Surgical Site Infections

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There has been a change in vernacular with respect to infections relating to surgical procedures, owing to confusion between infections of surgical incisions and those of traumatic wounds. Infections of surgical incisions are now referred to as surgical site infections (SSIs) [1]. Surgical site infections are recognized as a common surgical complication, occurring in about 3% of all surgical procedures and in up to 20% of patients undergoing emergency intra-abdominal procedures [2]. Potential complications include tissue destruction, failure or prolongation of proper wound healing, incisional hernias, and occasionally bacteremia. Additionally, recurrent pain and disfiguring and disabling scars may also result. Surgical site infections result in substantial morbidity, prolonged hospital stays, and increased direct patient costs. All of these factors have a substantial impact on patients and hospitals, and create a huge economic burden on the United States health care system [3]. Minimizing SSIs is a top priority for surgeons and hospitals to ensure the safest environment for patients undergoing surgery.

Definitions

What constitutes an SSI? Even experts disagree with respect to the appearance of the incision [2]. Is it cellulitis of the incision without drainage, or nonpurulent drainage without cellulitis? Is any incision infected that must be reopened, or is the requirement for antimicrobial therapy the best indicator? Most experts agree that surgical sites that do not harbor purulent fluid are not infected, but the lack of agreement otherwise means that any retrospective study of SSI is essentially unreliable and useless if it relied upon observation or antibiotic administration as diagnostic criteria.

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Infection may occur within the surgical site at any depth, starting from the skin itself and extending to the deepest cavity that remains after resection of an organ. Superficial SSI involves tissues down to the fascia (Fig. 1), whereas deep SSI extends beneath the fascia but not intracavitary. Organ/space infections are subfascial or intracavitary, but if related directly to an operation, are considered to be SSIs.

Cellulitis is infection-related erythema of skin (although other tissues may be affected) without drainage or fluctuance. Abscess refers to localized collections of purulent material within tissue. Necrotizing soft tissue infections (NSTIs) invade tissue widely and rapidly, causing widespread tissue necrosis. When fascia is involved, the infection is referred to correctly as necrotizing fasciitis. Myonecrosis refers to involvement of underlying muscle. However, NSTIs are exceedingly unusual in the postoperative period. Two rare but dangerous examples are SSIs caused by Streptococcus pneumoniae or Clostridium perfringens, which should be managed as would other NSTIs.

Epidemiology

Issues related to bacterial contamination of the surgical site have been well defined [2]. Clean surgical procedures are those where the operation has affected only integumentary and musculoskeletal soft tissues. Clean-contaminated procedures are those where a hollow viscus (eg, alimentary, biliary, genitourinary, respiratory tract) has been opened under controlled circumstances (eg, elective colon surgery). Contaminated procedures are those where bacteria has been introduced extensively into a normally sterile body cavity, but for a period of time too brief to allow infection to become established during surgery (eg, penetrating abdominal trauma, enterotomy during adhesiolysis for mechanical bowel obstruction). Dirty procedures are those where the surgery is performed to control established infection (eg, colon resection for complicated diverticulitis).

Numerous factors determine whether a patient will develop an SSI, including factors contributed by the patient, the environment, and the treatment (Box 1) [4]. As incorporated in the National Nosocomial Infections Surveillance System (NNIS) [4–6] (Table 1), the most recognized factors

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**Box 1. Risk factors for the development of surgical site infections**

*Patient factors*
- Ascites
- Chronic inflammation
- Corticosteroid therapy (controversial)
- Obesity
- Diabetes
- Extremes of age
- Hypocholesterolemia
- Hypoxemia
- Peripheral vascular disease (especially for lower extremity surgery)
- Postoperative anemia
- Prior site irradiation
- Recent operation
- Remote infection
- Skin carriage of staphylococci
- Skin disease in the area of infection (eg, psoriasis)
- Undernutrition

*Environmental factors*
- Contaminated medications
- Inadequate disinfection/sterilization
- Inadequate skin antisepsis
- Inadequate ventilation

*Treatment factors*
- Drains
- Emergency procedure
- Hypothermia
- Inadequate antibiotic prophylaxis
- Oxygenation (controversial)
- Prolonged preoperative hospitalization
- Prolonged operative time

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are the wound classification, American Society of Anesthesiology Class 3 or higher (chronic active medical illness; Box 2), and prolonged operative time, where time is longer than the 75th percentile for each such procedure. According to the NNIS classification, the risk of SSI increases with an increasing number of risk factors present, irrespective of the contamination of the incision (Table 2) and almost without regard for the type of operation (see Table 1, Fig. 2) [4].

Laparoscopic surgery is associated with a decreased incidence of SSI under certain circumstances, which has led to modifications of the NNIS risk classification [1]. For laparoscopic biliary, gastric, and colon surgery, one risk factor is subtracted if the operation is performed via the laparoscope. Thus, a new category has been created specifically for the circumstance, representing essentially a minus-1 risk factor. Laparoscopic surgery decreases the risk of SSI for several reasons. These include the smaller wound size, the limited use of cautery in the abdominal wall, and a diminished stress response to tissue injury. Laparoscopic appendectomy, however, is a special case. When no risk factors are present, the incidence of SSI after laparoscopic appendectomy is reduced significantly, but if any risk factor is present (as would be the case with either a perforated appendicitis or a procedure that lasts longer than one hour), then the advantage is lost.

More than 70% of surgical procedures are now performed on an outpatient basis, which poses major problems for surveillance of SSI [7]. Although many SSIs will develop in the first 5 to 10 days after surgery, an SSI may develop as long as 30 days after surgery. Estimates of the incidence of SSI thus depend upon voluntary self-reporting by surgeons, which is unreliable. Therefore, estimates of the incidence of SSI in NNIS are probably underestimates, although the data are the best that are available.

Host-derived factors may contribute to the risk of SSI. Factors of importance include advanced age [8], obesity, malnutrition, diabetes mellitus [9,10], hypcholesterolemia [11], and numerous other factors that are not accounted for specifically by the NNIS system. In one study of 2345 patients undergoing cardiac surgery, the overall incidence of SSI was 8.5% (199/2,345) [12]. The
relative risk for the development of SSI among diabetic patients was 2.29 (95% confidence interval (CI) 1.15–4.54), and the relative risk among obese patients (body mass index \( \geq 30 \)) was 1.78 (1.24–2.55). Malone and colleagues studied 5031 patients who underwent noncardiac surgery at a Veterans Affairs hospital over a six-year period ending in 1990. The overall incidence of SSI was 3.2%. Independent risk factors for the development of infection included ascites, diabetes mellitus, postoperative anemia, and recent weight loss, but not chronic obstructive pulmonary disease, tobacco use, or

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**Box 2. American Society of Anesthesiology (ASA) physical status score**

ASA 1
A normal healthy patient.

ASA 2
A patient with mild to moderate systemic disturbance that results in no functional limitations. Examples: Hypertension, diabetes mellitus, chronic bronchitis, morbid obesity, extremes of age.

ASA 3
A patient with severe systemic disturbance that results in functional limitations. Examples: Poorly controlled hypertension, diabetes mellitus with vascular complications, angina pectoris, prior myocardial infarction, pulmonary disease that limits activity.

ASA 4
A patient with a severe systemic disturbance that is life-threatening with or without the planned procedure. Examples: Congestive heart failure, unstable angina pectoris, advanced pulmonary, renal or hepatic dysfunction.

ASA 5
A morbid patient not expected to survive with or without the operative procedure. Examples: Ruptured abdominal aortic aneurysm, pulmonary embolism, head injury with increased intracranial pressure.

ASA 6
Any patient in whom the procedure is an emergency. Example: ASA 4E.

corticosteroid use [13]. In a prospective study of 9016 patients, 12.5% of patients developed a postoperative infection of some type within 28 days after surgery [14]. The likelihood of readmission for infection management and of death was 2.5% within the period. Multivariate analysis revealed that decreased serum albumin concentration, increased age, tracheostomy, and amputations were associated with an increased probability of an early infection, whereas factors associated with readmission due to infection included a dialysis shunt, vascular repair, and an early infection. Factors associated with 28-day mortality included advanced age, low serum albumin concentration, increased serum creatinine concentration, and an early infection [14].

Microbiology

Inoculation of the surgical site occurs during surgery, either inward from the skin or outward from the internal organ being operated on, hence the rationale for skin preparation and bowel preparation with antiseptics or

Table 2
Surgical site infection rates (percent) for selected procedures, National Nosocomial Infections Surveillance Program, 1992 to 2004

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Time cutpoint (h)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CABG chest/leg</td>
<td>5</td>
<td>1.25</td>
<td>3.39</td>
<td>5.43</td>
<td>9.76</td>
</tr>
<tr>
<td>Laparotomy</td>
<td>2</td>
<td>1.71</td>
<td>3.08</td>
<td>4.71</td>
<td>7.19</td>
</tr>
<tr>
<td>ORIF</td>
<td>2</td>
<td>0.79</td>
<td>1.41</td>
<td>2.81</td>
<td>4.97</td>
</tr>
</tbody>
</table>

*Abbreviations:* CABG, coronary artery bypass grafting (composite incidence for both incisions); ORIF, open reduction and internal fixation of fracture.


Fig. 2. Incidence of surgical site infection. (*Data from* CDC NNIS System. National nosocomial infections surveillance (NNIS) system report, data summary from January 1992 to June 2004, issued August 2003. Am J Infect Control 2003;31:481–98.)
antibiotics, and prophylactic oral or parenteral administration of antibiotic prophylaxis. The microbiology of SSI depends on the type of operation being performed, with an increased likelihood of infection caused by gram-negative bacilli after gastrointestinal surgery. However, most SSI are caused by gram-positive cocci (Table 3) [15], including Staphylococcus aureus, coagulase-negative staphylococci (usually Staphylococcus epidermidis), and Enterococcus sp., organisms that for the most part are skin-derived. With surgery of the head and neck, (when pharyngoesophageal structures are entered) or intestinal surgery, enteric aerobic (eg, Escherichia coli) and anaerobic (eg, Bacteroides fragilis) bacteria may cause SSI.

**Preoperative preparation**

The patient should be assessed for factors that can be corrected in the preoperative period before elective surgery. Open skin lesions should be allowed to heal if possible, and the patient should be free of bacterial infections of any kind. The patient should quit smoking if possible, preferably one month before surgery. The patient should shower with an antibacterial soap the night before the operation. The patient must not be shaved the night before, as the risk of SSI is clearly increased by bacteria that colonize the inevitable small cuts and abrasions [16]. Particular attention should be paid to the nutritional status of the patient. Obese patients should lose as much weight as is safely possible. Malnourished patients can benefit from even brief courses of enteral nutritional supplementation. As little as five days of enteral nutrition can reduce the risk of SSI significantly [17,18].

**Antibiotic prophylaxis and the risk of surgical site infection**

The administration of antibiotics before surgery to reduce postoperative SSI is common and beneficial in many circumstances. However, these

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Prevalence (%) of isolates</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Staphylococcus</em></td>
<td>19</td>
</tr>
<tr>
<td>Coagulase-negative <em>Staphylococcus</em></td>
<td>14</td>
</tr>
<tr>
<td><em>Enterococcus</em> sp.</td>
<td>12</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>8</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>8</td>
</tr>
<tr>
<td>Miscellaneous aerobic gram-negative bacilli</td>
<td>8</td>
</tr>
<tr>
<td><em>Enterobacter</em> sp.</td>
<td>7</td>
</tr>
<tr>
<td><em>Streptococcus</em> sp.</td>
<td>6</td>
</tr>
<tr>
<td><em>Klebsiella</em> sp.</td>
<td>4</td>
</tr>
<tr>
<td>Miscellaneous anaerobic bacteria</td>
<td>3</td>
</tr>
<tr>
<td>Miscellaneous aerobic gram-positive bacteria</td>
<td>2</td>
</tr>
</tbody>
</table>

antibiotics only protect the surgical incision, and antibiotics are not a panacea. If not administered properly, antibiotic prophylaxis will not be effective and may be harmful.

Some patients benefit from antibiotic prophylaxis whereas others may not. An increased risk of SSI occurs with an increasing degree of wound contamination (eg, contaminated versus clean) regardless of other risk factors (see Box 2) [6], and as the number of risk factors increases for a given type of operation (see Table 2). Antibiotic prophylaxis is indicated clearly for most clean-contaminated and contaminated (or potentially contaminated) operations. Antibiotics for dirty operations represent treatment for an infection, not prophylaxis, therefore that therapy will not be considered further. An example of a potentially contaminated operation is lysis of adhesions for mechanical small bowel obstruction. In this case, intestinal ischemia cannot be predicted accurately before surgery, and the possibility exists of an enterotomy during adhesiolysis, which increases the risk of SSI two-fold. An example of a clean-contaminated operation where antibiotic prophylaxis is not always indicated is elective cholecystectomy [19]. Antibiotic prophylaxis is indicated only for high-risk biliary surgery; patients at high risk include those over age 70, diabetic patients, and patients whose biliary tract has been instrumented recently (eg, biliary stent) [19]. The vast majority of patients who undergo laparoscopic cholecystectomy do not require antibiotic prophylaxis [20].

Elective colon surgery is a special circumstance among clean-contaminated operations and one where practices are evolving [21]. Historically, mechanical bowel preparation to reduce bowel feces made colon surgery safe. Antibiotic bowel preparation, standardized in the 1970s by the oral administration of nonabsorbable neomycin and erythromycin base, reduced the risk of SSI further to its present rate of approximately 4% to 8%, depending on the number of risk factors. Outpatient mechanical preparation is now common before elective colon surgery, but the three doses of oral antibiotics at approximately 18, 17, and 10 hours preoperatively are no longer given routinely in favor of parenteral antibiotic prophylaxis. A dose of parenteral cefoxitin or ampicillin-sulbactam (or a quinolone or monobactam plus metronidazole for the penicillin-allergic patient) is given within 1 hour before skin incision [21].

Antibiotic prophylaxis of clean surgery is controversial. Where bone is incised (eg, craniotomy, sternotomy) or a prosthesis is inserted, antibiotic prophylaxis is generally indicated. Controversy centers on cases of clean surgery of soft tissues (eg, breast, hernia). A randomized prospective trial has shown some benefit of prophylaxis, but the results are confounded by higher than expected infection rates in the control group [22].

Which antibiotic should be chosen from the plethora of available agents? Four principles should guide selection. First, the agent should be safe. Second, the agent should have an appropriately narrow spectrum of coverage of relevant pathogens. Third, the agent should not be one that is relied
upon for clinical treatment of infection, owing to the possibility that resistance may develop if the agent is overused. Finally, the agent must be administered for a defined, brief period of time (ideally, a single dose; certainly no more than 24 h). According to these principles, a third-generation cephalosporin or quinolone should never be used for surgical prophylaxis. Most SSIs are caused by gram-positive cocci. The most common etiologic agent causing SSI after clean surgery is *S. aureus*, followed by *S. epidermidis*. *Enterococcus faecalis*, *Escherichia coli*, and *Bacteroides fragilis* are common pathogens in SSI after clean-contaminated surgery. The antibiotic chosen should be directed primarily against staphylococci for clean cases and high-risk clean-contaminated elective surgery of the biliary and upper gastrointestinal tracts. A first-generation cephalosporin is the preferred agent for most patients, with clindamycin preferred for patients with a history of anaphylaxis to penicillin [23]. Although methicillin-resistant *S. aureus* (MRSA) has been isolated in the community from never-hospitalized patients, vancomycin prophylaxis is appropriate only in institutions where the incidence of MRSA infection is high (> 20% of all SSIs caused by MRSA).

When should parenteral antibiotics be given for optimum effect? The best time to give cephalosporin prophylaxis is within 1 hour before the time of incision [24] (Table 4). Antibiotics given sooner (except possibly for longer half-life agents such as metronidazole) are not effective, nor are agents that are given after the incision is closed. Antibiotics with short half-lives (< 2 h, eg, cefazolin or cefoxitin) should be re-dosed every 3 to 4 hours during surgery if the operation is prolonged or bloody [25]. There is still some benefit if the initial antibiotic dose is given intraoperatively, but none afterward.

Oral antibiotics can be administered for prophylaxis of SSI, provided that the agent is chosen carefully based on spectrum, oral bioavailability, and the potential need for the patients to take nothing orally for several hours before general anesthesia. Considering the ease with which venous

<table>
<thead>
<tr>
<th>Timing</th>
<th>No. patients</th>
<th>No. (%) infections</th>
<th>RR (95% CI)</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>369</td>
<td>14 (3.80)*</td>
<td>6.7* (2.9–14.7)</td>
<td>4.3* (1.8–10.4)</td>
</tr>
<tr>
<td>Preoperative</td>
<td>1,708</td>
<td>10 (0.59)</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Perioperative</td>
<td>282</td>
<td>4 (1.40)</td>
<td>2.4 (0.9–7.9)</td>
<td>2.1 (0.6–7.4)</td>
</tr>
<tr>
<td>Postoperative</td>
<td>488</td>
<td>16 (3.30)*</td>
<td>5.8* (2.6–12.3)</td>
<td>5.8* (2.4–13.8)</td>
</tr>
<tr>
<td>All</td>
<td>2,847</td>
<td>44 (1.5)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Early, administration more than two hours preoperatively, administration during the recommended interval (≤ 2 h before skin incision); perioperative, administration within 2 hours after the skin incision; postoperative, administration more than 2 hours after the skin incision is made.

*p < 0.0001 as compared to preoperative group. RR, relative risk; OR, odds ratio.

access can be established, there is little need for oral antibiotic prophylaxis except in the case of colon surgery.

For what duration should prophylactic antibiotics be administered? The need for hemostasis of the surgical incision creates an ischemic milieu. Antibiotics may not penetrate properly into the incision immediately following surgery because of hypoperfusion owing to divided and cauterized vessels. Single-dose preoperative prophylaxis should be standard [26], with intraoperative dosing as noted above. Unfortunately, excessively prolonged use is both pervasive and potentially harmful for the patient. A 24-hour regimen is often standard for orthopedic and cardiac/vascular surgery, owing in part to a lack of data to suggest otherwise. Other than for solid-organ transplant surgery, where therapeutic immunosuppression has made 48-hour regimens standard, prolonged antibiotic prophylaxis is not needed. In particular, antibiotics should not be administered to cover indwelling drains or catheters, in lavage fluid, or as a substitute for poor surgical technique.

Preoperative topical antiseptics or antibiotics may also help prevent SSI. A preoperative shower with an antiseptic soap (eg, povidone-iodine) should be a standard part of preoperative preparation, but is omitted often. Topical 2% mupirocin ointment applied to the nares of patients who are chronic carriers of *S. aureus* reduces the increased incidence of SSI that is characteristic of chronic staphylococcal carriage [27,28].

Prolongation of antibiotic prophylaxis beyond 24 hours not only provides no benefit, but also can be associated with several complications. *Clostridium difficile*-associated disease (CDAD) follows disruption of the normal balance of gut flora, resulting in overgrowth of the enterotoxin-producing *C. difficile*. The incidence of nosocomial CDAD is increasing [29]. The spectrum of disease is broad, ranging from asymptomatic illness to life-threatening transmural colitis with infarction or perforation. Although virtually any antibiotic may cause CDAD even after administration of a single dose, prolonged antibiotic prophylaxis clearly increases the risk. Prolonged prophylaxis also increases the risk of later nosocomial infections unrelated to the surgical site, and the emergence of multi-drug resistant pathogens. Both pneumonia and catheter-related infections have been associated with prolonged antibiotic prophylaxis [29,30], as has the emergence of SSI caused by MRSA [31].

Current status of antibiotic prophylaxis in the United States

The current status of antimicrobial prophylaxis for major surgery in the United States has been summarized by Bratzler and colleagues [32]. A retrospective study of 34,133 Medicare inpatients from 2965 acute-care hospitals was conducted among records of patients undergoing open-chest cardiac surgery, vascular surgery, colorectal surgery, hip and knee total-joint arthroplasty, and abdominal and vaginal hysterectomy in 2001. A dose of antibiotics was administered to only 55.7% of patients (54.8%–56.6%) within 1 hour of surgery, although the agents chosen were consistent with
published guidelines 92.6% (92.3%–92.8%) of the time. Disconcertingly, antimicrobial prophylaxis was discontinued within 24 hours of surgery only 40.7% (40.2%–41.2%) of the time, and within 12 hours only 14.5% of the time. Clearly, large numbers of patients are put at increased risk every day by excessive administration of prophylactic antibiotics.

Antibiotic prophylaxis of trauma-related infections

Traumatic injury is profoundly immunosuppressive, and injured patients are at high risk for the development of infection. The overall incidence of infection after trauma is approximately 25% [33], with infection of a wound (or an incision made as treatment) and nosocomial infection equally likely. Certain patterns of injury in particular are independently associated with infectious morbidity, including hemorrhagic shock, the need for blood transfusion, heavy wound contamination, central nervous system injury, colon injury, combined thoracoabdominal injuries, injuries to four or more organs, and increasing injury severity [34].

Certain characteristics of trauma add complexity. Obviously, antibiotics must be administered following injury and injured tissues are vulnerable. Patients in shock are hypotensive and vasoconstricted, and tissue penetration of antibiotics may be decreased. Ongoing blood loss may result in antibiotic loss in shed blood, especially if the agent is highly protein-bound or if the antibiotic is administered before hemorrhage is controlled. Postinjury fluid shifts and hypoalbuminemia can cause major fluctuations in volume of distribution, which can be difficult to estimate. As a result, it has been postulated that higher doses of antibiotics should be administered for the prophylaxis of post-traumatic infection.

Despite the high risk, the basic principles of antibiotic prophylaxis still apply: Use of a safe, narrow-spectrum agent for a defined brief period (certainly no more than 24 hours), preferably one that has a limited role in the therapy of infection (ie, first- or second-generation cephalosporin) [27]. Multiple studies indicate unequivocally that 24 hours of prophylaxis with a second-generation cephalosporin is all that is necessary following penetrating abdominal trauma, even in the presence of a colon injury or shock [35]. Although the severity of injury increases the risk of infection, severe injury is not a justification for prolonged surgical prophylaxis [29]. To do so is to increase the risk of subsequent antibiotic-resistant infection without benefit to the patient.

The operating room environment

Much of what is taken for granted in the modern operating room can, if lapses occur, result in increased rates of SSI. The elements of proper operating room design, management, and comportment have been reviewed with a close look at supporting evidence [16].

Although such factors as proper sterilization technique and ventilation should not be the everyday concern of the surgeon, operating room
personnel must remain vigilant. The surgeon must be attentive to his or her personal hygiene (eg, hand scrubbing, hair) and that of the entire team. Recent data indicate that a brief rinse with soap and water followed by use of an alcohol gel hand rub is equivalent to the prolonged (and ritualized) session at the scrub sink [36].

Careful preparation of the skin with an appropriate antiseptic is essential. No evidence has shown that one method (eg, alcohol-based versus povidone-iodine) is superior to another, nor has evidence been found to raise concerns about lack of efficacy of the new quick-drying gel formulations. However, there are also no data to show that untreated or iodine-impregnated adhesive plastic drapes reduce the risk of SSI, so routine use of such products may be foregone.

About 20% of surgical gloves fail during an operation, so contamination of the surgical field, as well as contact between surgeon and the patient’s body fluids, are possible. Therefore, attention must be paid to regular inspection of gloves during a procedure. Likewise, most surgical gowns in use offer limited protection (1.5–2 hours at most) against strikethrough of fluids. It may be prudent to change gowns and gloves regularly (every 2 hours or so) during long procedures, and certainly if there is any evidence of loss of integrity of barrier materials.

Although most flora that pose a risk for SSI are skin-derived and inoculated during the procedure, airborne bacteria, especially staphylococci, pose some risk. Surgeons who are chronic nasal carriers of \textit{S. aureus} have higher rates of SSI than do their noncolonized brethren. It is recommended that surgical masks should cover the nose and mouth at all times, and that unnecessary traffic into the operating room and conversation at the operating table be kept to a minimum.

Owing to evaporative water losses, administration of room-temperature fluids, and other factors, patients may become hypothermic during surgery if they are not warmed. Maintenance of normal core body temperature is essential for decreasing the incidence of SSI. Two studies have corroborated a seminal study showing that mild intraoperative hypothermia is associated with an increased rate of SSI following elective colon surgery [37]. In one randomized study, 30 minutes of active preoperative warming reduced the rate of SSI following minor clean operations [38], whereas an observational study of 290 patients showed that those who were allowed to become hypothermic during diverse operations had a significantly higher incidence of SSI [39].

**Management of the incision**

Cosmesis is important to patients, who naturally want wounds to be closed for the sake of appearance. On the other hand, closure of a contaminated or dirty wound is widely believed to increase the risk of SSI. This conflict poses a dilemma for surgeons. The search goes on for innovative methods or adjuncts to wound closure that will both promote healing and ease cosmetic
concerns. Few good studies exist to help sort out the multiplicity of tech-
niques, making this an area where tradition and anecdote seem to prevail
over science and wisdom. Tissues should be handled gently, and the use of
electrocautery for hemostasis should be minimized [40]. With respect to
wound closure, traditional teaching has advised that high-risk incisions
should be left open after surgery, with delayed primary closure performed
with sutures or adhesives approximately four days after surgery if the incision
“looks okay.” Incisions that are deemed “not ready” or that fail delayed pri-
mary closure are left to heal by secondary intention in a process that takes
weeks and consumes precious home care resources. Such an approach could
hardly be less satisfying to the scientist or the advocate of evidence-based
practice. Patients, assuredly, don’t like open incisions either.

Can contaminated incisions be closed primarily? The data that exist are
mixed. It appears that muscle-splitting appendectomy incisions can be
closed primarily. Pediatric surgeons have been doing so routinely, and deci-
sion analysis indicates that primary closure is cost effective if the rate of SSI
is less than 27% [41]. However, wound management techniques that may be
appropriate for appendectomy incisions may not be suitable for the manage-
ment of larger abdominal incisions. One large prospective study demonstrated
that primary closure of contaminated midline abdominal incisions led to
more wound failures and greater cost than did delayed primary closure [42].

Drains placed in incisions probably cause more infections than they pre-
vent. Sealing of the wound by epithelialization is prevented and the drain
becomes a conduit, holding open a portal for invasion of the wound by
pathogens colonizing the skin. Several studies of drains placed into clean
or clean-contaminated incisions show that the rate of SSI is not reduced
[43,44]; in fact, the rate is increased [45–49]. Considering that drains pose
a risk and accomplish little, they should rarely be used and removed as
soon as possible [50]. Under no circumstances should prolonged antibiotic
prophylaxis be administered to “cover” indwelling drains.

Wound irrigation remains controversial as a means of reducing the risk
of SSI. There is little information to suggest that routine low-pressure wash-
ing of an incision with saline reduces the risk of SSI [51], but high pressure
(i.e., pulse-irrigation) may be beneficial [52]. An increasing body of knowl-
edge suggests that topical antibiotics placed into the incision during surgery
can minimize the risk of SSI [53–55], but it might be desirable to accomplish
the same result with topical antiseptics rather than antibiotics to minimize
the possibility of the development of resistance.

The postoperative period

Blood transfusion

In surgery and trauma, blood transfusions are common and may be life-
saving. Alternatives to transfusions in the acute setting are few. However,
for hemodynamically stable postoperative patients, hemoglobin concentrations of > 7 g/dL are well tolerated [56]. An expanding body of evidence suggests that blood transfusion should be avoided, if possible. Blood transfusions have been associated with increased rates of nosocomial infection following penetrating abdominal trauma independent of related factors such as shock or acute blood loss [57]. Furthermore, blood transfusions have been associated with increased injury severity and increasing transfusion volume in unselected trauma patients [58]. Blood transfusion therapy of 6 to 20 units in the first 12 hours following multiple trauma was associated with an increased risk of nosocomial infection [59], and even a single-unit transfusion carried demonstrable risk in another study [60]. The risk of infection increased as the total transfusion volume increased, especially when units were transfused after more than 14 days of storage [59]. A recent meta-analysis estimated that transfusion of any volume of red blood cell concentrates more than triples the risk of nosocomial infection compared with no transfusion [61]. The postulated “storage lesion” is complex, but includes changes in oxygen affinity, decreased membrane fluidity and red blood cell deformability, shortened circulation time, and the biologic consequences of cytokine generation and release. Recently, observational studies have suggested that transfusion of critically ill patients increases the risk of nosocomial infection [62], may worsen organ dysfunction, and increases mortality [63].

Hyperglycemia, nutrition, and control of blood sugar

Hyperglycemia has several deleterious effects upon host immune function, most notably impaired function of neutrophils and mononuclear phagocytes. Hyperglycemia may also be a marker of the catabolism and insulin resistance associated with the surgical stress response, and that exogenous insulin administration may ameliorate the catabolic state.

Poor control of blood glucose during surgery and in the perioperative period increases the risk of infection, and worsens outcome from sepsis. Diabetic patients undergoing cardiopulmonary bypass surgery have a higher risk of infection of both the sternal incision and the vein harvest incisions on the lower extremities [64]. Tight control of blood glucose by the anesthesiologist during surgery decreases the risk. Moderate hyperglycemia (> 200 mg/dL) at any time on the first postoperative day increases the risk of SSI fourfold after noncardiac surgery [65]. In a large randomized trial of critically ill postoperative patients, exogenous insulin administration to keep blood glucose concentrations < 110 mg/dL was associated with a 40% decrease of mortality, fewer nosocomial infections, and less organ dysfunction [66]. Meta-analysis of the approximately 35 existing trials indicates that the risk of postoperative infection decreases significantly by tight glucose control, regardless of whether or not the patients had diabetes mellitus [67].
The need to manage carbohydrate metabolism carefully has important implications for the nutritional management of surgical patients. Gastrointestinal surgery may render the gastrointestinal tract unusable for feeding, sometimes for prolonged periods. Ileus is common in surgical ICUs, whether from traumatic brain injury, narcotic analgesia, prolonged bed rest, inflammation near the peritoneal envelope (eg, lower lobe pneumonia, retroperitoneal hematoma, fractures of the thoraco-lumbar spine, pelvis or hip), or other causes. Parenteral nutrition is used frequently for feeding, despite evidence of a lack of efficacy [68] and the possibility of hepatic dysfunction; hyperglycemia may be an important complication as well. Every effort should be made to provide enteral feedings, including the use of promotility agents such as erythromycin [69]. Early enteral feeding (within 36 hours) reduces the risk of nosocomial infection by more than one half among critically ill and injured patients [70].

**Oxygenation**

It seems logical that the administration of oxygen in the postoperative period should be beneficial for wound healing and the prevention of infection [71,72]. The ischemic milieu of the fresh surgical incision is vulnerable; vasodilation of local tissue beds to improve nutrient blood flow to an incision may help maintain normal body temperature for prevention of surgical site infection. Moreover, oxygen has been postulated to have a direct antibacterial effect [72]. However, clinical trials have had conflicting results [73,74]. In a study of 500 patients undergoing elective colorectal surgery, administration of 80% oxygen (versus 30% oxygen) during surgery and for two hours thereafter decreased the incidence of surgical site infection by more than 50% (5.2% versus 11.2%) [73], whereas another prospective trial of the utility of 80% versus 35% oxygen administered to 165 patients undergoing major intraabdominal procedures showed that the infection rate was twice as high (25.0% versus 11.3%) after 80% oxygen [74]. Although the latter trial can be criticized for the high overall rate of SSI (18.1%) and possible underpowering, controversy now surrounds the administration of supplemental oxygenation specifically to reduce the incidence of surgical site infection.

**New active device platforms for prevention of surgical site infection**

Innovative technologies can be combined with established surgical practice to possibly decrease further the risk of SSI. Recognizing that two thirds of SSIs are superficial and stem from bacterial inoculation during surgery, and that interventions to decrease SSI after surgery have little impact, surgical device manufacturers are introducing new dual-action or “active platform” devices. Such devices may soon reduce incidence of SSI.

To reduce the infection rates associated with plastic surgery, researchers are studying the use of implantable tissue expander shells impregnated
with antimicrobial agents [75]. Dermabond (Ethicon, Somerville, NJ), an oc
tylycyanacrylate tissue adhesive, is an effective barrier to gram-positive and gram-negative motile and nonmotile bacterial species [76]. The adhesive is noninvasive, easy to apply, and seals the incision rapidly compared with other wound-healing adjuncts. An antibacterial suture, VICRYL Plus Antibacterial (Ethicon), can inhibit \emph{S. aureus}, \emph{S. epidermidis} and methicillin-resistant strains of \emph{Staphylococcus} (MRSA and MRSE) [77]. Polyglyactin suture is coated with triclosan (2,2,4′-trichloro-2′-hydroxy-diphenyl ether), an anti-
septic agent that has been used in many commercial products, and that has activity against the common gram-positive bacteria known to cause SSIs. Triclosan appears to suppress the adherence of viable gram-positive bacteria to the suture, and to diffuse into adjacent tissues to provide a long-lasting antibacterial effect. Higher concentrations of triclosan may inhibit gram-

Kerlix Antimicrobial Dressing, (Tyco Health Care, Mansfield, MA), con-
tains polyhexamethylen biguanide, an antimicrobial component that resists bacterial colonization within the dressing and reduces bacterial penetration through the dressing [80]. This component may provide protection against gram-positive, gram-negative, and fungal microorganisms [80]. Native skin flora is not affected, promoting the maintenance of host defenses [80]. However, any benefit is questionable after incision epithelization occurs (by about 24 hours).

Acticoat with Silcryst Nanocrystals (Smith & Nephew, Largo, FL) is an effective antimicrobial barrier dressing. The nanocrystalline coating of silver kills a broad spectrum of bacteria in as little as 30 minutes and is effective for at least 3 days [81]. Acticoat dressing consists of three layers: An absorbent inner core sandwiched between outer layers of silver-coated, low-adherence polyethylene net. Nanocrystalline silver protects the wound site from bacte-
rial contamination, whereas the inner core helps maintain the moist environ-
ment best for wound healing. Acticoat 7 (Smith & Nephew), another antimicrobial barrier dressing, consists of five layers: Two layers of an absorbent inner core alternating with three layers of silver-coated, low-adherent polyethylene net. Acticoat and Acticoat 7 can be used to manage chronic wounds and burn wounds as an antimicrobial barrier layer, but the benefit for a vulnerable surgical incision is unknown.

\textit{Treatment of surgical site infection}

Only one constant has guided the management of an established SSI: In-
cise and drain the incision. Often, opening the incision and applying basic wound care (eg, topical saline-soaked wet-to-dry cotton gauze dressings) are sufficient, provided that the incision is opened wide enough to facilitate wound care and the diagnosis of associated conditions. Making an incision too small may fail to bring the infection under control. Most nostrums other
than physiologic saline applied to gauze dressings (eg, modified Dakin’s solution, 0.25% acetic acid solution) actually suppress fibroblast proliferation and may delay secondary wound healing.

Opening the incision adequately is essential not only to gain control of the infection, but also to diagnose and treat any associated conditions, such as skin, subcutaneous tissue, or fascial necrosis that requires debridement; fascial dehiscence or evisceration that requires formal abdominal wall reconstruction; or drainage from beneath the fascia that could signal an organ/space infection or an enteric fistula. Without control of complicating factors, an SSI is difficult or impossible to control.

Antibiotic therapy is not required for uncomplicated SSIs that are opened and drained adequately and that receive appropriate local care. Likewise, if antibiotic therapy is unwarranted, then culture and susceptibility testing of wound drainage are of no value and can be omitted. Even if cultures are taken, routine swabs of drainage are not recommended because the risk of contamination by commensal skin flora is high, reducing utility. Rather, tissue specimens or an aliquot of pus collected aseptically and anaerobically into a syringe are recommended for analysis.

Antibiotics may be indicated if there is systemic evidence of toxicity (eg, fever, leukocytosis) or cellulitis that extends more than 2 cm beyond the incision. Antibiotics are also indicated as adjunctive management of several of the complications mentioned above. The choice of antibiotic is defined by the operation performed through the incision and the likely infecting organism, as discussed. Coverage against gram-positive cocci is indicated in most circumstances.

Wound closure by secondary intention can be protracted and disfiguring. Reports of vacuum-assisted wound closure (VAC) proliferate. Putative benefits of VAC dressings include reduced inflammation, increased fibroblast activity, improved wound hygiene as fluid is aspirated continuously from the field, and more rapid wound contraction and closure [82]. However, these benefits remain conjectural in the absence of definitive Class 1 data.

Summary

Promoting the healing process is an important consideration for both surgeons and patients. Certain timeless principles remain important, including preparation of the patient, careful adherence to sterile technique and infection control, judicious short-term use of antibiotics, and minimization of interventions that impair host defenses. Growth factors, silver hydrocolloid dressings, and the application of negative-pressure dressings can promote healing of chronic wounds, while suture materials, dressings, and coated prosthetic devices may reduce the incidence of SSI. However, adherence to established guidelines has been demonstrated to reduce the incidence of SSI by 27% [83]. Reducing SSIs as much as possible should be the goal of all surgical practitioners and health systems.
References


