Optimum Operating Room Environment for the Prevention of Surgical Site Infections

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Abstract

Background: Surgical site infections (SSI), whether they be incisional or deep, can entail major morbidity and death to patients and additional cost to the healthcare system. A significant amount of effort has gone into optimizing the surgical patient and the operating room environment to reduce SSI.

Methods: Relevant guidelines and literature were reviewed.

Results: The modern practice of surgical antisepsis involves the employment of strict sterile techniques inside the operating room. Extensive guidelines are available regarding the proper operating room antisepsis as well as pre-operative preparation. The use of pre-operative antimicrobial prophylaxis has become increasingly prevalent, which also presents the challenge of opportunistic and nosocomial infections. Ongoing investigative efforts have brought about a greater appreciation of the surgical patient's endogenous microflora, use of non-bactericidal small molecules, and pre-operative microbial screening.

Conclusions: Systematic protocols exist for optimizing the surgical sterility of the operating room to prevent SSIs. Ongoing research efforts aim to improve the precision of peri-operative antisepsis measures and personalize these measures to tailor the patient's unique microbial environment.

Keywords: peri-operative management; prevention; surgical procedures; surgical site infection

THE MODERN DAY PRACTICE of surgical site infection (SSI) prevention is based on key observations from several 19th and early 20th century physicians and scientists. In 1846, Ignaz Semmelweis [1] noted that Austrian women delivering in teaching wards before the adoption of hand hygiene had a significantly higher mortality rate than women undergoing childbirth by midwives. While working in the Vienna General Hospital, Semmelweis first introduced the idea of hand washing with chlorinated water as a means of decreasing puerperal fever. It was not until Louis Pasteur's "germ theory" and the identification of *Staphylococcus* spp. and *Streptococcus pneumoniae* did Semmelweis' observation and empiric response regarding infection prevention resonate with practitioners.

Joseph Lister, the father of aseptic surgery, experimented with carbolic acid dressings for post-operative amputation patients while William Keen was one of the first surgeons to practice Lister's infection control in the operating room. Keen demanded that the patient's room be scrubbed with carbolic solution the day before the operation, and all those

participating in the surgery wash their hands [2,3]. Sterile gowns, caps, and mask implementation began in 1883. In 1889, when severe contact dermatitis to the carbolic acid solution developed in Caroline Hampton, the scrub nurse for William Stewart Halsted, Dr. Halsted commissioned the Goodyear Rubber Company to make a pair of rubber gloves for her to use during surgery [4]. Shortly thereafter, he mandated that the entire surgical team wear rubber gloves during the operation. In 1891, Ernst von Bergmann proved that heat sterilization of surgical instruments was superior to chemical methods [5,6].

In 1928, Alexander Fleming discovered the antimicrobial nature of penicillin, and modern day antimicrobial prophylaxis was begun. As scientists developed new and ever more powerful antimicrobial agents, the concept of a host microbiota associated with the skin, mucosal surfaces, urogenital, and gastrointestinal tract emerged, and researchers began to appreciate the vast range of in vivo environments in which these organisms flourished [7]. Later in the century, Frank Meleney [8] and William Altemier [9] demonstrated mixed

aerobic-anaerobic infections in cases of progressive gangrene of the abdominal wall leading to the acceptance that most surgical infections are polymicrobial. Armed with basic knowledge on pathogenesis, treatment, and prevention, widespread use of antiseptic techniques was adopted by all caretakers of surgical patients.

Modern Practices

Today, sterile technique is defined as a set of standard practices with the goal of minimizing microbial contamination to reduce the rate of SSI. While the standard practices may vary slightly depending on the institution and clinical situation, maintaining an aseptic operating room environment generally focuses on environmental cleaning, hand hygiene, pre-operative skin preparation for the patient, surgical attire, and general technique while working in a sterile field. Many medical and government agencies have published guidelines for maintaining a sterile environment while in the operating room. The National Guideline Clearinghouse and the US Department of Human and Health Services published 12 recommendations for operating room personnel regarding the maintenance of sterile technique. Surgical gowns, gloves, and drapes should be used in the operating room, and sterile technique should be applied once gowned and draped. Instruments brought onto the sterile field should be placed and handled in such a way as to maximize the maintenance of sterility. The sterile field should be monitored constantly by all operating room personnel [10].

The Association of Perioperative Registered Nurses also outlined guidelines for ensuring sterile technique with choices of gowns, gloves, and drapes based on the barrier classification of each product. The choice of personal protective equipment and drapes depends on anticipated degree of contact with infectious fluids. Duration and type of procedure should also be considered, because personnel exposure in minimally invasive surgery differs from that in open procedures [11]. The American National Standards Institute and the Association for the Advancement of Medical Instrumentation have categorized barrier protectors based on the level of liquid penetration. Level one surgical gowns and drapes resist impact penetration only. Level two resistance prevents soiling under hydrostatic pressure. Level three and level four gowns and gloves can withstand incrementally higher hydrostatic pressure testing without break in sterility [12].

In recent years, plastic adhesive skin barriers to protect against wound infection have gained popularity with the intent to prevent contamination of the surgical incision by the skin microbiota. Plastic adhesive drapes are placed over the incision site to protect the open incision from migrating skin bacteria adjacent to the surgical site. In a review of 4,000 patients and seven trials, however, no evidence exists in support of its efficacy in reducing SSI [13]. A second surgical site protection approach for shielding exposed tissues to microbes is the use of double ring wound protectors when a visceral cavity is entered (abdomen, thorax) and the wound is exposed to a contaminated epithelial surface such as the mouth, intestine, vagina. The idea is to wall off the exposed subcutaneous tissues from possible contamination during performance of the procedures such as colon resections and

hysterectomies when the vaginal epithelium is breached. Such appliances have shown some success in randomized trials, indicating efficacy in reducing SSIs.

Recently, a company has been launched that provides continuous irrigation of the compartmentalized wound to wash away any contaminants that might accumulate during the procedure. Finally, use of chlorhexidine gluconate as a surgical site irrigation agent has been proposed and trials are currently under way. A major assumption in these trials is that the operative field cannot be maintained perfectly sterile and therefore barrier protection is needed.

A major area of concern for sterility has traditionally been the hands of surgical team members, which are often the most proximate contaminating vector to the patient's tissue. As a result, the choice of cleansers for surgical hand antisepsis has been much debated. The two most common cleansers in the peri-operative setting are aqueous scrubs and rubbing alcohol products. Chlorhexidine gluconate and povidone-iodine are the two most common aqueous scrubs, and washing is performed in a systematic manner to prevent back contamination. Alcohol rubs are applied to dry hands, and the rub is allowed to evaporate before applying surgical gloves.

A Cochrane Review published in 2016 [14] concluded that there was no firm evidence to suggest that one type of hand cleanser is superior to another in reducing SSI. The investigators did find weak evidence, however, to suggest that chlorhexidine gluconate was superior to povidone-iodine and alcohol rubs were superior to aqueous solutions in reducing colony-forming units (CFUs). Further, low quality evidence showed that a three-minute scrub reduced more CFUs than a two-minute scrub. Pre-operative skin antisepsis at the operative site was also reviewed by Cochrane Wounds Group in 2015. The review found that some evidence exists in support of 0.5% chlorhexidine in methylated spirits over alcohol povidone-iodine paint in lowering SSI [15]. Pre-operative showering or bathing with chlorhexidine did not reduce SSI compared with normal soap [13].

The World Health Organization published the first ever international guidelines for prevention of SSI in November 2016 [16]. The recommendations focused on pre-, intra-, and post-operative actions that showed evidence-based benefits while considering resource and cost limitations. Several notable recommendations for pre-operative interventions included the use of mupirocin 2% ointment for patients with nasal carriage of *S. aureus* undergoing cardiothoracic or orthopedic surgical procedures; hair removal, if necessary, should be performed with clippers rather than shaving because of microscopic cuts caused by the blade in a razor [17]. Strong intra-operative recommendations included use of 80% fraction of inspired oxygen for patients undergoing general anesthesia with endotracheal tube to enhance tissue oxygenation and host defenses [18,19], plus the maintenance of normothermia [20]. Wound protectors with a single or double ring received conditional recommendation [21]. Studies focusing on surgical site irrigation resulted in conflicting and insufficient evidence [17,22,23]. No recommendation was formulated for use of double gloving or changing of surgical instruments for incision closure [16].

Breaks in sterile technique and microbial contamination in the operating room are categorized into four types based on how quickly the event is recognized. Type 1 break is caught

immediately. Types 2 and 3 are recognized progressively later. A type 4 break is not recognized at all by the operating room team. The most common breaks in sterile technique are with pre-operative instrument sterilization, placement of sterile instruments onto a designated sterile field, hand washing and drying, gloving, gowning, draping, cleansing of the incision area, and general surgical technique [24]. Meticulous attention during each phase of the operative setup by all personnel helps to limit inadvertent microbial contamination. During the procedure, operating room doors should remain closed unless necessary team members need to enter or exit. The operating room should also have high efficiency particulate air filters, positive air pressure, and directional airflow to reduce airborne microbial contamination [25].

Despite standard aseptic practice, meaningful breaks in sterile technique do occur, which can result in significant morbidity and hospital costs. In the autumn of 1999, SSIs developed with the same strain of *Pseudomonas aeruginosa* in 16 patients who underwent median sternotomies at a hospital in Ann Arbor, MI. This strain of bacteria was linked back to the onycholysis of one nurse's thumbnail. The reason behind the significant break in technique was thought to be a new brand of latex surgical gloves that were introduced into the operating room during this period; however, the evidence for such a theory was weak, because the use of the gloves in other surgical settings did not result in similar results [26]. Future research is thus needed to determine host and environmental reservoirs of nosocomial pathogens [27].

Even with best practices to maintain sterility, it is impossible to eradicate all bacteria from the operating room. The patient and all of the operating room employees introduce host-associated microbes near the sterile field through skin, hair, and nasal shedding as well as via breath aerosol transmission despite wearing standard operating room attire [28]. Many attempts have been made to address this seemingly unavoidable bioburden. One example is the use of protective suits with hoods and self-contained exhaust system [29], which has been adopted by many orthopedic practices, especially for joint replacements [29]. While studies do show that its use can improve measures of sterility inside the operative field (e.g., bacterial colonization), there is insufficient evidence to suggest their use decreases surgical infections [29,30]. Another tried solution is the use of ultraviolet (UV) radiation to further sterilize the operating room. The use of UV lights began as early as the 1940s [31]. Similar to the initial enthusiasm for space suits, early studies showed that it does decrease the bioburden within the operating room [32]. There is little evidence to suggest, however, that its use decreases the rate of hospital-associated infections [33].

Future Directions

As our refinement of surgical sterility continues, the prevention of SSIs may well take our efforts beyond the confines of the operating room and into the lives of patients themselves. From the very beginning of antisepsis and surgical infection control, the primary focus has been microbial eradication. While microbial elimination is and will remain an essential component of the effort to reduce SSIs, a growing body of evidence suggests that it alone may not be sufficient. Recent advances in the understanding of the human microbiome have demonstrated that human microbial homeostasis

predicates on a series of complex interactions involving the host and its constituent microbes, the disruption of which likely contributes to deep SSIs [34]. Surgeons have long recognized that the stress of surgery, in and of itself, renders the patient more susceptible to infection. Our current understanding of how the microbiome responds to surgery and hospitalization, however, remains inadequate to combat peri-operative infectious complications [35].

Nonetheless, major investigative efforts are under way in an attempt to elucidate and properly manage infectious surgical complications. For instance, we know that a primarily purgative pre-operative preparation such as bowel preparation or prophylactic antibiotics can reduce intestinal bacterial load while exerting selective pressure of the residual microbiota. This artificial selection can result in opportunistic as well as nosocomial infections (e.g., *Clostridium difficile* colitis) [35,36].

These new insights have begun to alter our approach toward preventing SSI. Perhaps rather than blanket elimination, it is sometimes more advantageous to simply suppress the virulence of potential pathogens. Our laboratory has reported the use of phosphorylated polyethylene glycol (Pi-PEG) to suppress bacterial virulence while preserving the core microbiome [37]. It has been shown that operative injuries can result in a depletion of intestinal phosphate, which in turn can upregulate the virulence of certain potential pathogens [38]. Virulence suppression is achieved by repletion of phosphate via Pi-PEG [38]. As our understanding of the dynamics of bacterial virulence increases, it is possible that we will be able to selectively contain potential pathogens before and after surgical procedures rather than employing a carpet-bomb approach for microbial elimination, which is essentially impossible.

Finally, there is an effort under way to elucidate the dynamic microbial ecology of the hospital environment via the hospital microbiome project [39] to better understand infection pathogenesis. Sequencing technology and point of care diagnostics are now available to create a dynamic microbial map of how microbes move in and out of our environment and how patients and instruments become the vectors of transmission. Emerging technology may soon be able to allow us to consider the hospital as a microbial ecosystem in which interventions move beyond mass sterilization. Much like any healthy ecosystem, the most effective way to exclude unwanted invaders may be to populate the environment with a diverse set of health promoting microbiota that not only protect innate surfaces, but also patients' tissues.

Conclusion

As our antisepsis efforts continue, we need to consider the need to revolutionize our approach toward preventing SSIs. Key developments will likely include more personalized peri-operative antiseptic approaches. Bode and colleagues [40] found that screening surgical patients who are nasal carriers of *S. aureus* and treating them accordingly significantly decreased the rate of SSIs, especially deep surgical infections. As we improve our understanding of human-microbial interaction and cross-talk, we have the opportunity to develop specific therapeutic interventions before, during, and after surgical procedures to reduce SSI. We envision a future in which patient screening of the microbiome before

operations can be used to predict the probability of infection and thereby the patients' response to surgical intervention. This knowledge would allow us to tailor the appropriate therapy for a particular patient and the potential pathogen. Understanding the dynamic and complex relationship that exists among our patients, their endogenous microbiota, and the pathogenesis of SSIs will help to guide surgeons and surgical practices on the march toward personalized surgical procedures.

Author Disclosure Statement

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