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Surgical Site Infection Prevention and Control: An Emerging Paradigm

By the American Academy of Orthopaedic Surgeons Patient Safety Committee* and Richard P. Evans, MD (Chairperson)

The Current State of Infection in Orthopaedic Surgery

The Centers for Disease Control and Prevention (CDC) estimates that 22% of all health-care-associated infections are surgical site infections. A CDC estimate from 2001 suggests that approximately 290,000 surgical site infections occur annually in the United States, resulting in $1 billion to $10 billion in direct and indirect medical costs. Approximately 8000 patient deaths are associated with these infections. Staphylococcus species including Staphylococcus aureus are the leading nosocomial pathogens in hospitals throughout the world and altogether account for almost 30% of the pathogenic isolates of health-care-associated infection reported to the National Healthcare Safety Network from January 2006 to October 2007.

Multiple-drug-resistant organisms include methicillin-resistant Staphylococcus aureus and vancomycin-resistant enterococci, which colonize the skin and are spread by contact. Over 30% of the population is colonized with Staphylococcus aureus, and an increasing proportion of these resident bacteria is methicillin-resistant Staphylococcus aureus. As many as 4% of health-care workers may be colonized with methicillin-resistant Staphylococcus aureus, with up to 5% of these persons having a clinical infection. These contribute to two types of infection, surgical and so-called nonsurgical (methicillin-resistant Staphylococcus aureus) infection. Additionally, there are two types of methicillin-resistant Staphylococcus aureus. Community-acquired methicillin-resistant Staphylococcus aureus and hospital-associated methicillin-resistant Staphylococcus aureus together have resulted in an increase in the incidence of nonsurgical infection of all types. Because of the increasing incidence, severity, and extent of disease caused by multiple-drug-resistant organisms, the prevention and treatment of these infections have become a national priority.

The Healthcare Infection Control Practices Advisory Committee (HICPAC) is a federal advisory committee made up of fourteen external infection control experts who provide advice and guidance to the CDC and the Secretary of the Department of Health and Human Services regarding the practice of health-care infection control and strategies for surveillance, prevention, and control of health-care-associated infections in United States health-care facilities. The CDC established the National Nosocomial Infections Surveillance System in 1970, and selected hospitals in the United States routinely began reporting nosocomial infection surveillance data for aggregation into a national database. The CDC published the "Guideline for Prevention of Surgical Site Infection, 1999," presenting evidence-based recommendations for the prevention of surgical site infection and providing a detailed discussion of the preoperative, intraoperative, and postoperative issues relevant to the genesis of surgical site infection.

In 2002, the Centers for Medicare and Medicaid Services (CMS), in collaboration with the CDC, implemented the CMS-CDC Surgical Infection Prevention Project. The goal of the project is to decrease the morbidity and mortality associated with postoperative surgical site infection by promoting appropriate selection and timing of the administration of prophylactic antimicrobials. The project was based on the experience that the CDC had gained from implementation of the National Nosocomial Infection Surveillance System and on efforts by the CMS to improve health-care quality through its Medicare Quality Improvement Organizations. The Joint Commission on the Accreditation of Healthcare Organizations subsequently transitioned the Surgical Infection Prevention Project to the Surgical Care Improvement Project, effective July 1, 2006.

The Surgical Care Improvement Project (SCIP) is a national partnership of governmental organizations committed to improving the safety of surgical care through the reduction of postoperative complications. The goal of the SCIP is to reduce the incidence of surgical complications nationally by 25% by the year 2010. Its milestones for infection prevention include:

SCIP INF 1: Prophylactic antibiotic received within 1 h prior to surgical incision

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SCIP INF 2: Prophylactic antibiotic selection for surgical patients
SCIP INF 3: Prophylactic antibiotics discontinued within 24 h after surgery end time
SCIP INF 5: Postoperative surgical site infection diagnosed during index hospitalization
SCIP INF 6: Surgery patients with appropriate hair removal

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No outside funding was received for this study.

Modifiable Risk Factors in Surgical Site Infection and Possible Preoperative Interventions

Multiple risk factors for orthopaedic surgical site infection have been identified. Direct scientific evidence showing that modification of these risk factors will lead to a decrease in surgical site infection is scarce, and much work in this field remains to be done. It is still imperative, however, that surgeons have an extensive knowledge of modifiable risk factors affecting the wound-healing process. Some of these risk factors can be eliminated or modified preoperatively (Fig. 1).

Patients with rheumatoid arthritis undergoing total joint arthroplasty are at a two to threefold greater risk of acquiring a postoperative surgical site infection than are patients with osteoarthritis. A good working relationship with the patient’s rheumatologist is critical to making decisions about medication management. While nonsteroidal anti-inflammatory drugs do not seem to increase transfusion requirements, morbidity, or mortality directly, they may, through a variety of mechanisms, increase intraoperative and postoperative bleeding. Increased bleeding may lead to a postoperative infection, especially in an already compromised host. Inadequate doses of perioperative corticosteroids can lead to disease flares and, in rare instances, to adrenal insufficiency. Corticosteroid therapy has been shown to increase infection rates and affect wound-healing.

The increased survivorship of human immunodeficiency virus (HIV)-positive patients has created a new subset of potential candidates for total joint replacement and other orthopaedic procedures. Studies from other disciplines, however, have suggested that specific risk factors influencing operative morbidity, especially infections related to wound-healing, include an absolute CD4 count of <200 cells/μL or a viral load of >10,000 copies/mL.

Modifiable risk factors. Many patients have risk factors that make them more susceptible to the development of infections. A number of those infections may be preventable through the identification and treatment of modifiable risk factors. HIV = human immunodeficiency virus, and MRSA = methicillin-resistant Staphylococcus aureus.
Diabetes has been associated with an increased risk of surgical site infection in several orthopaedic disciplines\textsuperscript{10-12}. While this so-called diabetic disadvantage may be due, in part, to the impact of the disease on a patient's biology and physiology, it is more likely that the acute effects of perioperative hyperglycemia are even more detrimental. Further research is needed to evaluate whether routine screening for diabetes and hyperglycemia among patients having elective orthopaedic surgery is warranted.

Malnutrition is a known risk factor for deep infection after a variety of orthopaedic surgical procedures\textsuperscript{13,14}. A total lymphocyte count of $<1500$ per mm$^3$ (1.5 $\times$ 10$^3$/L), a serum albumin level of $<$3.5 g/dL, or a serum transferrin level of $<$226 mg/dL have been associated with an increase in wound complications. It may benefit all patients with abnormal markers of nutrition to obtain preoperative nutritional supplementation. Patients should obtain sufficient protein intake and specific daily vitamin and mineral supplementation, particularly vitamins A and C, zinc, and copper\textsuperscript{15}.

The use of tobacco products, including cigarettes, causes microvascular vasoconstriction due to nicotine and activation of the sympathetic nervous system\textsuperscript{16,17}. Carbon monoxide found in cigarette smoke also contributes to tissue hypoxia by binding to hemoglobin to form carboxyhemoglobin. Carboxyhemoglobin has a high affinity for oxygen and decreases the delivery of oxygen to tissues. Smoking intervention programs may decrease the risk of postoperative complications, especially wound-healing, even when instituted four to six weeks before surgery\textsuperscript{16}.

Obesity has been shown to lead to an increased rate of postoperative complications, including surgical site infection, in several studies\textsuperscript{18,19}. One study found the risk of an infection was 6.7 times higher in obese patients who had a total knee replacement and 4.2 times higher in obese patients who had total hip replacement\textsuperscript{18}.

One of the most common organisms found in orthopaedic surgical site infection is \textit{Staphylococcus aureus}. A strong association exists between nasal carriage of \textit{Staphylococcus aureus} and the development of \textit{Staphylococcus aureus} surgical site infections\textsuperscript{20}. Carriers are two to nine times more likely to acquire \textit{Staphylococcus aureus} surgical site infections than are non-carriers. In patients who acquire \textit{Staphylococcus aureus} surgical site infections, paired \textit{Staphylococcus aureus} isolates from the wound can match those from the nares 30% of the time.

A preoperative screening and topical decolonization protocol that has been proposed and studied at length includes mupirocin ointment applied to the nares twice daily for five days prior to surgery\textsuperscript{21}. Some investigators include the use of a chlorhexidine bath once daily for five days before surgery\textsuperscript{22}. Questions about whether screening and treating all surgical patients will lead to a decrease in overall \textit{Staphylococcus aureus} species surgical site infections warrant further study. Until more information has been obtained from such studies, it is recommended that patients at risk for \textit{Staphylococcus colonization} be screened and treated preoperatively with a decolonization regimen. In patients found preoperatively to be carriers of methicillin-resistant \textit{Staphylococcus aureus}, the use of antibiotics such as vancomycin in place of (or possibly in addition to) cefazolin as prophylaxis may be beneficial, although strict guidelines have not been established.

Urinary tract infections are generally classified into upper and lower tract infections. In orthopaedic patients being evaluated for elective surgery, lower urinary tract infections, particularly cystitis, are most common\textsuperscript{23,24}. Postoperative urinary tract infection has been identified as a risk factor for peri-prosthetic joint infection in several studies, although not all\textsuperscript{24}. Deep infection in the involved joint after hip or knee arthroplasty may be the result of hematogenous seeding from the urinary tract. It is unclear whether there is an association between preoperative bladder infections and deep prosthetic infection\textsuperscript{26}.

Postoperative anemia treated with allogenic blood transfusion has been reported as a risk factor for surgical site infection\textsuperscript{27,30}. Several studies have shown that, when preoperative anemia is corrected, the risk of postoperative allogenic blood transfusions is diminished. Several blood conservation regimens are available, and the literature is not clear as to the best method to decrease the risk of postoperative allogenic blood transfusion.

Antimicrobial Prophylaxis in Surgical Site Infection

A great surge forward in the battle against surgical site infections happened as early as the mid-nineteenth century with the theories of the British surgeon Joseph Lister\textsuperscript{30}. His discovery and practice of reproducible techniques of antisepsis within the Glasgow Royal Infirmary staved to discredit the prevailing idea of the time concerning “bad air” and its so-called causation of wound infection, postoperative illness, and death. Recognizing the importance of Louis Pasteur’s work at the time, Lister advocated the use of carbolic acid as a means to prevent surgical site infections. Building on this seminal work, the origin of the modern theory of antibiotic prophylaxis of surgical site infection was presented by Burke in 1961\textsuperscript{31}. In an effort to more fully explore previously failed attempts to prove efficacy for preoperative antibiotic prophylaxis, Burke discovered the importance of the antibiotic being present in the system, as measured by local tissue drug levels, prior to the inoculation of \textit{Staphylococcus aureus} into the surgical incisions of guinea pigs.

All surgical wounds are at risk for bacterial contamination as pathogenic organisms can enter primarily through the incision or from hematogenous dissemination\textsuperscript{32}. While normal skin flora consisting of aerobic gram-positive cocci are endemic, contamination by enteric bacteria may also occur by proximity to body orifices or transference. The so-called tipping point for these potential pathogens is variable and multifactorial. Certainly the host immune response plays a major role, with local wound conditions, bacterial virulence, and the presence of nonviable substrates playing important, but lesser, roles. The preoperative goal is to optimize intraoperative sterility of the wound to minimize the bacterial load to a level that will not overwhelm host defenses.
Certain procedures, such as dental or urological procedures, have been observed to cause hematogenous seeding of bacteria into joint implants, both in the early postoperative period and for many years following implantation. Antibiotic prophylaxis prior to dental intervention may be beneficial in certain patients who have previously undergone total joint replacement. Although there is no scientifically strong study to directly show the benefits of prophylactic dental screening, following this low risk, commonsensical approach, previously advocated by cardiac surgeons for their patients, may one day prove beneficial.

The choice of a prophylactic antimicrobial agent should attempt to balance the most minimal impact possible on the normal flora of the host and the local region’s bacterial population but still be potent against the organisms of concern: aerobic gram-positive cocci. Cephalosporins are first choice unless the patient has a documented beta-lactam allergy or the surgical prevalence of methicillin-resistant Staphylococcus aureus is high, in which case one should consider using vancomycin or teicoplanin. Targeted allergy consultation and penicillin allergy skin-testing can decrease prophylactic vancomycin use in patients undergoing elective orthopaedic surgery. Current or previous infection with methicillin-resistant Staphylococcus aureus and known methicillin-resistant Staphylococcus aureus colonization may be indications to choose vancomycin for surgical prophylaxis. There is no evidence that routine use of vancomycin instead of cephalosporins for prophylaxis in institutions with perceived high rates of methicillin-resistant Staphylococcus aureus infection will result in fewer surgical site infections. There is some evidence that preoperative screening and decolonization with mupirocin ointment and chlorhexidine or triclosan soap may reduce the frequency of methicillin-resistant Staphylococcus aureus surgical site infections after orthopaedic procedures.

The infusion of antibiotics should begin within sixty minutes before incision and be completed at the time of the incision. Administration of the antimicrobial at the time of anesthesia induction is safe and results in adequate tissue drug levels at the time the incision is made. An analysis of cefazolin levels in bone following immediate preoperative intravenous drug administration demonstrated cefazolin concentrations in bone sixty times the minimum inhibitory concentration for penicillin-resistant Staphylococcus aureus. Intraoperative redosing may be warranted if prolonged or excessive bleeding occurs or if there are factors (e.g., extensive burns) that may shorten the half-life of the antimicrobial (Table I).

The majority of quality evidence has demonstrated that antimicrobial prophylaxis after wound closure does not provide any additional protection from surgical site infection. Continuing antibiotic prophylaxis for longer than twenty-four hours after wound closure or maintaining prophylactic antibiotics “to cover” while postoperative drains and catheters are in place is not beneficial and does not reduce rates of surgical site infection, but it may contribute to the development of antimicrobial resistance.

### Intraoperative Factors in Surgical Site Infection

Although many preoperative and postoperative measures, especially antibiotic prophylaxis, have been shown to be effective in reducing surgical site infection rates, many consider the intraoperative environment to be critical. Within the operating room, there are numerous factors under the control of the surgeon, nurses, anesthesiologist, and the other members of the operating-room team that may affect the risk for development of a surgical site infection. The very design of the operating room may be critically important. None of the measures we take in the operating room to prevent surgical site infection can be singled out as the one on which we must focus, but rather we must pay attention to detail throughout the process as collectively our efforts do make a difference.

Several studies have shown a reduced infection rate in orthopaedic implant surgeries performed in ultraclean air facilities and with the surgical team wearing body exhaust suits. Laminar airflow results in a significant reduction in airborne bacterial colony-forming units, but a substantial decrease in infection rates has not been shown. This is due to the many uncontrolled variables in operating-room infection control. The CDC, in its 2003 review, downgraded its support for laminar flow and classified it as an unresolved issue in the prevention of surgical site infection. On the basis of that review, some authors have disputed the results of studies...
showing laminar flow efficacy\textsuperscript{55,54}. Decades of use of laminar flow operating-room ventilation in combination with other infection control measures have improved infection rates; however, no uniform opinion about laminar flow efficacy has developed.

The use of very specific types of ultraviolet light arranged in a very specific manner in the operating room has also been shown in some studies to be effective, but others have not found effectiveness\textsuperscript{55-57}.

Sir John Charnley is credited with using a combination of laminar flow with body exhaust suits. Studies generally have not looked at the separate effect of these two factors, but rather have looked at the combined effect. The use of body exhaust suits in conjunction with laminar flow provides patients with additional protection from bacterial shedding, hair, exposed skin, and mucous membranes of operating-room personnel\textsuperscript{60}. Body exhaust suits may also prevent the patient from contaminating operating-room personnel, although this reverse isolation protection is still unstudied. Although widely used and accepted, it cannot be said that the body exhaust suits alone have been proven effective.

The surgeon hand scrub is probably the most ritualized step in the preparation for surgery. Clocks and timers have been installed and used to mandate the traditional ten-minute scrub, and the use of the nail cleaner and scrub brush for a full ten minutes has often been mandated\textsuperscript{56,62}. Alcohol-based agents show an immediate reduction of 95\% of the resident flora and a 99\% reduction with repeated applications\textsuperscript{63}. Chlorhexidine can be left on the hands, and it will continue to lower bacterial counts during the procedure\textsuperscript{64}.

Various types of gloves, double-gloving techniques, and indicator gloves have been recommended in the orthopaedic literature. The conclusions from the Cochrane Database summarize well the current knowledge: “There is no direct evidence that additional glove protection worn by the surgical team reduces surgical site infections in patients, however the review has insufficient power for this outcome. The addition of a second pair of surgical gloves significantly reduces perforations to innermost gloves. Triple gloving, knitted outer gloves and glove liners also significantly reduce perforations to the innermost glove. Perforation indicator systems results [sic] in significantly more innermost glove perforations being detected during surgery.”\textsuperscript{65}

Shaving of the hair about the surgical area and the surgical scrub of the patient is another factor steeped in tradition. In the past, it was not unusual for the entire lower extremity to be shaved the evening before a knee arthroscopy. However, use of a safety razor more than twenty-four hours prior to surgery carries a 20\% infection risk\textsuperscript{66}. Even shaving with a safety razor immediately prior to surgery carries a 3.1\% risk. Use of a depilatory agent or no hair removal at all is associated with the lowest surgical site infection rate of 0.6\%\textsuperscript{77}. It is recommended that, when shaving is necessary, an electric razor be used. Having the patient shower with a skin antiseptic the night prior to reporting for surgery has been shown to significantly decrease skin bacterial counts of staphylococci and yeast (p < 0.001)\textsuperscript{69}. The skin cleaning and preparation continues in the operating room, where there are several different methods. One is the use of one-step water-insoluble iodophor-in-alcohol solution. These solutions have been shown to fulfill the requirements for an operative site skin preparation and substantially improve drape adhesion\textsuperscript{70}. Chlorhexidine gluconate topical scrub may be used as well, but its decreased resistance to removal by water or saline solution may decrease its effectiveness to kill seeded bacteria\textsuperscript{70}.

Studies have also shown that the number of individuals in the operating room and the amount of movement of these individuals within the operating room both increase the number of colony-forming units as measured by settle plates within the operating room\textsuperscript{72}. Thus, nonessential personnel should not be allowed into the operating room, and movement, especially into and out of the operating room, should be minimized.

In one study comparing wound irrigation with (208 patients) and without (206 patients) Betadine (povidone-iodine), the infection rate was 0.5\% and 2.9\%, respectively\textsuperscript{73}. This difference was significant (p = 0.0146). Antibiotics are often added to the irrigant, but most of the literature is not supportive of their use\textsuperscript{72}. Detergents and castile soaps interestingly have been around for many years and have good literature support. Burd et al., in 1999, found a significant difference between groups of rats with polymicrobial wounds (control compared with detergent irrigation) for total number of culture-positive sites (p < 0.0001), culture-positive animals (p = 0.02), and quantitative cultures (p < 0.02)\textsuperscript{74}. Other experiments have revealed that surfactant irrigation was more effective than saline solution or antibiotic solution in animal wounds in the removal of adherent bacteria from metallic surfaces, bone, and bovine muscle\textsuperscript{74}.

Many surgical packs today include both a bulb syringe and a pulsatile lavage system. The majority of the literature supports the use of pulsatile lavage, but this recommendation still remains controversial. Hargrove et al. found that the pulsatile lavage group had a significantly lower total infection rate (p < 0.009) and, specifically, a decreased “joint space” or deep infection rate compared with normal saline solution washout by jug or syringe when undergoing hip hemiarthroplasty for trauma\textsuperscript{75}. In an ovine wound model, proponents for low-pressure lavage demonstrated that high-pressure pulsatile lavage causes deeper penetration of bacteria and may result in greater bacterial retention in the soft tissues compared with low-pressure lavage\textsuperscript{76}.

The debate over when or if a drain is indicated is as lively as any. Drinkwater and Neil found no clear evidence of any benefit\textsuperscript{77}. In their 1995 study, the authors speculated that the use of a surgical drain in joint arthroplasty created a passageway for postoperative infection if the drain remained in place for more than twenty-four hours. In another study of bilateral total knee arthroplasties with and without drains, no difference was found in swelling, quadriceps function, drainage, or infection\textsuperscript{77}. Finally, in a meta-analysis, it
was concluded that drains increase the transfusion need following total hip and knee replacement and have no major benefit.

There is very little literature with regard to the effect of different suture materials on infection rates. In a general surgery report comparing Vicryl and Vicryl Plus (polyglactin suture coated with triclosan) in abdominal wound closures, the infection rate was 10.8% with plain Vicryl and 4.9% with Vicryl Plus.

Antibiotics have been added to polymethylmethacrylate bone cement by operating surgeons in the United States for many years, while prepackaged antibiotic-loaded cement has been commercially available outside the United States. The U.S. Food and Drug Administration has approved the sale of commercially produced antibiotic-loaded cement for use during the second stage of a two-stage total joint revision following the elimination of an active infection, but specifically not for prophylaxis. The most important data with regard to prophylactic use of antibiotic-loaded cement comes from European registries. Engesaeter et al. reviewed the Norwegian Arthroplasty Register revision rates for 56,275 cemented and uncemented primary total hip replacements followed for zero to sixteen years. The risk of revision due to infection was equal for prostheses implanted with antibiotic cement and uncemented implants. Prostheses implanted with antibiotic cement had a lower risk of revision than those without antibiotic cement. Common concerns with antibiotic-impregnated bone cement are the potential for the development of an allergic reaction and the promotion of resistant bacterial strains. However, in the Norwegian registry of more than 100,000 patients, there have been no reports of an allergic reaction and no evidence of the development of resistance.

In conclusion, there are few issues that can so severely compromise a patient outcome as a nosocomial infection. This complication may manifest as a mild and annoying cellulitis or as a severe and life-threatening surgical site infection. It has the potential to compromise and even take the life of any individual undergoing surgery. While the threat of surgical site infection remains ever present, an emerging paradigm of surgical site infection prevention and control has matured. This paper has reviewed nosocomial infections, drug-resistant organisms, modifiable risk factors, preoperative screening, and tools and techniques related to orthopaedic infection prevention and control.

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