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REVIEW ARTICLE

Surgical site infections: epidemiology and microbiological aspects in trauma and orthopaedic surgery

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Abstract

Causative agents of wound infections and the routes by which they access surgical incision sites have been recognised for more than a century. Despite knowledge of the factors that influence the risks of surgical site infections (SSIs) and the means to prevent and/or control them, surgical patients still get infections. Traditional systems of classifying and diagnosing SSIs and the diversity of microbial flora reported in contemporary SSIs will be described. Strategies available to prevent and control SSIs will be critically reviewed and the need to develop alternative approaches will be discussed.

Introduction

Until the middle of the 19th century, surgery was largely feared because of the likelihood that life-threatening wound infections known as 'hospital gangrene' would result. In those times the majority of surgical incision sites became infected and mortality rates of 70–80% were not unusual for patients with deep or extensive infections (1). Preventing and treating wound infections must have been difficult before the causes of infection were understood. The recognition by Robert Koch in 1876 that infectious agents caused infectious diseases stimulated early microbiologists to isolate and characterise many pathogens and the most common causes of wound infection were known before the end of the 19th century.

In conflict zones, where traumatic injuries frequently occur, preventing and treating wound infection has always been important. Military surgeons during the American Civil War used tincture of iodine in the treatment of contaminated traumatic wounds. The development of the concept of aseptic surgery with the liberal use of carbolic acid by Joseph Lister dramatically reduced surgical infection rates in civilian operating theatres and generally promoted the use of antiseptics. During World War I the importance of debridement and the need for delayed closure of traumatic wounds were established. In the beginning of the 20th century, Paul Ehrlich promoted the idea of selectively inhibiting the pathogens that caused infections, but it was the discovery and development of antibiotics that revolutionised the management of infection. Sulphonamides and penicillin were first used to control wound infection during World War II. By 1969 the availability and diversity of antibiotics prompted the US Surgeon General to suggest that ' . . . The time has come to close the book on infectious diseases' (2). However, the emergence and wide dissemination of antibiotic-resistant microbial strains has proved this statement to be premature.

Key Messages

- in hospitalised patients, surgical site infections (SSIs) are the third most frequently reported infection and often account for 12-16% of all nosocomial infections
- *Staphylococcus aureus* is most frequently recovered from SSIs with antibiotic resistant strains such as methicillin-resistant staphylococci, vancomycin-resistant enterococci and extended spectrum beta-lactamase Gram negative bacteria of increasing concern
- it has been estimated that 40–60% of SSIs are preventable and that effective control relies on a multitude of interventions that include surveillance, antimicrobial prophylaxis, eradication of carrier status, infection control programmes and education
- the capacity for rapid evolution in micro-organisms indicates that new ways to prevent and treat SSIs will always be required
- with the lack of investment in discovering new antibiotics, other strategies to reduce wound infection include the development of vaccines for orthopaedic patients, phage therapy and negative pressure wound therapy

Despite knowledge of the natural reservoirs of infectious agents and their transmission routes to susceptible patients, surgical patients experience wound infections. This article will explore some of the reasons for this.

Epidemiology of surgical site infections (SSIs)

Information on the epidemiology of SSIs has been collected since the 1960s when definitions of infection and categories of wounds were established. From a study conducted in five hospitals by the United States National Research Council and the National Academy of Science in which the effect of ultraviolet light in operating theatres on infection rates was investigated, it was evident that the extent of microbial contamination at a surgical site was an important risk factor for subsequent wound infection (3). A system of classifying operative wounds into four categories based on microbial contamination (clean, clean-contaminated, contaminated and dirty) was devised and has since been used in reporting postoperative infections (4). The need to identify surgical patients at risk of infection and to reduce infection rates was also realised. During the 1970s, the US Center for Disease Control (CDC) started an initiative called National Nosocomial Infections Surveillance (NNIS) to monitor hospital-acquired infections, which included SSIs (5). The effectiveness of infection control strategies was assessed by the Study on the Efficacy of Nosocomial Infection Control (SENIC) project (6). Similar schemes have been developed in other countries. In the UK, for example, the Nosocomial Infection National Surveillance System (NINSS) was developed (7). In hospitalised patients, SSIs are the third most frequently reported infection and often account for 12–16% of all nosocomial infections (8).

Definitions of SSIs

The CDC published definitions for nosocomial infection in 1988, which included surgical wound infections (9). These were used by NNIS to monitor nosocomial infections, although definitions for SSIs were modified in 1992 (10) to indicate three wound locations: superficial incisional SSIs, deep incisional SSIs and organ space SSIs. Similar definitions have been used elsewhere, but there is no universally accepted classification system, which makes comparison between hospitals difficult (11). Within the UK a definition that is largely used is 'A surgical site infection occurs when micro-organisms get into the part of the body that has been operated on and multiply in the tissues' (7). Because 2 of the 16 criteria used in the CDC SSI definitions have been regarded as subjective, a surgeon's opinion is not used in the UK, and, instead of culturing micro-organisms from clinical samples, the presence of pus cells is used as an indicator of infection (7).

Diagnosis of wound infection

The diagnosis of infection in surgical wounds essentially depends on clinical signs and symptoms, with guidance from numerical systems such as ASEPSIS (12) or the Southampton Wound Assessment Scoring Scale (13). However, a prospective observational study of wounds in 4773 surgical patients admitted to London hospitals for more than 2 days demonstrated that experienced practitioners found that different methods to diagnose infection in 5804 surgical wounds did not give consistent results (14).

Microbiological investigation of wounds is not always indicated and antimicrobial interventions may be selected on an empirical basis. Nevertheless, in the Leiden University Medical Centre an investigation was undertaken to determine whether surgeons could have improved their clinical management strategies by knowing the results of microbiological cultures at the time of the diagnosis. A retrospective analysis of laboratory reports from microbiological investigations of 701 patients admitted between 1997 and 2005 was conducted. It was found that a diagnosis of SSI was supported by culture results in most instances, but less frequently with trauma patients and cases of less severe wound infections. This suggested that trauma surgeons might have used antibiotics too liberally in some circumstances (15).

Pathogens associated with contemporary SSIs

Bacteria have mainly been associated with SSIs and *Staphylococcus aureus* has been the most frequently reported causative agent (5). However, the range of pathogens associated with SSIs varies with location, with low incidence of antibiotic-resistant bacteria recently reported in one Swiss hospital (16). Until recently, the identity of pathogens causing SSIs was derived from conventional techniques to culture pathogens that are routinely used in hospital laboratories throughout the world, but the application of modern molecular techniques to characterise the bacterial diversity in chronic SSIs has begun to alter perceptions. In 23 chronic SSIs it was demonstrated that two previously unknown Bacteroidales were present in all of the SSIs investigated, six genera were identified in most of the wounds and anaerobic bacilli rather than aerobic cocci predominated (17). This suggests that unculturable bacteria are present in SSIs and that multiple species are present.

Antibiotic-resistant strains have increasingly been associated with nosocomial infections; methicillin-resistant *S. aureus* (MRSA), methicillin-resistant coagulase-negative staphylococci, vancomycin-resistant enterococci and extended spectrum beta-lactamase Gram-negative bacteria have caused particular concern (15,18).

The microbial flora of the wounds of modern combat-injured personnel has been shown to be especially extensive. In addition to *S. aureus*, beta-haemolytic streptococci and clostridia, *Aeromonas*, *Acinetobacter*, *Achromobacter*, *Comomonas*, coliforms, enterococci, *Pseudomonas* and *Bacillus* have been recovered from trauma wounds of military personnel (19). Also, a small group of soldiers repatriated from the Green Zone in Afghanistan with wounds heavily contaminated with environmental debris have experienced invasive fungal soft-tissue infections caused by *Rhizopus*, *Apophysomyces*, *Mucor*, *Saksenaea*, *Absidia* and *Chaetomium* (19). Many infections in combat zone personnel now involve antibiotic-resistant or multidrug-resistant organisms, and organisms producing extended beta-lactamases are a particular problem (20).

Outcomes of SSIs

SSIs have diverse clinical, financial and social impacts, from increased length of hospital stay, increased morbidity and mortality, increased risk of readmission and increased treatment costs. It has been estimated that in the USA SSIs cost approximately $1·6 billion annually (21) and that preventing one postoperative infection caused by MRSA could save one hospital as much as $60 000 (22). Costs of SSIs are, however, related to the different categories of surgery and generalisations are not always sound (23).

Risk factors for SSIs

In addition to the extent of microbial contamination at an incision site (3), host factors (such as age, nutritional status, life style, comorbidities, immunocompetency and coexisting infections), the length of the preoperative hospital period, preoperative procedures (such as skin preparation/antisepsis, antimicrobial prophylaxis and preoperative shaving) and the duration and performance of the operation contribute to increased risks of SSIs (24). Many limitations have been addressed, with effective sterilization of surgical instruments, improved operation theatre ventilation systems, optimal surgical techniques and barriers to prevent cross-infection in place.

Controlling SSIs

Opinions on the ability to eliminate SSIs are divergent. It has been estimated that 40–60% of SSIs are preventable and that effective control of SSIs relies on a multitude of interventions that includes surveillance, antimicrobial prophylaxis, eradication of carrier status, infection control programmes and education (25).

Surveillance of SSIs

In many countries monitoring SSIs and reporting individual surgeon as well as procedure-specific infection rates has been one important way to reduce infection rates. A surveillance programme that was initiated in a Dutch orthopaedic surgical department led to reduced infection rates following elective hip and knee replacements over 5 years, although specific causes were not discovered (26). In this project, the importance of promoting awareness of infection control measures by integrating infection control practitioners with the surgical team was considered valuable. From the data published in the National Healthcare Safety Network report issued in December 2009, it was estimated that 6000–20 000 SSIs were associated with hip and knee replacements annually in the USA between 2006 and 2008 (27). In the UK, surveillance of SSIs in NHS hospitals was reported for 17 surgical categories from April 2004 until March 2011 (28). It has been a requirement of the Department of Health since April 2004 for all NHS Trusts where orthopaedic surgery is performed to conduct surveillance for a minimum of 3 months in each financial year in at least one of four procedures: hip prosthesis, knee prosthesis, repair of neck of femur and reduction of long bone fracture. Trends in the rates of SSIs in hip and knee replacements have fallen since 2004–2005. Mandatory surveillance of orthopaedic surgery demonstrated that 91 362 procedures were performed in 2010–2011 and that *S. aureus* was the most frequent cause and members of the Enterobacteriaceae were the second most common cause of SSI (28).

Antimicrobial prophylaxis

The use of antibiotics to prevent infection has long been recognised (29), but it is usually restricted to surgical procedures involving open fractures, recent prosthetic joint replacement, puncture wounds or dirty surgical location where high infection rates are common. Antibiotics are also used in surgical procedures where infection rates are normally low, but where SSI would lead to a disastrous event. Guidelines on using antibiotics to prevent SSIs were first devised in 1999 in the USA (30). Agents should ideally be bactericidal, effective against expected pathogens, without side effects for the patient, and relatively cheap. Cefazolin and other cephalosporins are often selected, with vancomycin restricted for life-threatening infections of MRSA. Timing of administration is critical and 30–60 minutes before surgery is advised (29).

Eradication of carrier status

The feasibility of screening elective surgical patients for MRSA and methicillin-sensitive *S. aureus* followed by decontamination by topical mupirocin and chlorhexidine showers was tested in an American hospital and shown to result in significantly reduced rates of postoperative infections (31). Substantial savings have been predicted for hospitals implementing a preoperative screening and decolonisation strategy (32). Yet, it is possible that antibiotics may be poorly selected and administered at an inappropriate time.

Guidelines to prevent SSIs

Guidelines to minimise SSIs have been established in several countries and are regularly updated. American guidelines to prevent SSIs devised in 1999 led to a national Surgical Infection Prevention (SIP) project that began in 2002 and monitored adherence to three preventive measures. In 2006 it was extended to SCIP with the aim of reducing surgical complications by 25% by 2010 with five preventive measures (33). A recent evaluation of 60 853 operations at 112 hospitals suggested that, although adherence to the precautionary measures had improved from 2005 to 2009, risk-adjusted SSIs at patient and hospital levels remained stable (33). Advice to eliminate SSIs in orthopaedic surgery offered by the Association for Professionals in Infection Control and Epidemiology (34) stressed the need for teamwork, collaboration and effective communication between practitioners. Adoption of an SSI 'bundle' approach is logical (35).

Guidelines for the prevention of infection after combat-related injuries were formulated in 2008 and revised in 2011; they have been endorsed by the Infectious Diseases Society of America and the Surgical Infection Society (36).

Emphasis on care in the combat zone was highlighted, and recommendations included the administration of high-dose cefazolin (with metronidazole, if required), as well as the use of negative pressure wound therapy (NPWT; V.A.C.® Therapy, KCI, San Antonio, TX) and also oxygen during air transport (36).

Guidelines for the prevention and treatment of SSIs were commissioned by the National Institute for Health and Clinical Excellence (NICE) in the UK in 2008. Recommendations were organised into four sections: on information for patients and carers, the preoperative phase, the intraoperative phase and the postoperative phase (37). Compliance with NICE guidelines by all surgeons in a Swiss multicentre study has been found to be low (38) and illustrates how attitudes and opinions on the importance of prevention strategies differ.

Efficacy of some control measures

Clinical practice has been influenced by evidence-based medicine for nearly 20 years. Reviews of clinical evidence derived from randomised controlled trials provide the strongest impetus for change. Within the realms of SSI there are pertinent Cochrane reviews to evaluate the six tenets central to conventional surgical practice:

- Preoperative skin antiseptics for preventing SSIs after clean surgery (39)
- Antimicrobial drugs for treating MRSA colonisation (40)
- Preoperative hair removal to reduce SSI (41)
- Surgical hand antisepsis to reduce SSIs (42)
- Preoperative bathing or showering with skin antiseptics to prevent SSI (43)
- Dressings and topical agents for surgical wound healing by secondary intention (44).

None of these systematic reviews provide strong evidence to support the efficacy of any of these strategies. Rather than discarding these preventive measures, it indicates that suitable research to validate these approaches has not been published. Maybe if objective evidence were to be obtained, compliance would be improved.

Future ways to prevent and control SSIs?

It is clear that compliance with guidelines designed to limit SSIs could be improved by all members within surgical teams. Additionally, preoperative screening for antibiotic-resistant pathogens and decolonisation of patients could help to reduce the rates of SSIs. Surveillance of SSIs will provide valuable feedback on performance to individual surgeons as well as surgical units, and continual reminders or updates on infection control measures will be important. However, the ability of micro-organisms to rapidly evolve indicates that new ways to prevent and treat SSIs will always be required. As new antibiotics are not being developed at present, other strategies to reduce wound infections must be sought. The development of a vaccine for orthopaedic patients has been shown by a computer model to offer a cost-effective method of preventing MRSA infection (45). Phage therapy may yet be an effective antimicrobial intervention in wounds. Another strategy is the use of NPWT. This has already been suggested for combat-related injuries (37) and NPWT with instillation could be extended to wider use in orthopaedic surgery (46). NPWT has also been used with topical application of manuka honey to treat non-healing surgical wounds (47).

Conclusion

Much is understood about the causes, prevention, treatment and impact of SSIs on patients and health care resources. Although SSIs are preventable and rates of SSIs have reduced in contemporary surgical units, it appears that absolute elimination is an unachievable goal. With the limited development of new antibiotics and the perpetual emergence of antibiotic-resistant strains, alternative antimicrobial interventions are going to be increasingly important.

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