated and emergency abdominal surgeries. The study did, however, highlight the importance of appropriate patient selection by pointing out that some studies did not find any discernible benefits in lower-risk procedures.[65] Several randomized controlled trials were included in a 2024 meta-analysis that found evidence of the benefit of incisional NPWT for SSI prevention to be moderately certain. Pooling only RCTs (792 patients) showed a -12% (95% CI: -22% to -1%) risk difference in favor of NPWT. Higher protective effects were found in studies where the SSI incidence in the control arm was ≥20%, suggesting that high-risk groups would gain the most.[66] In a multicenter randomized prospective study conducted in 2025, among general surgery patients undergoing emergency laparotomy (n=90), 10 out of 45 patients (22.2%) in the study group and 20 out of 45 patients (44.4%) in the control group suffered from SSI. The difference was significant (p=0.025). While ciNPWT did not significantly alter deep SSI rates, it did significantly lower superficial SSI rates (20% vs. 40%, p=0.038).[67]

The extensive 2025 NEPTUNE experiment, a randomized controlled trial, found that routine application of iNPWT during emergency laparotomy did not prevent SSI more than alternative dressings. This negative finding in the emergency surgery group illustrates how effectiveness varies based on the clinical context. A comprehensive evaluation of preventive NPWT in closed surgical wounds revealed evidence of efficacy beyond SSI reduction, including decreased wound dehiscence, decreased drainage output and time, decreased readmission incidence, and decreased need for wound debridement.[68] Current research indicates that NPWT is especially useful in high-risk groups with predicted SSI rates ≥20%, surgeries involving hardware or implants, obese patients, contaminated wounds, and where resource allocation permits cost-effective deployment.[69]

AI Prediction Models

With notable advancements in recent years, artificial intelligence applications for SSI prediction represent a fast developing field. An AI framework to forecast SSI in patients having surgery for metastatic spinal illness was successfully developed in a 2025 study. The gradient-boosting machine model's extraordinarily high predictive validity and reliability were demonstrated by its AUC of 0.986. The software recognized important risk indicators, such as the type of tumor, length of operation, and smoking status, and it enabled interactive physician input for real-time risk assessment.[70] In a 2025 machine learning study, XGBoost models for SSI risk stratification in a personalized medicine framework were developed using routinely collected healthcare data in orthopaedic surgery. The study showed that ML algorithms trained on structured data and clinical notes performed better than conventional statistical methods.[71] A neural network study conducted in 2025 examined the identification of SSI in electronic health records covering 28,864 surgical procedures from five different procedure types, yielding an F1 score of 0.77 (NHSN) and 0.58 (NSQIP) and an area under the receiver operating characteristic curve of 0.98 (NHSN) and 0.92

(NSQIP). The fact that a single model trained on all domains outperformed models specific to a surgery or registry is noteworthy and suggests that AI systems trained on a range of surgical populations may be better at generalization.[72] In a 2023 machine learning study for SSI prediction after lumbar surgery, four variables were associated with SSI: hemoglobin, hyperglycemia, sebum thickness, and modic alterations. When used in conjunction with visualization tools that facilitate clinician decision-making regarding SSI risk and intervention requirements, the developed prediction model demonstrated strong predictive performance.[73] Deep learning models using a range of data modalities, particularly imaging data, demonstrate excellent accuracy for predicting surgical site infections, according to a 2022 comprehensive review and meta-analysis that examined AI and machine learning for predicting surgical complications. Multimodal approaches that integrate EMR data, imaging, lab results, and clinical notes have outperformed single-modality models.[74] A successful implementation of an AI model requires several key elements, including having access to large, diverse, high-quality datasets from multiple institutions that guarantee generalizability; integrating multiple data modalities; incorporating temporal data that captures perioperative changes; rigorous external validation in various settings; making the model interpretable to gain clinician trust; integrating the model seamlessly into clinical workflows; and continuously monitoring and updating as clinical practice changes.[75]

Microbiome-Based SSI Prevention

An innovative 2024 study published in Science Translational Medicine found that endogenous microbiomes in patients before surgery account for 86% of surgical site infections (SSIs), rather than environmental contamination. Genomic analysis comparing preoperative microbiome samples with postoperative SSI isolates from 204 patients undergoing instrumented spine surgery revealed no evidence of common-source infection or between-patient pathogen transfer. Significantly, 59% of SSI isolates were ineffective with the prophylactic antibiotic, and their resistance phenotypes were significantly correlated with the patient's preoperative resistome (P=0.0002).[76]

In 2022, a comprehensive review of novel strategies for SSI prevention focused on the patient's microbiome and antibiotic resistance, emphasizing how the need for customization and the spread of antibiotic resistance will put strain on the current one-size-fits-all prophylactic guidelines. The review suggests personalized approaches that target the distinct microbiota of each patient.[77] A prospective study was carried out in 2025 to describe the preoperative rectal microbiota of 133 patients undergoing abdominal surgery using distinct "enterosignatures" (ES). It was discovered that the Firmicutes ES considerably raised SSI risk, whereas the Prevotella ES significantly reduced SSI risk. The Firmicutes-to-Prevotella ES ratio is a great, independent predictor of SSIs (odds ratio 1.35; 95% CI: 1.09-1.66; p=0.005) that could be used to identify high-risk patients prior to surgery.[78]

A scoping review conducted in 2024 found that optimizing the microbiome with probiotics, synbiotics, and postbiotics can help reduce surgical site infections and other surgical outcomes. Interventions aimed at the perioperative microbiota have been demonstrated to enhance immune responses, reduce dysbiosis brought on by antibiotics and surgery, stop bacterial translocation by fortifying the gut barrier, and cut SSIs by 85%. Specific perioperative microbiome treatments have produced remarkable outcomes. For patients undergoing pancreatic and colorectal surgery, the use of antibiotics for five days prior to surgery and fourteen days following surgery reduced the risk of SSI from 21% to 2%. Similar outcomes were demonstrated with perioperative probiotics, which accelerated bowel recovery and reduced the incidence of diarrhea by 50%. Patients undergoing liver transplants who took probiotics several weeks before surgery reported 90% fewer postoperative infections.[79]

Future research priorities include understanding how surgical stress and antibiotic exposure alter the composition of the microbiome, examining the role of gut microbiota in systemic immune function and wound healing, examining probiotic and prebiotic interventions to modulate preoperative microbiota, and identifying high-risk bacterial profiles and resistance patterns through rapid preoperative microbiome screening techniques.[80]

Antibiotic Prophylaxis Timing and Redosing

Recent meta-analyses have provided strong evidence that intraoperative redosing of preventive antibiotics during lengthy surgeries is necessary. In 2024, a comprehensive review and meta-analysis of seven observational studies with 4,671 patients found that redosing intraoperative antibiotics significantly reduced the risk of SSIs compared to non-redosing (OR=0.65; 95% CI=0.45-0.94; p=0.02). Subgroup analysis showed that redosing decreased the risk of SSI, particularly when operating time was at least 4 hours and postoperative antibiotic treatment was avoided. For procedures taking longer than three to four hours, the authors recommend intraoperative redoing to reduce the risk of infection.[81]

For surgeries lasting more than four hours, redosing after four or eight hours (depending on the drug's half-life) guarantees safe and effective surgical prophylaxis, per the Scottish NHS boards' (2022) good practice recommendations. Redosing might be required in situations where intraoperative blood loss exceeds 1,500 milliliters, and it should take the patient's unique circumstances into account.[82] The 2022 Egyptian National Guidelines for Antimicrobial Prophylaxis in Surgery state that the redosing interval should be determined from the time the preoperative dose is given, not from the beginning of the procedure. If the process takes longer than two drug half-lives or if there is a significant blood loss (>1,500 mL), a redo is necessary.[83]

Preoperative Decolonization

A comprehensive review of pre-surgical nasal decolonization of Staphylococcus aureus conducted in 2022 found that nasal mupirocin twice daily for 3–5 days is the standard approach for decolonizing both MSSA and MRSA carriers, often in combination with chlorhexidine gluconate bathing. Recolonization occurs in 30–60% of patients between seven and eighteen months after short-term nasal mupirocin treatment, but 90% of patients successfully decolonize within one week.[84]

According to a 2021 systematic review and meta-analysis that compared targeted and universal mupirocin-based decolonization, uniform mupirocin-based decolonization may reduce all SSIs, superficial SSIs, and Staphylococcus aureus-related SSIs, but it may not reduce deep SSIs or MRSA-specific SSIs in patients undergoing heart surgery. Even though screening and customized decolonization methods have shown benefits in some situations, the review stressed that universal decolonization without screening may be more cost-effective when compared to mupirocin resistance selection.[85]

According to the 2022 Health Technology Assessment, perioperative eradication of S. aureus carriage is associated with significant healthcare improvements and cost savings because it prevents S. aureus SSIs, but the advantages must be balanced against the potential for selecting mupirocin resistance. Mathematical modeling shows that universal decolonization is more economical than targeted strategies when the risk of mupirocin resistance selection is considered. A 2016 study discovered that using mupirocin nasal ointment twice a day and washing the body with chlorhexidine every day for five days reduced the incidence of S. aureus SSIs.[86][87]

CONCLUSION

Surgical site infections remain a substantial and preventable source of postoperative morbidity, death, and healthcare burden in general surgery. Their multifaceted etiology-spanning patient-related comorbidities, procedural and environmental factors, microbiological features, and institutional practices-highlights the need for an integrated, multidisciplinary approach to prevention. Evidence consistently shows that no single intervention is sufficient; rather, coordinated bundles combining preoperative optimization, meticulous intraoperative technique, timely and appropriate antibiotic prophylaxis, and vigilant postoperative care produce the most meaningful reductions in SSI rates. Emerging techniques such as antimicrobial-coated sutures, negative-pressure wound therapy, AI-driven risk prediction models, and microbiome-targeted interventions have demonstrated promise effects, particularly in high-risk patients. Strengthening adherence to international guidelines (WHO, CDC, SHEA/APIC) and maintaining hospital-wide quality improvement initiatives are critical for sustainable progress. In the end, consistent application of evidence-based methods, ongoing observation, and institutional dedication to patient safety are necessary for effective SSI prevention. Healthcare systems can greatly lower the incidence of SSI and enhance surgical results by using both tried-and-true and cutting-edge tactics.

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