



# Surgical site infections: epidemiology, microbiology and prevention

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## KEYWORDS

Epidemiology;  
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**Summary** Surgical site infections (SSIs) are defined as infections occurring up to 30 days after surgery (or up to one year after surgery in patients receiving implants) and affecting either the incision or deep tissue at the operation site. Despite improvements in prevention, SSIs remain a significant clinical problem as they are associated with substantial mortality and morbidity and impose severe demands on healthcare resources. The incidence of SSIs may be as high as 20%, depending on the surgical procedure, the surveillance criteria used, and the quality of data collection. In many SSIs, the responsible pathogens originate from the patient's endogenous flora. The causative pathogens depend on the type of surgery; the most commonly isolated organisms are *Staphylococcus aureus*, coagulase-negative staphylococci, *Enterococcus* spp. and *Escherichia coli*. Numerous patient-related and procedure-related factors influence the risk of SSI, and hence prevention requires a 'bundle' approach, with systematic attention to multiple risk factors, in order to reduce the risk of bacterial contamination and improve the patient's defences. The Centers for Disease Control and Prevention guidelines for the prevention of SSIs emphasise the importance of good patient preparation, aseptic practice, and attention to surgical technique; antimicrobial prophylaxis is also indicated in specific circumstances. Emerging technologies, such as microbial sealants, offer the ability to seal and immobilise skin flora for the duration of a surgical procedure; a strong case therefore exists for evaluating such technologies and implementing them into routine clinical practice as appropriate.

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## Introduction

The term 'surgical site infection' (SSI) was introduced in 1992 to replace the previous term

'surgical wound infection'.<sup>1</sup> SSIs are defined as infections occurring within 30 days after a surgical operation (or within one year if an implant is left in place after the procedure) and affecting either the incision or deep tissue at the operation site.<sup>2</sup> These infections may be superficial or deep incisional infections, or infections involving organs or body spaces (Figure 1).<sup>2</sup> SSIs remain a major cause of morbidity and mortality, despite

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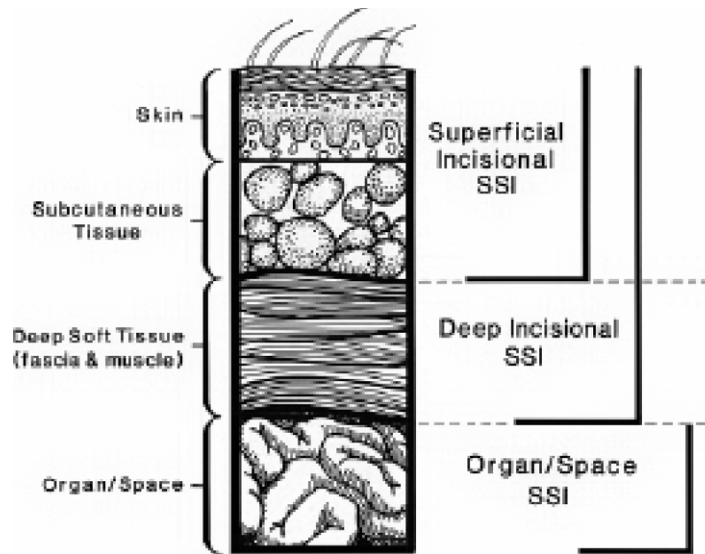


Fig. 1. Classification of surgical site infections (SSIs) according to the Centers for Disease Control National Nosocomial Infections Surveillance (CDC NNIS) system.<sup>1</sup> Reproduced with permission from Mangram *et al.*<sup>2</sup>

improvements in infection control techniques and surgical practice, and impose substantial demands on healthcare resources.<sup>2</sup> Continuing vigilance is therefore required to minimise the incidence of such infections. This requires a systematic approach, with attention to multiple risk factors related to the patient, the procedure, and the hospital environment.

## Epidemiology of SSIs

Studies of the epidemiology of SSIs are complicated by the heterogeneous nature of these infections: the incidence varies widely between procedures, between hospitals, between surgeons and between patients.<sup>3</sup> Data from the United States Centers for Disease Control National Nosocomial Infections Surveillance (CDC NNIS) system show that SSIs are the third most frequently reported nosocomial infections, accounting for 14–16% of such infections among hospitalised patients and 38% among surgical patients.<sup>2,4</sup> Similarly, European data suggest that the incidence of SSIs may be as high as 20% depending on the procedure, the surveillance criteria used and the quality of data collection.<sup>5</sup>

The increasing use of minimally invasive (laparoscopic) surgery has resulted in a decrease in the incidence of SSIs. For example, in patients undergoing cholecystectomy, the SSI rate following laparoscopic procedures has been reported to be 1.1%, compared with 4% following open procedures.<sup>6</sup> Similarly, in patients with acute appendicitis, the SSI rate has been reported to be 2% with minimally invasive procedures and 8% with open procedures.<sup>6</sup> Possible reasons for the

lower incidence of SSIs with minimally invasive procedures include the smaller incision, earlier mobilisation, reductions in postoperative pain, better preservation of immune system function, and decreased use of central venous catheters.<sup>6</sup>

## Impact of SSIs on healthcare resources

SSIs impose a substantial clinical burden. Patients with SSIs are more likely to require readmission to hospital or intensive care unit (ICU) treatment, and are at higher risk of death, than those without such infections. For example, in a case-control study involving 215 matched pairs of patients with and without SSIs, the relative risk for death associated with SSIs was 2.2 [95% confidence interval (CI): 1.1–4.5], and those for readmission and ICU treatment were 5.5 (4.0–7.7) and 1.6 (1.3–2.0), respectively.<sup>7</sup> Moreover, patients with SSIs required longer hospitalisation; the median duration of hospitalisation in infected patients was 11 days, compared with 6 days in uninfected patients, and the median extra duration attributable to SSIs was 6.5 days (95% CI: 5–8). Similarly, a review of the incidence and health economic implications of SSIs in Europe found that the mean length of extended hospitalisation was 9.8 days.<sup>8</sup> As a result, SSIs incur considerable increases in healthcare costs. In the case-control study described above, the median excess cost associated with SSIs during a first hospitalisation was \$3089 (95% CI: \$2139–4163), and this figure increased to \$5038 in patients who required readmission.<sup>7</sup> Similarly, European data suggest that the mean cost of prolonged hospitalisation due to SSIs is €325 per day.<sup>8</sup> Deep

Table 1  
Patient-related and procedure-related factors that may influence the risk of surgical site infections (adapted from Mangram *et al.* [2]).

Patient-related	Procedure-related
Age	Duration of surgical scrub
Nutritional status	Skin antisepsis
Diabetes	Preoperative shaving
Smoking	Preoperative skin preparation
Obesity	Duration of operation
Coexistent infection at a remote body site	Antimicrobial prophylaxis
Colonisation with micro-organisms (particularly <i>Staphylococcus aureus</i> )	Operating room ventilation
Altered immune response	Inadequate sterilisation of surgical instruments
Length of preoperative hospital stay	Foreign material in the surgical site
	Surgical drains
	Surgical technique
	– poor haemostasis
	– failure to obliterate dead space
	– tissue trauma

SSIs involving organs or body spaces are associated with even longer prolongations of hospitalisation, and further increases in costs, compared with SSIs that affect only the incision.<sup>2,9</sup>

Cost estimations from the literature include:

- Whitehouse *et al.*<sup>10</sup>: orthopaedic, 59 matched pairs: Median total direct cost of hospitalizations per infected patient was \$24,344, compared with \$6,636 per uninfected patient (P=0.0001).
- Hollenbeak *et al.*<sup>11</sup>: cardiothoracic (US) (CABG and valve surgery), 41 matched pairs: Mean additional cost per SSI = \$14,000–20,000.
- Hebert *et al.*<sup>12</sup>: clinical orthopaedic: Reimbursement received resulted in an estimated net loss of approximately \$15,000 per case to the hospital for the group as a whole, but approximately \$30,000 per case per Medicare patient.

### Risk factors for SSIs

A number of patient-related and procedure-related factors have been shown in univariate or multivariate analyses to influence the risk of SSIs (Table 1). Potential patient-related factors include older age, pre-existing infection, colonisation with *Staphylococcus aureus* and other potential pathogens, diabetes and smoking.<sup>2</sup> Procedure-related factors include poor surgical technique, the duration of the operation, the quality of preoperative skin preparation and inadequate sterilisation of surgical instruments.<sup>2</sup> A recent analysis has identified age and low serum albumin concentrations as the most important patient-related factors, and the quality of surgical technique as an important procedure-related factor; this analysis has also concluded that most SSIs are attributable to patient-related factors rather than procedure-related factors.<sup>13</sup>

The risk of SSI in an individual patient can be estimated using various scoring systems, such as the NNIS SSI Risk Index.<sup>2</sup> This index has a range of 0–3, and is calculated by assigning one point for each of three variables:

- Duration of surgery longer than the approximate 75th percentile of the duration of the specific operation being performed.
- The presence of a contaminated, or dirty or infected, wound.
- A score of >2 (i.e. mild systemic disease) on the American Society of Anesthesiologists (ASA) Physical Status Classification.

### Microbiology of SSIs

In most SSIs, the responsible pathogens originate from the patient's endogenous flora.<sup>2</sup> The most commonly isolated organisms are *S. aureus*, coagulase-negative staphylococci, *Enterococcus* spp. and *Escherichia coli*; however, the pathogens isolated depend on the procedure (Table 2). An increasing number of SSIs are attributable to antibiotic-resistant pathogens such as methicillin-resistant *S. aureus* (MRSA) or *Candida albicans*. This development may reflect the increasing number of severely ill or immunocompromised surgical patients, and the widespread use of broad-spectrum antibiotics.<sup>2</sup> Pathogens may also originate from preoperative infections at sites remote from the operative site, particularly in patients undergoing insertion of a prosthesis or other implant.<sup>2</sup>

In addition to the patient's endogenous flora, SSI pathogens may originate from exogenous sources such as members of the surgical team, the operating theatre environment, and instruments and materials brought within the sterile field during

Table 2  
Pathogens commonly associated with different surgical procedures (adapted from Mangram *et al.*<sup>2</sup>)

Type of surgery	Common pathogens <sup>a</sup>
Placement of graft, prosthesis or implant	<i>Staphylococcus aureus</i> ; CoNS
Cardiac	<i>S. aureus</i> ; CoNS
Neurosurgery	<i>S. aureus</i> ; CoNS
Breast	<i>S. aureus</i> ; CoNS
Ophthalmic	<i>S. aureus</i> ; CoNS; streptococci; Gram-negative bacilli
Orthopaedic	<i>S. aureus</i> ; CoNS; Gram-negative bacilli
Non-cardiothoracic	<i>S. aureus</i> ; CoNS; <i>Streptococcus pneumoniae</i> ; Gram-negative bacilli
Vascular	<i>S. aureus</i> ; CoNS
Appendectomy	Gram-negative bacilli; anaerobes
Biliary tract	Gram-negative bacilli; anaerobes
Colorectal	Gram-negative bacilli; anaerobes
Gastroduodenal	Gram-negative bacilli; streptococci; oropharyngeal anaerobes (e.g. peptostreptococci)
Head and neck	<i>S. aureus</i> ; streptococci; oropharyngeal anaerobes (e.g. peptostreptococci)
Obstetric and gynaecological	Gram-negative bacilli; enterococci; Group B streptococci; anaerobes
Urological	Gram-negative bacilli

<sup>a</sup> CoNS, coagulase-negative staphylococci.

the procedure. Such pathogens are predominantly aerobes, particularly Gram-positive organisms such as staphylococci and streptococci.<sup>2</sup>

The risk of an SSI developing after microbial contamination of the surgical site will depend on the dose and virulence of the pathogen and the patient's level of resistance, according to the relationship

$$\text{Risk of SSI} = \frac{\text{Dose of bacterial contamination} \times \text{virulence}}{\text{Resistance of patient}}$$

The risk of SSI is considered elevated when the level of contamination exceeds 10<sup>5</sup> organisms per gram of tissue,<sup>14</sup> although lower doses may be required if foreign material such as sutures is present.<sup>2</sup> The virulence of the organism relates to its ability to produce toxins or other factors that increase its ability to invade or damage tissue. Mortality rates in patients infected with highly virulent pathogens such as MRSA may be as high as 74%.<sup>15</sup>

### Strategies for SSI prevention

Strategies for the prevention of SSIs are based both on reducing the risk of bacterial contamination and on improving the patient's defences against infection. This requires a 'bundle' approach,

with attention to multiple patient-related and procedure-related risk factors. Several studies in a variety of clinical settings have shown that such approaches can produce significant reductions in SSI rates during follow-up periods of up to two years.<sup>16–22</sup>

Evidence-based guidelines for the prevention of SSIs have been published by the CDC.<sup>2</sup> The development of such guidelines is complicated by the heterogeneous nature of SSIs, which makes it difficult to generalise findings from a study in a specific patient population (e.g. orthopaedic surgery patients) to a wider setting, and by the fact that the impact of many routine practices (e.g. wearing surgical gloves) cannot be evaluated for ethical or logistic reasons.<sup>2</sup> The principal recommendations of the CDC guidelines are summarised in Table 3.

### Preoperative strategies

Preoperative strategies focus on controlling patient-related risk factors and appropriate hand/forearm antisepsis for surgical team members (Table 3). Pre-existing infections at sites remote from the operation site should be identified and treated, and if practicable elective surgery should be delayed until such infections have resolved. Obese patients should be encouraged to lose weight

Table 3

Principal (category 1) recommendations of the Centers for Disease Control and Prevention (CDC) guidelines for surgical site infection (SSI) prevention (adapted from Mangram *et al.*<sup>2</sup>)

### Preoperative

#### *Preparation of the patient*

- (1) Where possible, identify and treat remote infections, and postpone surgery until such infections have resolved (1A)
- (2) Do not remove hair around the operation site, unless it will interfere with the operation (1A)
- (3) If hair is removed, this should be done immediately before the operation, preferably with clippers (1A)
- (4) Adequately control blood glucose in diabetic patients, and avoid perioperative hyperglycaemia (1B)
- (5) Encourage tobacco cessation (1B)
- (6) Do not withhold necessary blood products as a means of preventing SSIs (1B)
- (7) Require patients to shower or bathe with an antiseptic agent on at least the night before the operation (1B)
- (8) Thoroughly wash and clean around the incision site to remove gross contamination before performing antiseptic skin preparation (1B)
- (9) Use an appropriate antiseptic for skin preparation (1B)

#### *Hand/forearm antisepsis for surgical team members*

- (1) Keep nails short and do not wear artificial nails (1B)
- (2) Perform preoperative surgical scrub for at least 2–5 min using an appropriate antiseptic. Scrub hands and forearms up to the elbows (1B)
- (3) After performing the surgical scrub, keep hands up and away from the body (elbows flexed). Dry hands with a sterile towel and don sterile gown and gloves (1B)

#### *Management of infected or colonised surgical personnel*

- (1) Educate and encourage surgical personnel who have signs and symptoms of transmissible infectious illness to report conditions promptly to their supervisors and occupation health service (1B)
- (2) Develop well-defined policies concerning patient care responsibilities when personnel have potentially transmissible infectious conditions (1B)
- (3) Obtain appropriate cultures from, and exclude from duty, surgical personnel with draining skin lesions until infection has been ruled out or resolved (1B)
- (4) Do not routinely exclude personnel who are colonised with organisms such as *S. aureus* or Group A streptococci unless such personnel have been linked epidemiologically to dissemination of the organism in the healthcare setting (1B)

#### *Antimicrobial prophylaxis*

- (1) Administer antimicrobial prophylaxis only when indicated and select agent according to efficacy against most common pathogens associated with a specific procedure (1A)
- (2) Administer initial dose intravenously, timed so that bactericidal concentrations are established in serum and tissues when incision is made. Maintain therapeutic concentrations in serum and tissue throughout the procedure until at most a few hours after wound closure in the operating theatre (1A)
- (3) Before elective colorectal operations, mechanically prepare the colon by use of enemas and cathartic agents. Administer non-absorbable oral antimicrobial agents in divided doses on the day before the operation (1A)
- (4) For high-risk caesarean section, administer prophylaxis immediately after the umbilical cord is clamped (1A)
- (5) Do not routinely use vancomycin for antimicrobial prophylaxis (1B)

### Intraoperative

#### *Ventilation*

- (1) Maintain positive pressure in the operating theatre with respect to corridors and adjacent areas (1B)
- (2) Maintain at least 15 air changes per hour, of which three should be fresh air (1B)
- (3) Filter all air, recirculated and fresh, through appropriate filters (1B)
- (4) Introduce all air at the ceiling, and exhaust near the floor (1B)
- (5) Do not use UV radiation in the operating theatre to prevent SSI (1B)
- (6) Keep operating theatre doors closed except as needed for passage of equipment, personnel, and the patient (1B)

#### *Cleaning and disinfection of environmental surfaces*

- (1) When visible soiling or contamination with blood or other body fluids of surfaces or equipment occurs during an operation, clean affected areas with disinfectant before the next operation (1B)
- (2) Do not perform special cleaning or closing of operating theatres after contaminated or dirty operations (1B)
- (3) Do not use tacky mats at the entrance to the operating suite or theatre for infection control (1B)

#### *Microbiological sampling*

- (1) Do not perform routine environmental sampling of the operating theatre. Perform microbiological sampling of operating theatre environmental surfaces or air only as part of an epidemiological investigation (1B)

#### *Sterilisation of surgical instruments*

- (1) Sterilise all surgical instruments according to published guidelines (1B)

*continued on next page*

Table 3, *continued*

- (2) Perform flash sterilisation only for patient care instruments that will be used immediately (e.g. to reprocess a dropped instrument). Do not use flash sterilisation for reasons of convenience, as an alternative to purchasing additional instrument sets, or to save time (1B)

#### *Surgical attire and drapes*

- (1) Wear a surgical mask that fully covers the mouth and nose when entering the operating theatre if an operation is about to begin or already under way, or if sterile instruments are exposed. Wear the mask throughout the operation (1B)
- (2) Wear a cap or hood to cover fully the hair on the head and face when entering the operating theatre (1B)
- (3) Do not wear shoe covers for the prevention of SSI (1B)
- (4) Wear sterile gloves if a surgical team member. Put on gloves after donning surgical gown (1B)
- (5) Use surgical gowns and drapes that are effective barriers when wet (i.e. materials that resist liquid penetration) (1B)
- (6) Change scrub suits that are visibly soiled, contaminated and/or penetrated by blood or other potentially infectious materials (1B)

#### *Asepsis and surgical technique*

- (1) Adhere to principles of asepsis when placing intravascular devices or when administering intravenous drugs (1A)
- (2) Handle tissue gently, maintain effective haemostasis, minimise devitalised tissue and foreign bodies (e.g. sutures, charred tissue, necrotic debris), and eradicate dead space at the surgical site (1B)
- (3) Use delayed primary skin closure or leave incision open to heal by second intention if the surgical site is considered to be heavily contaminated (1B)
- (4) If drainage is necessary, use a closed suction drain. Place drain through a separate incision distant from the operative incision. Remove drain as soon as possible (1B)

#### *Postoperative incision care*

- (1) Protect an incision that has been closed primarily with a sterile dressing for 24–48 h postoperatively (1B)
- (2) Wash hands before and after changing dressings and any contact with the surgical site (1B)

#### *Surveillance*

- (1) Use CDC definitions of SSI without modification for identifying SSI among surgical inpatients and outpatients (1B)
- (2) For inpatient case-finding (including readmissions), use direct prospective observation, indirect prospective detection, or a combination of direct and indirect methods for the duration of hospitalisation (1B)
- (3) For outpatient case-finding, use a method that accommodates available resources and data needs (1B)
- (4) For each patient undergoing an operation chosen for surveillance, record those variables shown to be associated with increased SSI risk (e.g. surgical wound class, duration of operation, etc.) (1B)
- (5) Periodically calculate operation-specific SSI rates stratified by variables shown to be associated with increased SSI risk (e.g. NNIS risk index) (1B)
- (6) Report appropriately stratified, operation-specific, SSI rates to surgical team members. The optimum frequency and format for comparisons of SSI rates will be determined by stratified case-load rates and the objectives of local continuous quality improvement initiatives (1B)

Category 1 recommendations are 'strongly recommended for implementation', and are supported by well designed clinical, or epidemiological studies; category 1A and 1B recommendations differ only in the strength of the supporting evidence.

before surgical operations and smokers should be encouraged to stop smoking (although such lifestyle modifications may be unrealistic for many patients). On the night before the operation, the patient can wash or shower with an antiseptic agent, and immediately before the operation the skin should be adequately cleaned with an antiseptic solution. However, hair removal should be avoided unless it is likely to interfere with the operation. If hair removal is necessary, clippers should be used rather than shaving, since there is evidence that shaving can result in microscopic skin cuts that can act as foci for subsequent colonisation and infection.<sup>2,23</sup>

Short courses of antimicrobial prophylaxis are widely used to reduce SSI risk. The aim of this

approach is not to sterilise tissue, but to reduce intraoperative contamination to levels where it does not overwhelm the patient's defences.<sup>2</sup> Antimicrobial prophylaxis is primarily indicated in elective procedures in which skin incisions are closed in the operating theatre. The choice of agent should be based on the pathogens most commonly associated with the procedure being performed (see Table 2). In practice, broad-spectrum beta-lactam agents (particularly cephalosporins) are most widely used, with an agent such as metronidazole being added if necessary to provide cover against anaerobes; vancomycin is not recommended for routine prophylaxis (Table 3). The first dose should be timed to ensure that bactericidal concentrations

are achieved in serum and tissue at the time of the incision, and these concentrations should then be maintained for up to a few hours after wound closure in the operating theatre.

Surgical personnel should undertake a thorough surgical scrub before donning surgical gowns and gloves. Personnel who are colonised or infected with potential pathogens should be encouraged to report their condition, and procedures developed to prevent transmission of pathogens from colonised personnel to the patient.

### Perioperative strategies

The CDC guidelines emphasise the importance of good surgical technique and aseptic precautions for the prevention of SSIs. Good surgical technique requires attention to the maintenance of haemostasis, removal of devitalised tissue and foreign bodies as completely as possible, and elimination of dead space at the surgical site. Gloves, facemasks, caps, gowns and sterile drapes should be used to minimise transmission of potential pathogens to the wound. Surgical instruments should be adequately sterilised according to published guidelines; flash sterilisation should be reserved only for instruments intended for immediate use (for example, an instrument that has been inadvertently dropped during the operation).

It should be noted that despite precautions such as these, some contamination of the surgical site is inevitable because some endogenous bacteria remain even after excellent preoperative preparation of the site.<sup>24</sup> The use of emerging technologies such as microbial sealants (see the paper by Wilson in this supplement) therefore warrants attention in order to reduce the risk of contamination further.

### Postoperative strategies

The risk of SSI can persist for up to 30 days after a surgical operation or for as long as one year after an operation in which the patient is given an implant; indeed, a significant proportion (12–84%) of SSIs are first detected after the patient has been discharged from hospital.<sup>2</sup> The CDC guidelines recommend that incisions that have been closed by primary intention should be protected by sterile dressings for 24–48 h, and that personnel should use sterile technique when changing dressings on any kind of skin incision (Table 3).

### Surveillance

Surveillance of SSIs, and reporting appropriate data back to surgeons, have been shown to be effective

components of strategies to reduce SSI risk.<sup>2,25</sup> The CDC guidelines recommend that both direct (based on observation of the surgical site by appropriate medical personnel) and indirect (based on retrospective review of patients' records and discussions with clinical staff) methods should be used to document the incidence of SSIs associated with specific procedures and that these data should be reported back to the surgical team.

### Conclusion

SSIs impose a substantial burden of mortality and morbidity, which in turn imposes heavy demands on healthcare resources due to prolonged hospitalisations. Furthermore, in addition to the increased healthcare costs associated with SSIs, there are indirect costs resulting from lost productivity on the part of the patients and their families. SSIs therefore continue to pose an important clinical challenge.

It is important to recognise that much of this burden of morbidity and mortality associated with SSIs is preventable. There is good evidence that attention to multiple patient-related and procedure-related risk factors leads to a decrease in SSI risk in diverse clinical settings. In addition, emerging technologies such as microbial sealants offer the potential for assisting in the mobilisation of skin flora which may assist in further reductions in infection rates and hence savings in the healthcare costs associated with SSIs. There is a strong case for evaluating such technologies, and for considering implementing them into routine clinical practice as appropriate.

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