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REVIEW

# Prevention and surveillance of surgical infections: A review

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**Abstract**

Optimal patient care cannot be realized without effectively managing risks related to healthcare-associated infections (HAI). Among human hospital admissions in the United States in 2002, there were approximately 4.5 HAI per 100 admissions, with surgical site infections (SSI) accounting for an estimated 20%, or approximately 2 SSI per 100 procedures. When considering the occurrence of disease in a population, it is important to remember that disease does not occur randomly in populations. Therefore, when thinking about managing risks associated with the occurrence of SSI, consideration should be given to key factors in disease development (the agent, the host, and the environment), and a multifaceted approach to prevention efforts should be considered, including the identification of high-risk populations, adherence to aseptic principles, judicious use of antimicrobial drugs, and surveillance targeting SSI to better inform infection control practices within a facility. Although not all HAI are preventable, it is important to focus efforts on the preventable fraction and to take all reasonable precautions to mitigate foreseeable risks.

## 1 | INTRODUCTION

Optimal patient care cannot be realized without effectively managing risks related to healthcare-associated infections (HAI), those infections associated with the delivery of healthcare.[1] It is well recognized in human healthcare that HAI result in increased morbidity and mortality and can increase the duration of hospitalization as well as the cost of care.[2] In 2002, there were approximately 4.5 HAI per 100 human hospital admissions in the United States, with surgical site infections (SSI) accounting for an estimated 20%, which equates to approximately 2 SSI per 100 procedures.[3] Although similar surveillance data in veterinary medicine are limited, a syndromic surveillance study conducted in 2006 estimated the incidence of surgical site inflammation per 100 hospitalization days in veterinary critical care animals to be 2.8 (95% CI 2.1, 3.9) among dogs, 1.5 (95% CI 0.7, 3.0) among cats, and 1.6 (95% CI 0.8, 3.1) among horses.[4,5] Although not all of these HAI are preventable, it is important to focus efforts on the preventable fraction and to take all reasonable precautions to mitigate foreseeable risks.

The landmark Study on the Efficacy of Nosocomial Infection Control, conducted in US human healthcare facilities (1970–1976), demonstrated that HAI rates could be reduced by as much as 32% if hospitals employed trained infection control personnel, conducted surveillance activities to inform efforts, and reported results back to stakeholders.[6] Although equivalent data in veterinary infection control are limited, it is not unreasonable to anticipate a similar impact when using these same practices. Indeed, key to the prevention of SSI is understanding the underlying epidemiology, which can be elaborated through surveillance activities. To do this, however, there must be a common language or, rather, a common definition for SSI.

## 2 | DEFINING SURGICAL SITE INFECTIONS

In human medicine, SSI are broadly defined as 3 types, (1) superficial incisional (affecting only the skin and/or subcutaneous tissues), (2) deep incisional (affecting fascial and muscle layers), and (3) organ/space (any area other than the skin that was opened or manipulated during surgery),[7] and are commonly classified as (1) clean (nontraumatic, uninfected), (2) clean-contaminated (controlled entrance of hollow viscus), (3) contaminated (open traumatic wound, inflammation), or (4) dirty (perforated viscus, pus).[7] These types and classifications can also be applied to veterinary medicine; however, they are not necessarily uniformly applied in all research referenced in this review. Although this may impact numerical estimates of risk, the risk factors discussed in this review have been consistently identified in multiple studies under varying conditions (Hill's criteria of consistency of effect[8]), giving confidence that these factors are associated with the occurrence of SSI in veterinary medicine despite potential classification differences.

## 3 | EPIDEMIOLOGY OF SURGICAL SITE INFECTIONS

When considering the occurrence of disease in a population, it is important to remember the central tenet of epidemiology: disease does not occur randomly in populations. Therefore, when managing risks associated with the occurrence of HAI, 3 key factors should be considered in the development of disease, the agent, the host, and the environment, commonly referred to as the epidemiologic triad.

In this case, the agent may be physical, chemical, or biological; of particular concern are the types of surgical procedure and the presence of potential pathogens—endogenous or exogenous—and their associated virulence factors. Endogenous microorganisms may be derived from normal inhabitants of body sites such as the gastrointestinal tract or nasopharynx or are from sites of infection, whereas exogenous microorganisms are derived external to the patient from the animate (personnel) or inanimate environment.

Host factors are commonly considered to be intrinsic factors like genetics and immune status and extrinsic factors such as the population structure and the likelihood of exposure. Veterinary hospitals knowingly bring together potentially infectious animals in varying stages of compromise. As a result, appropriate precautions should be taken according to an animal's systemic level of disease, existing comorbidities (diabetes mellitus, neoplasia), and immune status (pregnancy, immunosuppressive therapies) when performing a diagnostic workup and providing medical care.

Finally, environmental factors are generally considered to be extrinsic factors such as the animate and inanimate environment as well as therapeutic interventions (catheterization, surgical implants). When considering SSI, the literature consistently reports an increased risk associated with the duration of surgery, time of perioperative clipping, and number of persons in the operating room.[9–12] One simple way to remember important external factors is to consider "time, trash, and trauma," with time being indicative of duration of surgery, trash referring to surgical site contamination, and trauma referring to factors that may influence tissue health and healing (vascularization, dead space, devitalization)[13]—all issues that can be managed by the surgical team.

## 4 | MANAGING RISKS ASSOCIATED WITH SURGICAL SITE INFECTIONS

When thinking about managing risks associated with SSI, it can be useful to consider 4 broad categories commonly used to classify HAI: events associated with a device, procedures, compliance, and etiologic agent, all of which may be associated with the occurrence of SSI in a particular facility.

In the occurrence of SSI, device-associated events are commonly reported for surgical implants; the greatest risk is reported for contaminated wounds with surgically placed implants, followed by clean surgical procedures with implants, and the lowest risk is among clean surgical procedures without implants.[9,14] In general, risk reduction efforts should focus on implant placement (indication, technique), maintenance (routine care), and removal (no longer required, signs of inflammation/infection).

Of particular concern is the formation of biofilm on indwelling medical devices such as surgical implants. Biofilms are microbial communities that produce protective extracellular matrices that not only promote bacterial adhesion to surfaces but also provide a protective framework,[15] enhancing bacterial survival from environmental insults (drying and disinfectants), and affording some protection from the immune system and antimicrobial therapy.[16,17]

Procedure-associated events are commonly reported for surgical sites and can be related to surgical preparation or particular aspects of the surgical procedure such as length of surgery, tissue handling, or experience of the surgeon. Reports suggest that the infection risk increases with the duration of surgery, including clean and clean-contaminated wounds among dogs having orthopedic, minimally invasive, or open surgery.[10,11] In horses, the risk increases with nonclean surgical sites, implants, and standing procedures[14] as well as with arthroscopy with large subchondral bone lesions (>40 mm) or long abdominal incisions (>27 cm).[18–20] In cattle, SSI risk has also been shown to increase with increasing wound contamination (with the lowest incidence associated with clean and the highest reported for dirty wounds).[13] In addition, the odds of a glove perforation have been shown to increase with surgical time as well as with the invasiveness of the procedure.[21–24] Although glove perforations tend to occur more commonly in the nondominant hand,[23,24] there appears to be no difference with regard to surgeon experience (board-certified vs resident).[23]

Compliance-associated events are commonly attributed to hand hygiene, cleaning and disinfection protocols, and ineffective use of barrier precautions, and they can result in substantial animal morbidity and mortality as well as financial cost to the facility.[25] Hand hygiene is one of the most important infection control measures for the prevention of infectious disease transmission,[26–30] whether this is inside the operating theater or during preoperative and postoperative patient care. Although as a profession hand hygiene is known to be important,[31,32] overall compliance can be quite low among small-animal practitioners (14%–20% of hand hygiene opportunities),[31,33–35] which likely promotes the transmission of infectious agents to animals, personnel, and the environment. Multiple obstacles have been identified regarding hand hygiene compliance including forgetfulness or being "too busy," damage to skin from frequent hand washing, and a lack of available hand hygiene supplies.[32,35] To some degree, a lack of compliance can be overcome through hand hygiene education and awareness campaigns.[33,34] In addition, because frequent hand washing can compromise skin integrity (not only decreasing compliance but also increasing the risk for bacterial colonization[36,37]), it is also important to provide lotions and moisturizers to promote healthy skin. Finally, it is imperative to have personnel dedicated to ensuring that hand hygiene supplies are readily available.

There are many different biocides available for preparation of surgical sites, including povidone iodine, chlorhexidine, and alcohol-based solutions, all of which have been shown to have an equivalent impact on bacterial growth on the skin.[38,39] In addition, povidone iodine and chlorhexidine solutions reportedly decrease the occurrence of SSI among dogs undergoing orthopedic or soft tissue surgery.[38] Many factors may contribute to the efficacy of presurgical scrubs, and, variable efficacies are reported. However, it is important to keep in mind that, although personnel tend to comply with protocols during times of increased observation, in general, they tend to gravitate away from protocols.[33] Hence, although biocides are known to be effective for reducing bacterial contamination of the skin, they must be used in their intended manner to be effective.

Surgical site infections connected to etiology-associated events are those linked to a specific agent. Without performing routine surveillance as discussed below, events can be difficult to identify. Despite this, 82% of American Veterinary Medical Association-accredited veterinary teaching hospitals reported infectious disease outbreaks in their facilities within a 5-year period, with *Salmonella* and methicillin-resistant *Staphylococcus* the most commonly identified bacteria.[40] Environmental contamination is commonly associated with the occurrence of epidemic disease in both large- and small-animal hospitals.[25,41–44] Although a comprehensive review is beyond the scope of this article, when considering the occurrence of SSI, it is important to note the role that an animal's normal flora may play. Of particular concern are *Staphylococcus*, *Enterococci*, *Pseudomonas,* and *Escherichia coli*, all of which can exhibit multidrug resistance and can persist in the hospital environment.[9,45,46] In addition, *Acinetobacter spp*, which can also persist in the hospital environment, are newly emerging as potential pathogens in veterinary medicine.[44,47]

## 5 | PREVENTION OF SURGICAL SITE INFECTIONS

Although not all SSI are preventable, there is a preventable fraction. With this in mind, this review considers 4 areas of activity that can help inform decision making when managing risks associated with SSI: (1) identification of high-risk patient populations, (2) adherence to aseptic principles, (3) judicious use of antimicrobial drugs (AMD), and (4) SSI surveillance activities.

### 5.1 | Identification of high-risk animals

On the basis of the epidemiology, patients should be assessed for factors that may contribute to the development of an SSI, including general health, comorbidities (diabetes mellitus, neoplasia), wound classification (contaminated), and the presence of implanted medical devices. Of particular concern is the association of *Staphylococcus spp* carriage and development of SSI, an association that is not only seen in human medicine but has also been identified in dogs carrying methicillin-resistant *Staphylococcus pseudintermidius.*[45] In addition, consideration should be given to events in the postoperative period[9] because horses that experience postoperative colic, presumably leading to contamination of the incision site, are much more likely to develop an SSI.[19,20] It is clear that each facility's patient population is unique; therefore, consideration should be given to performing targeted or intermittent surveillance (see discussion below) to determine high-risk patient groups in each facility's patient population.

### 5.2 | Adherence to aseptic principles

Antisepsis is a relatively recent concept that was introduced into surgical practice by Joseph Lister in 1867.[48] Very broadly, aseptic technique includes all practices employed to prevent contamination with microorganisms,[49] including the surgical facilities and environment, surgical site, surgical team, and surgical equipment. Although in practice the use of aseptic technique will not eliminate all microorganisms from the surgical site, if it is applied appropriately, aseptic technique may reduce the number of microorganisms to a level that is of limited consequence.

Presurgical hand antisepsis is an important step in the prevention of SSI. Irrespective of surgeon, use of an alcohol-based hand rub has been shown to be as effective as a chlorhexidine gluconate or povidone iodine scrub for reduction of bacterial counts on hands prior to surgery, and[50,51] alcohol-based hand rubs may have a greater sustained effect.[50] It is important to remember that veterinarians in training may not be as skilled at performing a presurgical hand antisepsis and that alcohol rubs may not be as effective with this group of veterinary personnel.[52] Inexperience may contribute to evaporation of alcohol-based hand rubs before completing surgical hand preparation, so this group may benefit from using a chlorhexidine gluconate product.[52]

Preoperative surgical preparation of the skin is another important component of surgical asepsis. Although taught to use a repeated mechanical scrubbing technique working from in to out with chlorhexidine gluconate or povidone iodine, rinse, and repeat 2 more times, it may be reasonable to abbreviate this procedure. In a recent equine study, a simple nonmechanical preparation technique was as effective at reducing bacterial counts on the skin as a conventional mechanical technique[53]; another report in cattle described similar findings when an abbreviated presurgical mechanical scrub was used.[54] Although these are just 2 studies, they suggest that presurgical scrubs can be more efficient, thereby reducing the time from clipping to surgery, a factor that has been associated with increased SSI risk.

Glove use not only is an important component of hand hygiene but is also of particular importance to surgical asepsis. Surgical glove failures are relatively common, although they are typically unrecognized by the wearer.[22,55,56] To reduce the likelihood of a glove failure during a surgical procedure, surgeons often double glove or use reinforced gloves, particularly during orthopedic procedures. In a recent randomized control trial, no difference was found in contamination events (glove failures) between double gloving and the use of reinforced gloves,[21] suggesting that surgeon comfort and dexterity can drive glove selection (either double glove or reinforced gloves) without compromising patient care.

### 5.3 | Judicious use of AMD

Although AMD should be used when required, they should be used judiciously.[57] This includes use of fully effective doses at adequate intervals for appropriate clinical indications, use of narrow-spectrum AMD specific for the isolated organisms based on antimicrobial susceptibility testing, selection of AMD against which the isolated organisms are not prone to develop resistance according to current scientific and clinical principles, changing AMD only after an effective treatment period, restriction of indiscriminate use of antimicrobial drugs (limiting use to ill or at-risk animals, and treat only as long as required to achieve clinical response), and use of topical or local rather than systemic therapy whenever possible.[57]

Another consideration in judicious use is that of prophylaxis or the use of AMD without an established infection. A recent randomized clinical trial found that the use of postoperative oral cephalexin or potentiated amoxicillin for 7 days reduced the infection risk among dogs undergoing a clean orthopedic surgery requiring plate fixation.[10] However, some have found no difference in SSI rates among dogs undergoing clean orthopedic surgeries with and without antimicrobial therapy,[18] and others have found similar joint infection rates among horses undergoing elective arthroscopy without the use of antimicrobial drugs compared with historical reports when AMD were used.[58] Although there is debate regarding the use of prophylaxis, these findings suggest that this practice should be considered on a case by case basis, especially if the patient has other risk factors for the development of an SSI.

One method for veterinary practices to ensure judicious use is to develop an antimicrobial stewardship program (ASP) focused on improving patient outcomes while minimizing unintended consequences. Such programs generally place emphasis on coordinated efforts advocating the appropriate use (selection, dosage, route, and duration) of AMD. A detailed description of antimicrobial stewardship programs is beyond the scope of this article, and readers are referred to Dellit et al.[59] Briefly, ASP should be managed by a multidisciplinary team and include a multifaceted approach with core strategies like prospective surveillance with feedback, restricting use of AMD considered to be critically important to public health, and employing education to ensure foundational knowledge and improve program compliance.[59] In addition, due consideration should be given to managing disease without the use of AMD because not all infections are bacterial, and not all bacterial infections require systemic antimicrobial therapy.[60] In some instances, local therapy may be appropriate, and, in other instances, the resolution of an underlying condition may eliminate a secondary bacterial infection without the use of AMD. Finally, ASP should not be relied on as a primary prevention strategy because microorganisms will inevitably be exposed to AMD in veterinary hospitals, and, consequently, patients will be exposed to resistant bacteria. Therefore, appropriate infection control practices should be employed to reduce the spread of resistant organisms and the likelihood of resistant bacteria becoming established in the hospital environment.

### 5.4 | Surgical site infection surveillance activities

Surveillance, the systematic collection, analysis, and interpretation of events in a population, is an important tool used in the management of an infectious disease control program because it is not possible to manage what is not measured.[61] Surveillance has 2 components, a system of monitoring for a particular event of concern (SSI) and a critical limit at which a predetermined action will be taken to mitigate a perceived risk (this should be facility specific and is typically related to risk aversion of stakeholders). Surveillance data then allow a facility to establish a baseline or an expected level of a particular outcome, process, or event and instigate corrective actions if levels deviate from this endemic level. A comprehensive review is beyond the scope of this review, and readers are referred to Burgess et al[61] for additional information. There are multiple methods for performing surveillance activities, each with different advantages and disadvantages.

#### 5.4.1 | Active surveillance

Active surveillance is conducted for the express purpose of identifying an outcome or indicator of interest, in this case SSI. This type of surveillance provides primary data that are typically of high quality; however, there are time and monetary costs. A recent prospective study of canine orthopedic patients found that only 65% of SSI were documented in the medical record; the remaining 35% were detected only upon completion of a follow-up survey with the owner 30 days postoperatively.[9] This finding was mirrored by a more recent study that identified an additional 28% of SSI by using active postdischarge surveillance.[62] These studies provide evidence of the important role that active surveillance can play in understanding the epidemiology of SSI in a given practice.

#### 5.4.2 | Passive surveillance

An alternative to active surveillance is passive surveillance, which uses information that has been collected for another purpose (diagnostic laboratory samples). This type of surveillance is relatively inexpensive and simple to perform but is considered a secondary data source, and, as such, there is limited control over the quality of the data. For example, in the study by Turk et al,[9] only 8% of SSI were detected before the patient was discharged from the hospital. Relying solely on passive surveillance and only reviewing medical records without any follow-up would have grossly underestimated the occurrence of SSI in the patient population.

#### 5.4.3 | Syndromic surveillance

Yet another option is to perform syndromic surveillance, which uses nonspecific indicators of disease (inflammation) that are often present before a definitive diagnosis can be determined. This type of surveillance is relatively easy to perform but relies on formalized definitions to allow consistent monitoring. For example, continuing with the prospective study describe above,[9] an additional 5.2% of dogs had incision abnormalities classified as inflammation. Relying solely on syndromic surveillance for surgical site inflammation also would have grossly underestimated the occurrence SSI in this patient population. Although both passive and syndromic surveillance data are limited, an increase from baseline levels could trigger active surveillance to gain a better perspective on the occurrence of SSI at a facility. Finally, although continuous surveillance can be performed, targeted or intermittent surveillance of high-risk or high-cost problems has also been shown to be effective.[63] Targeted or intermittent patient surveillance allows focused effort on a particular type of patient (orthopedic vs all surgical patients), a specific pathogen (*S pseudintermidius*), or a specific syndrome (SSI or febrile patients) and can impact resources less.

In conclusion, veterinarians have an ethical responsibility to consider infection control in daily practice, and this includes managing risk related to the occurrence of SSI. Veterinary infection control is in its infancy, but a recognizable standard of care for infection control is beginning to emerge.[64] Veterinarians must take reasonable precautions to mitigate foreseeable risks associated with infectious disease in patients and hospital personnel, and infection control programs should be tailored to the unique set of structural and operational circumstances at each facility. Considerations may include financial and personnel considerations, available facilities, hospital populations, and the hospital administration level of risk aversion. Although infection control efforts should be facility specific, there are common features that provide the foundation for every infection control program: (1) protocols for proper hygiene of personnel and the environment, (2) a surveillance component to inform efforts, (3) protocols designed to disrupt the chain of transmission, and (4) education to create understanding and awareness of infection control practices.[64] It is essential to remember that disease does not occur randomly in populations; that the agent, host, and the environment must be considered; and that not all HAI are preventable. Finally, all reasonable precautions must be taken to prevent the preventable fraction.

## CONFLICT OF INTEREST

The author declares no conflicts of interest related to this report.

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