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Review article

Severe local wound infections after vascular exposure in the groin and other body areas: Prevention, treatment and prognosis

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ABSTRACT

Severe surgical site infections (SSIs) are a frequent nosocomial complication after vascular interventions, an important cause of postoperative morbidity, and a substantial burden to the health care system. Patients undergoing arterial interventions are at elevated risk of SSIs, possibly because of the presence of several risk factors in this patient population. In this review, we examined the available clinical evidence for the prevention, treatment, and prognostication of postoperative severe SSIs after vascular exposure in the groin and other body areas. Results from studies evaluating preoperative, intraoperative, and postoperative preventive strategies and several treatment options are reviewed. In addition, risk factors for surgical wound infections are analyzed in detail and related evidence from the literature is highlighted. Although several measures have been implemented over the time to prevent them, SSIs continue to pose a substantial health care and socioeconomic challenge. Therefore, strategies to decrease the risk and improve the treatment of SSIs for the high-risk vascular patient population should be the focus of continuing improvement and critical review. This review aimed at identifying and reviewing the current evidence for preventing, treating, and performing stratification according to the prognosis of postoperative severe SSIs after vascular exposure in the groin and other body areas.

1. Introduction

Surgical site infection (SSI), according to the Centers for Disease Control and Prevention (CDC), is defined as an infection occurring within or around surgical sites within 30 days after the index procedure or 90 days after a procedure with implantation of prosthetic material, such as a prosthetic graft or implanted endovascular device [1]. The GIVE Multicentre Cohort Study, a prospective cohort study examining groin SSIs among vascular patients, has indicated that patients who develop SSIs have a significantly prolonged median length of stay (6 v 5 days; P =.005). The study reported a greater readmission rate for patients with SSI than without SSI (21% readmitted v 6%, respectively) [2].

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SSIs after vascular surgery are a frequent nosocomial complication and an important cause of postoperative morbidity. Patients undergoing arterial interventions are at elevated risk of SSIs (overall incidence of 5% to 10%) [3].

Lower extremity bypass surgery for limb salvage is associated with the highest risk of SSI (incidence between 5% and 30%) [4,5]. Groin incision infections are the most frequent SSI (8.1% overall incidence, and 6.3% and 1.9% incidence of superficial and deep wound infection, respectively) [6].

SSI severity is often associated with longer hospitalization, a need for wound care, and the potential for catastrophic vascular reconstruction infection. SSIs are associated with increased morbidity, mortality, length of hospitalization, and health care costs [7].

SSIs are often localized to incision sites (superficial/deep incisional SSI) and have the potential to extend into deep tissues and to involve vascular reconstruction sites.

The CDC created a surgical wound classification system to preemptively identify patients at risk of (SSI) [1] (Table 1). Postoperative SSIs after vascular surgery can be classified as superficial, deep, and organ/space SSI by the diagnostic criteria described by the CDC [1] (Table 2). The severity of SSI can be defined by the Szilagyi grading system, according to the grading of vascular graft involvement and complications [8] (Table 3). Signs and symptoms of SSI include redness, delayed healing, fever, pain, tenderness, warmth, or swelling.

SSIs increase the likelihood of fascial disruption and wound dehiscence and, if left untreated, may progress to a necrotizing soft-tissue infection and/or sepsis. Development of SSI is an independent risk factor for the development of sepsis in the postoperative period across multiple surgical populations. This risk of sepsis increases with organ/space involvement and with delays in recognition and treatment of SSI [9]. In case of severe SSI the wound site produces pus and may also reopen (Fig. 1).

Therefore, rapid identification of causative bacteria is crucial to establish and select the most appropriate antibiotic therapy. Theoretically, any bacteria can cause SSIs and vascular graft infections. In vascular surgery, the most common causative organisms are *Staphylococcus aureus* and coagulase-negative staphylococci. The most common micro-organisms isolated in SSIs of the groin are Gram-negative *Pseudomonas aeruginosa*, Gram-positive *Staphylococcus epidermidis* and *S aureus* [4,10].

The prevalence of antibiotic-resistant bacteria, particularly those belonging to the *Staphylococcus* family, has increased in vascular SSIs after vascular surgery, as in all surgical specialties, over time [11].

Given SSIs' potential risks for patients and burden on the health care system, several measures have been implemented to minimize SSI occurrence, such as patient preparation, intraoperative measures, and postoperative wound care.

2. Methods

A literature search was performed in three databases (PubMed, EMBASE and Cochrane Library) to identify all publications on vascular SSIs in the English language between January 1, 2008 and December 31, 2022. To achieve maximum sensitivity of the search strategy, we searched for the following terms: "severe local wound infections after vascular exposure" or combinations including the following keywords: SSI, vascular SSI, surgical wound infection, SWI, groin infection and SSI in vascular surgery. Studies investigating various prevention and treatment strategies, and studies reporting the prognosis of severe local wound infections after vascular exposure in the groin and other body areas were deemed eligible. We excluded abstracts, case reports, conference presentations, editorials, and expert opinions. The references of selected publications were also screened to include other relevant literature. Only articles with full text in English were considered for this review. The primary data search was performed by one author (M.M.) and the results were cross checked by another author (A.L.). If there was any disagreement between investigators, this was discussed and resolved by all authors. Data were extracted from article texts, tables, and figures and included the title, year of publication, study design, sample size, study population, patient characteristics, outcomes, findings, and conclusions. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Guidelines for the inclusion of the study were followed. The search generated 530 articles; according to the previously described approach, after the reading of the title and abstract, 79 articles were eligible for a com-

Table 1 – The Centers for Disease Control and Prevention's surgical wound classification system.

Class	Clinical findings
I: Clean	Uninfected wounds, no inflammation is present, and are primarily closed. If the draining of these wounds is necessary, a closed draining method is necessary. These wounds do not enter respiratory, alimentary, genital, or urinary tracts.
II: Clean-contaminated	These wounds lack unusual contamination. These wounds enter the respiratory, alimentary, genital, or urinary tracts. However, these wounds have entered these tracts under controlled conditions.
III: Contaminated	These are fresh, open wounds that can result from insult to sterile techniques or leakage from the gastrointestinal tract into the wound. Incisions made that result in acute or lack of purulent inflammation are considered class 3 wounds.
IV: Dirty-infected	These wounds typically result from improperly cared for traumatic wounds. These wounds demonstrate devitalized tissue, and they commonly result from microorganisms present in perforated viscera or the operative field

Table 2 – Summary of Centers for Disease Control and Prevention's criteria for incisional surgical site infections[a] described.

Diagnostic criteria	Superficial SSI	Deep SSI	Organ/space SII
1	Infection occurs within 30 d after surgery	Infection occurs within 30 d after surgery or within 1 y if implant is in place	Infection occurs within 30 d after surgery or within 1 y if implant is in place
+2	Infection involving skin and subcutaneous tissue of the incision	Infection involving deep soft tissues of the incision such as the fascia and muscle layers	Infection involving any part of the anatomy (eg, organs or spaces), other than the incision, which was opened or manipulated during an operation
+3	Patient has at least one of the following: • purulent drainage from the skin incision • organisms isolated by a culture or non-culture based microbiologic test performed for the purpose of clinical diagnosis or treatment and • at least one sign or symptom: localized pain or tenderness, localized swelling, redness or heat, superficial incision opened by surgeon and is culture positive or not cultured • diagnosis of a superficial incisional SSI by a physician or physician designee	Patient has at least one of the following: • purulent drainage from the deep incision • deep incision spontaneously dehiscent or opened by surgeon and organisms isolated by a culture or non-culture based microbiologic test performed and • at least one sign/symptom: fever (>38°C), localized pain or tenderness • abscess found on direct examination, by radiological or histopathological examination - diagnosis of on organ/space SSI by a physician or physician designee	And at least one of the following: • purulent drainage from a drain that is placed through a stab wound into the organ/space. • organisms isolated from an aseptically obtained culture of fluid or tissue • abscess found on direct examination, by radiological or histopathological examination • diagnosis of on organ/space SSI by a physician or physician designee

Abbreviation: SSI, surgical site infection.
[a] For diagnosis of SSI, diagnostic criteria 1, 2, and 3 must all be true.

Table 3 – Szilagyi grading systems.

Grade	Clinical findings
Szilagyi I	Cellulitis involving the wound with skin necrosis, superficial wound dehiscence, and local infection
Szilagyi II	Infection involving subcutaneous tissue with deep wound dehiscence and fat necrosis
Szilagyi III	Infection involving the vascular graft

prehensive evaluation. After full-text reading, we ultimately selected 67 articles that satisfied the prespecified selection criteria; 19 articles were conversely excluded because either the topic did not address the study question (n = 12) or because of missing data (n = 7) (Fig. 2).

3. Results

The articles selected were divided into those reporting risk factors (n = 15), prevention measures (n = 38), treatment (n = 24), and prognosis (n = 3).

3.1. *Risk factors*

The reported surgical wound infection rates in clean procedures ranged between 2% and 5%; however, vascular wound infections have been reported to occur at a higher rate (between 5% and 10%), possibly because of the presence of several concomitant risk factors in this patient population [12]. Multiple risk factors contribute to SSIs (Table 4).

Fig. 1 – Example of severe groin wound infection after femoral endarterectomy and evolution.

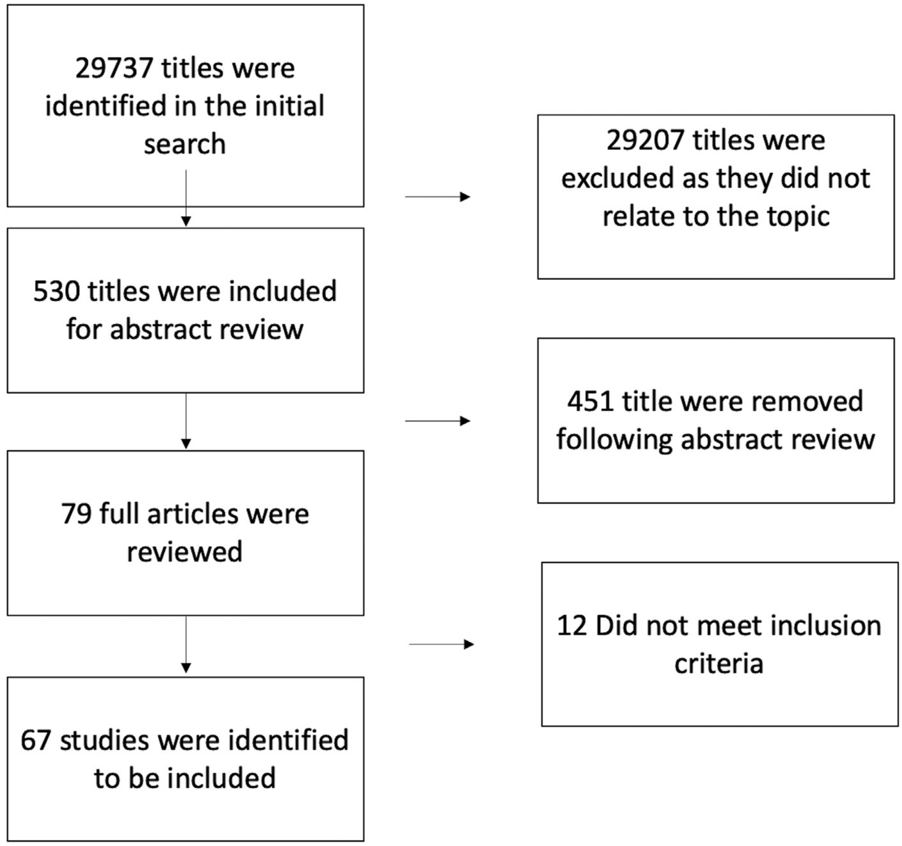

Fig. 2 – Diagram of papers selection.

Table 4 – Patient and operation characteristics that may influence the risk of surgical site infection.

Patient-related risk factors	Perioperative risk factors
Age	Breach in aseptic technique
Obesity	Open surgery
Diabetes mellitus	Presence of airborne bacteria in the operating room
Smoking	Groin incision
Colonization with microorganisms	Usage of prosthetic material
Altered immune response	Emergency/urgent procedure
Prolonged preoperative hospitalization	Procedure time > 3.5 h
Infection on a remote or adjacent site	Intraoperative hypothermia
Lower limb infection (ulcer, gangrene, cellulitis)	Blood transfusion
Malnutrition	Reintervention

3.2. *Age and comorbidities*

Age, obesity, prolonged length of hospital stay, diabetes mellitus, type and site of incision, and smoking were the most reported risk factors for SSI development.

The physiological changes brought on by aging and the elevated prevalence of chronic disease and weakened immune systems in the older population accounted for the higher frequency of SSI in patients older than 65 years. Recent research has found that the incidence of surgical wound infections increases by 2.3 times after the age of 70 years (odds ratio = 2.3; 95% CI, 1.1–4.5) [13].

A large proportion of patients undergoing vascular surgery are affected by diabetes: in a 2016 systematic review and meta-analysis, the overall effect size for the association between diabetes and SSI was odds ratio = 1.53 (95% predictive interval, 1.11–2.12; $I^2 = 57.2\%$). Abdominal fat and skin creases increase the complexity of placing precise incisions, sound closure of the wounds and wound dressing, hence increasing the potential risk of wound dehiscence, maceration and infection, particularly at the level of the groin [13].

On the basis of the current literature, smoking appears to increase the likelihood of developing SSIs and several other postoperative complications [14]. To decrease the risk of pulmonary complications and wound complications, such as SSI, recommendations suggest that smoking should be stopped at least 4 to 6 weeks before elective surgery [15].

3.3. *Nutritional status*

The immune system can be substantially influenced by nutritional status. Several studies have shown an association between malnutrition and a compromised host immunological response. Patients may become more susceptible to postoperative infections as a result of these immune system changes, and malnutrition has been identified as a risk factor for poor surgical results [16]. An epidemiologic association between incisional SSIs and malnutrition has been difficult to demonstrate consistently for all surgical subspecialties, and consensus is lacking regarding the optimal timing and dosage of nutrient-enhanced formulas for SSI prevention [17]. Currently, no formal recommendations have been made for nutritional supplementation for SSI prevention.

3.4. *Types of surgical incisions in the groin*

Incision type and location play central roles in the rates of wound infections. In groin incisions, surgeons have two main options: vertical and transverse incision. A recent review by Canteras et al [18] compared the incidence of SSI in transverse versus vertical groin incision. According to the authors, the potential advantages of the transverse incision include the following:

- surgical incision along the Langer lines;
- skin and subcutaneous tissue divided according to a more favorable pathway, thus decreasing vascular damage and increasing oxygen tension for the skin; and
- exposure of femoral vessels without passage through the groin crease—an area likely to be colonized by microorganisms, thereby decreasing the risk of surgical wound infections.

The main disadvantage of a transverse incision is the risk of poor or insufficient proximal and distal exposure of femoral vessels. The review concluded, despite low evidence, that wound infections occur less frequently in transverse groin incisions than vertical groin incisions [18]. However, the two incisions are not always equivalent, and different surgical indications might dictate the surgical approach, particularly when distal control of the profunda femoral artery is needed.

3.5. *Type of surgery*

Procedure-specific risk factors for vascular SSIs include open versus endovascular intervention, the presence of a groin incision, the use of prosthetic material for vascular reconstruction, the emergency setting, procedures lasting more than 3.5 hours, intraoperative hypothermia, and a requirement for blood transfusion [3].

The procedure type also predicts the risk of wound infection. Among procedures, the lowest SSI incidence is found after abdominal aortic aneurysm repair, and a similar incidence is observed after open (0.2%) and endovascular (0.16%) repair (when an open femoral cut-down is used) [19]. After carotid artery surgery, an incidence of 0.2% to 0.5% has been observed, whereas rates ranging between 5% and 30% after infrainguinal reconstructions have been reported [4]. The GIVE {Groin Wound Infection after Vascular Exposure) multicenter cohort study has reported an SSI incidence of 8.6% for groin wounds [2]. SSI incidence after vascular according to the anatomic location is reported on Table 5.

Table 5 – Surgical site infection incidence after vascular exposure in the groin and other body areas.

Type of surgical intervention	SSI incidence, %
Abdominal aortic aneurysm repair	0.2
Carotid endarterectomy	0.2–0.5
Infrainguinal arterial reconstructions	5–30
Groin	8.6

SSI is a leading cause of failure of prosthetic and autogenous arteriovenous (AV) accesses, and it frequently requires hospitalization. Infection associated with AV access in hemodialysis patients is multifactorial. It has long been recognized that immune function is compromised in uremic and dialysis-dependent patients. As a result of transcutaneous access to the circulation, *Staphylococcus* spp are the most frequent causative organisms, with an increasing frequency of antibiotic resistance in these species. Diagnosis of peripheral AV access site infection is usually clinically obvious and manifested by localized findings, such as tenderness, erythema, cellulitis, and drainage, which are usually related to puncture site hematoma, pseudoaneurysm, or incisional complications. The reported incidence of infections affecting the AV access site ranges from 0.56% to 5% per year for autogenous AV access and 4% to 20% per year for prosthetic AV grafts [20].

3.6. *Patient microbiome*

Patients may develop endogenous infections when commensal microorganisms shift from states of colonization to infection, because of factors that perturb the microbiome. Infections from exogenous and endogenous bacteria may be triggered by similar microorganisms; therefore, determining which of the two sources is the infection's main cause can be challenging. However, research using molecular methods to track specific *S aureus* strains has demonstrated that up to 80% of SSIs are caused by the preoperative patient microbiome [21,22]. Such correspondence between bacteria isolated from patient's samples and those isolated from the infected wound is more difficult to demonstrate for other bacteria [23,24]. Wound infection in the era of modern surgical practice has been described as a "failure to control the host-microbiome during surgery" [23].

4. *Prevention*

SSIs may often be prevented with appropriate care before, during, and after surgery. The World Health Organization (WHO) [12] and National Institute for Health and Care Excellence

(NICE) [25] have provided evidence-based recommendations for measures for the prevention of SSI.

For the purpose of clarity, we have divided possible preventive measure applicable to the preoperative, intraoperative, and postoperative period defined as follows:

- Preoperative: phase preceding the entry of the patient into the surgical theatre
- Intraoperative: phase from the time when the patient is admitted to the surgical theatre to the time when the patient is transported to the recovery room or post-anesthesia care unit
- Postoperative: phase from the time the patient is wheeled out of the surgical theatre

4.1. *Preoperative*

4.1.1. *Preoperative bathing*

Regarding preoperative measures, in best clinical practice, patients bathe or shower before surgery to decrease the bacterial skin load. Either a plain or an antimicrobial soap may be used for this purpose, and no specific recommendations have been made regarding whether preoperative bathing with an antimicrobial soap is more effective than bathing with plain soap to prevent SSI [12].

4.1.2. *Hair removal*

Hair should not be removed at the operative site unless the presence of hair will interfere with the operation. No evidence indicates that hair removal routinely decreases the risk of SSI. However, removal is often necessary to facilitate adequate exposure, suturing, and application of adhesive drapes and wound dressings. As needed, hair must be removed with electric clippers with a single-use head on the day of surgery because clipping appears to result in fewer SSIs than shaving [25].

4.1.3. *Nasal decolonization of S aureus*

S aureus is the most frequent cause of SSIs, and the nose is the most typical site of *S aureus* colonization. Preoperative nasal decolonization of *S aureus* may lessen the bacterial burden and prevent the organisms from spreading to the surgical site, thus lowering the risk of SSI. Nasal mupirocin is the most widely used topical antibacterial agent for nasal decolonization [26]. No standard decolonization protocol is supported by the literature, but evidence indicates that patients undergoing cardiothoracic, vascular, orthopedic, gastrointestinal, or general surgery with known nasal carriage of *S aureus* can benefit from a preoperative intranasal application of mupirocin 2% ointment combined with chlorhexidine body wash to decrease SSIs [27]. Outstanding issues in this topic included whether nasal decolonization should be universal (for all patients entering the hospital) or targeted (for high-risk procedure/high-risk patients) and whether it might be cost-effective.

4.1.4. *Saphenous vein mapping in lower extremity bypass*

An area of particular concern in SSI prevention and treatment is peripheral vascular surgery, given the high incidence of wound infections in lower extremity procedures. Linni et al [28], in a prospective randomized trial, have demonstrated that preoperative duplex vein mapping of the great saphenous vein in infrainguinal bypass surgery avoids unnecessary surgical exploration and an intraoperative change in surgical strategy, thus leading to significantly lower postoperative major SSIs and consecutive readmission than that in the control group of patients who did not receive preoperative duplex vein mapping of the ipsilateral great saphenous vein.

4.2. *Intraoperative*

4.2.1. *Hand hygiene*

The WHO and NICE [12,25] guidelines recommend that surgical hand antisepsis be performed by all team members to remove microorganisms and ensure minimal contamination of the operative field. Guidelines strongly advise surgical hand preparation before donning of sterile gloves, either by washing with an appropriate antimicrobial soap and water or by using an alcohol-based hand scrub approved for surgical scrubbing. In a Cochrane systematic review published in 2008 and updated in 2016 [29], 14 randomized controlled trials were included, reporting either the rate of SSIs or the number of colony-forming units on participants' hands as the primary outcome. The main finding was that no clear evidence indicates that one type of antisepsis (alcohol-based hand scrub or aqueous scrub) is better that another in decreasing SSI. However, moderate or very low-quality evidence suggests that alcohol-based hand scrubs with additional antiseptic ingredients may be more effective than aqueous scrubs in decreasing colony-forming units.

4.2.2. *Surgical antibiotic prophylaxis*

Surgical antibiotic prophylaxis is the administration of an effective antimicrobial agent before exposure to contamination during surgery to prevent the growth of microorganisms in the surgical wound, which may contaminate the interstitial space, fibrin scaffolds, hematomas, or prosthetic material when it is implanted. All patients benefit from 24 hours of perioperative antibiotic therapy and antibiotic prophylaxis is a surgical standard in modern medicine. This is an effective method of decreasing the risk of local postoperative infection [4].

For effective antibiotic prophylaxis, a first- or second-generation cephalosporin, alone or in conjunction with a glycopeptide or lipopeptide, should be administered 30 to 60 minutes before the incision [3]. Multiple randomized trials have demonstrated the benefits of antibiotic prophylaxis during arterial reconstruction. In particular, the European Society for Vascular Surgery 2019 guidelines recommend perioperative IV antibiotic prophylaxis before both open and endovascular abdominal aortic aneurysm repair, with the choice of agent based on local institutional guidelines [30]. The administration of intraoperative antibiotic prophylaxis (covering both Gram-positive and Gram-negative bacteria) and the potential addition of a second similar dose during the surgery, if the interventions last longer than 4 hours and/or the blood loss exceeds 1,500 mL, significantly decreases the incidence of inguinal SSI during vascular surgery [4].

The NICE Guidelines recommend that a repeat dose of antibiotic be administered when the operation is longer than the half-life of the antibiotic given. Prophylaxis will generally be effective in decreasing the risk of SSI if the antibiotic is adequately effective against potentially contaminating microorganisms and elevated medication levels are maintained during the surgical procedure [25].

4.2.3. *Skin preparation*

Another intraoperative measure is surgical site preparation of the intact skin of the patient in the operating room. The WHO [12], NICE [25], and CDC [1] recommend the use of alcoholic chlorhexidine gluconate for skin preparation in patients undergoing surgical procedures. A recent systematic review and network meta-analysis comparing the effects of different preparations of chlorhexidine gluconate and povidone-iodine antiseptics on SSI has indicated that alcoholic formulations of 4% to 5% chlorhexidine gluconate appear to be safe and twice as effective as povidone-iodine antiseptics (alcoholic or aqueous solutions) in preventing infection after clean surgery in adults [31].

4.2.4. *Adhesive drapes*

The role of adhesive drapes in SSI prevention, whether plastic (Steri-Drape) or iodine-impregnated, remains controversial. These drapes are intended to provide a mechanical barrier preventing skin flora from migrating into the operative site. No strong evidence indicates that adhesive drapes decrease SSI rates, whereas some studies have reported that they accelerate recolonization by maceration. Impregnated drapes appear to be superior, although international guidelines remain inconclusive [32].

4.2.5. *SSI closure technique*

Intradermal absorbable sutures are associated with lower rates of groin incision infections than transdermal sutures, and have been found to decrease groin SSI in patients undergoing arterial vascular interventions involving a groin incision [33,34].

Wound irrigation and intracavity lavage are theoretically believed to wash away organisms that originated from the incised skin edges during surgery or that have contaminated the wound from the environment. However, the host defense, represented by white blood cells that migrate into the cavity or space in the early inflammatory phase, may be unnecessarily “diluted” by lavage. No current evidence in the literature indicates that wound and intracavity lavage is useful for SSI prevention [25,35].

A recent review and meta-analysis of the literature comparing the use of a wound drain (closed system on suction) versus standard care in groin incision has shown no significant difference in preventing SSIs. The same work has evaluated the use of platelet-rich plasma, the application of fibrin glue to the wound before closure, and administration of local antibiotics within the surgical site just before wound closure, but has found no significant effects on SSI prevention [34].

4.3. *Postoperative*

4.3.1. *Closed incision negative pressure therapy*

Negative pressure wound therapy (NPWT) on closed sutured surgical incisions has emerged as an innovative dressing that can potentially decrease SSI. In closed incision negative pressure therapy (ciNPT), a polyurethane foam or gauze is placed over the length of the incision, secured with a protective occlusive tape and attached to a commercially available NPWT device set at between −75 mm Hg and −125 mm Hg, in a continuous suction [36]. CiNPT, compared with standard wound dressings, such as conventional adhesive plaster, has been found to significantly decrease all complications of groin incision after vascular surgery [37].

In a recent systematic review of the literature, including six randomized controlled trials reporting on a total of 733 groin wounds, prophylactic negative pressure wound therapy, as compared with standard surgical wound care, has been found to improve outcomes in patients undergoing arterial surgery via a groin incision: patients with negative pressure wound therapy have a lower risk of developing SSI ($P < .001$), a lower risk of revision surgery ($P = .02$), and a shorter hospital stay ($P = .01$) [38].

Gombert et al [39] reported the results of a randomized prospective trial (AIMS trial) evaluating 188 patients who underwent femoral cutdown for vascular procedures, 45% of which were reoperations, in two study centers. Significantly fewer SSIs were observed in the intervention group with ciNPT (n = 98) than the control group (n = 90) receiving standard wound dressing (13.2% *v* 33.3%; $P = .002$).

Several meta-analyses [40,41] have demonstrated a significant decrease in SSIs with NPWT after a variety of surgical procedures. Svensson-Björk et al [37], in a meta-analysis of ciNPT after arterial surgery, found a lower rate of SSI with ciNPT than with standard wound dressings. However, Ge et al [42], in an updated meta-analysis of 17 randomized controlled trials, found that ciNPT, compared with standard wound dressing, results in significantly lower rates of other wound complications, such as dehiscence, seroma, hematoma, skin necrosis and bleeding, but not SSIs. These results are consistent with those from a recent single-center prospective cohort study on patients receiving elective vascular surgery with groin incisions, which did not indicate a decrease in the incidence of deep SSIs, which implicate the highest morbidity and costs [43]. CiNPT appears to be a promising technology in arterial surgery; however, further confirmation and cost-effectiveness analysis are needed.

A simplified, ultraportable NPWT device is the PICO system (PICO; Smith & Nephew). Several studies have explored the benefits of NPWT on closed surgical wounds in infrainguinal surgery, all of which have shown that NPWT used over closed surgical wounds is associated with a decrease in overall wound complication rates after peripheral vascular surgery. However, the studies did not agree on whether PICO dressing decreases wound infection rates [44,45].

A randomized controlled trial registered at ClinicalTrials.gov (identifier: NCT01913132) comparing the effects of PICO dressing and standard wound dressing on postoperative SSI remains ongoing. This multicenter study includes two distinct vascular procedures with high SSI risk profiles: femoral thrombendarteriectomy and lower limb bypass. The outcomes of this trial may have implications in postoperative wound care in patients receiving vascular surgery [46].

4.4. *Multidisciplinary SSI team*

Leading international organizations, including WHO, recognize that multidisciplinary management is necessary to achieve a concerted approach to providing care that is appropriate to meet patients' needs [47]. Successful surgical wound treatment requires a multidisciplinary team strategy, in both acute-care and community settings. The multidisciplinary team approach includes sharing of professional responsibilities and areas of competence, planning and making decisions, while providing high-quality patient care in complex scenarios. Several studies [45–51] have suggested that the implementation of a multidisciplinary strategy in SSI prevention and treatment may contribute to decreasing SSI occurrence in patients undergoing surgery. However, the role of a multidisciplinary approach for SSI after vascular exposure warrants additional evaluation.

5. Treatment

5.1. *Wound debridement*

When a superficial or deep SSI is suspected or confirmed, the treatment involves opening of the wound, drainage of infected fluid—which should be cultured—and debridement of necrotic and devitalized tissue. The presence of necrotic material or slough within the wound margin serves as a medium for bacterial proliferation and delays healing, and therefore should be removed. Not all forms of debridement have the same effects on wounds or ulcers, because their modes of action differ. The type of debridement should be tailored to the wound presentation, the patient's comorbidities and the patient's home state. In most cases, debridement may be performed in an outpatient setting, but in more complex cases, extensive debridement should be performed in a theatre with appropriate access to analgesia/anesthesia, an ability to perform hemostasis and appropriate instruments. Mechanical debridement is performed with forceps, and scalpels or scissors. Ideally, all foreign bodies are also excised because they can delay healing and promote infections. Serial debridement is continued until no necrotic tissue remains and granulation tissue is present [52,53].

5.2. *Antibiotic therapy*

Not all SSIs require antibiotic treatment: superficial wound infections (CDC class I–II, Szilagyi grade I) may respond to drainage of pus (eg, by removal of sutures) and topical antisepsis.

The severity of the infection, the existence of systemic symptoms, and the patient's comorbidities all play roles in determining whether antimicrobial therapy is necessary. Antibiotic therapy should be started under the following clinical circumstances: cellulitis in the surrounding skin after wound opening; persistent inflammation of subcutaneous or deeper tissue after debridement or drainage; presence of implanted material, such as vascular grafts within the infected area; and presence of systemic signs of infection, such as fever, leukocytosis or septic shock [15].

Antibiotic therapy poses a risk of adverse drug reactions, and the development of resistant bacteria and an associated risk of *Clostridioides difficile* infection. When antibiotic treatment is deemed necessary, patients should be treated with an "empirical" therapy covering the most likely infecting pathogens and *S aureus*, the most common cause of SSIs after all operation types. In this setting, considering local resistance patterns is critical [12].

Isolated *S aureus* strains are occasionally sensitive to penicillin. *Staphylococci* are frequently distinguished as methicillin-resistant *S aureus* and methicillin-sensitive *S aureus*. In addition, methicillin-resistant *S aureus* may be of hospital origin, characterized by extended resistance to antibiotics (multidrug resistance bacteria) [11]. The prevalence of *Staphylococcal* strains causing vascular SSI is best understood as a biofilm-mediated infection. Biofilms are complex three-dimensional communities of microorganisms, which are usually found attached to inert or living surfaces and encased within a self-produced protective matrix of extracellular polymeric substances. Biofilm-associated SSIs are extremely difficult to treat with conventional antibiotics, owing to the multiple tolerance mechanisms of the multidrug-resistant bacteria, which are usually arranged in polymicrobial communities [54].

Antibiotic therapy should be reviewed in light of clinical progress and after culture results have been reported. To identify the responsible pathogen, several methods of sampling have been proposed, but questions persist regarding optimum techniques. Two techniques for swabs are widely accepted: the Levine and Z-technique methods. The main drawback is that swabs are believed to capture microorganisms from the surface rather than microorganisms that have invaded the wound, and a high degree of colonization of the wound by the skin microbiota can occur. Whereas wound swabs can be used to identify pathogenic organisms, tissue biopsies enable more accurate quantification of the bacterial load and the presence of deep tissue organisms, and can help distinguish colonization from true infection [52]. For vascular wound infections that are resistant to healing, several biopsies can be useful, because of the marked difference in the distribution of bacteria in the wound bed. For deeper SSIs (CDC class III, Szilagyi grade II), surgically acquired or aspirated material is required to provide the best microbiological diagnosis. Finally, in cases of infection involving the vascular graft (CDC class IV, Szilagyi grade III), removal of the implant and sending it to a microbiological laboratory with adjacent tissue samples can provide relevant diagnostic information [52]. Available studies have addressed a wide range of culture techniques, wound types and severity of infections; thus, a substantial gap in knowledge persists regarding the optimal sampling technique. Technical inconsistencies in current research and a lack of clinical end points do not unequivocally support the use of one technique over another. Several technologies and techniques allowing for rapid identification (ideally at bedside, in the future) of the involved bacteria are rapidly developing and may enable specific treatments to be administered in very early stages of infection, thereby decreasing potential therapeutic delays and inappropriate antibiotic administration [55].

5.3. *Complicated wound dressings*

Wounds that have been opened because of SSIs are usually healed by secondary intention with frequent wound packing and removal, which decreases the microbial wound burden by removing wound slough and accumulated drainage. Healing by secondary intention involves prolonged healing times. Numerous dressing options are available for wound healing by secondary intention, such as alginates, foams, hydrocolloids, hydrogels and polyurethane films. Evidence is insufficient to recommend one option over another. Dressings that maintain moisture, absorb exudate, are impermeable to water and bacteria, and do not cause trauma to granulation tissue, facilitate healing. Retention of moisture is important because wound fluids contain tissue growth factors that facilitate re-epithelialization and promote autolytic debridement. Dressing changes may initially be required up to three times daily and are continued until the wound surface is mostly covered by granulation tissue. Dressings can then be changed once a day or every other day to avoid disturbing the healing process and to be less traumatic to the developing granulation tissue and new epithelial cells [15].

5.4. *Negative pressure wound therapy*

According to the NPWT instructions for use, wound infection is considered a contraindication associated with the possibility of promoting bacterial growth, because the dressing is left on the bed of an infected wound for several days. Nonetheless, these instructions have not limited many physicians' use of this device for infected wounds. Although the mechanism of action is not fully understood, NPWT appears to promote SSI healing and decrease the length of hospital stay. However, NPWT is associated with high medical costs [56]. According to a recent study, NPWT modulates cytokines toward an anti-inflammatory profile, and promotes a decrease in exudate and an increase in the amount of granulation tissue, thus probably increasing in the concentration of local antibiotics [57]. NPWT has become an established therapy for wound management. Nevertheless, whether NPWT decreases the bacterial bioburden remains controversial.

Many advancements have been made in NPWT technology, including NPWT with instillation and dwell. NPWT with instillation and dwell promotes wound healing by wound cleansing, irrigation, and nonexcisional debridement. NPWT with instillation and dwell appears to facilitate solubilization, detachment, and elimination of infectious materials, such as slough and thick exudate, before or after operative debridement, and in cases in which surgical debridement is not an option [58].

A major feature of NPWT is that the treatment can be continued at home, thereby further decreasing the hospitalization stay, and ensuring greater patient comfort, and partial or complete return to daily activities, and consequently increasing quality of life.

5.5. *Vascular graft involvement by the SSI*

Vascular graft infections are a devastating complication of vascular reconstructive surgery [59]. Moreover, vascular graft infection is a rare but fatal complication in the long-term after abdominal aortic aneurysm open and endovascular repair [60]. An extensive discussion on this topic is beyond the scope of the present review. We mention this topic to discuss the management of Szilagyi grade III SSIs.

Although the long-established practice of graft excision with extra-anatomic revascularization is essential in grade III Szilagyi SSI treatment, in situ reconstruction techniques in appropriately selected patients have been associated with improved outcomes, notably regarding the presence of low-virulence organisms and the availability of an autogenous conduit [61]. Arterial and vein grafts have the benefit of lower re-infection rates than those of prosthetic grafts. Bovine pericardium grafts are a valid alternative increasingly being used in infected vascular beds, particularly in situations in which a homograft or vein material is not available [62]. High-virulence bacterial or fungal infections, with substantial periarterial or graft phlegmon, and a lack of availability of an autogenous conduit, have been associated with diminished mortality and amputation rates with graft excision and extra-anatomic revascularization [53].

The EndoVAC technique is an alternative treatment option in high-risk surgical patients with infected groin wounds with femoral artery reconstruction and disrupted vascular anastomosis, when neither traditional radical surgery nor conservative simple negative pressure wound therapy is considered feasible. The EndoVAC technique is an hybrid procedure that consists of three consecutive steps. The first step is relining of the infected reconstruction with a stent graft; the second step is surgical revision of the infected area, which included extensive soft tissue debridement followed by removal of the infected vascular prosthesis without clamping the reconstruction; and the final step is VAC therapy to permit granulation and secondary delayed healing or suture, followed by long-term antibiotics [63,64].

AV access site infection is a particular kind of vascular graft infection. The recommended therapy for these complications depends on the status of the AV access (patent or occluded), on the type of AV access conduit (autogenous vs prosthetic) and on the extent of its involvement by the infection. Intact autogenous AV access infections have occasionally resolved with 4 to 6 weeks of parenteral broad-spectrum antibiotics. When the infection truly involves the prosthetic conduit, systemic antibiotics alone are usually inadequate and total or subtotal excision is needed and a new AV fistula is constructed in a clean field [20].

5.6. *Muscle flap coverage*

An interesting topic is muscle flap coverage; a growing body of research and experience suggests that muscle flap coverage, in addition to graft removal with or without vascular reconstruction, may be efficacious in managing complex groin wounds, and improving graft and limb salvage and survival [53].

A recent review and meta-analysis by Shimbo et al [65] has indicated the differences in outcomes between the sartorius muscle flap, rectus femoris muscle flap, and gracilis muscle flap: the rates of overall complications were 20.3% (95% CI, 12.1% to 28.2%; $I^2 = 0\%$), 23.2% (95% CI, 11.2% to 34.5%;

$I^2 = 10.2\%$), and 18.0% (95% CI, –3.5% to 37.8%; $I^2 = 0\%$) for the sartorius muscle flap, rectus femoris muscle flap, and gracilis muscle flap, respectively. The rate of 30-day mortality was lowest for the sartorius muscle flap (5.3%; 95% CI, –6.1% to 16.6%; $I^2 = 0\%$). The effectiveness and safety of muscle flap reconstruction for infected groin wounds after vascular surgery appears promising. However, more data are required to clearly indicate which type of muscle flap is ideal for each wound type.

6. *Prognosis*

With increased knowledge and understanding of the various factors involved in their prevention and treatment, SSIs have good chances of healing in almost all instances. Nevertheless, overall health care costs and patients' personal costs (in terms of not only quality of life but also economic costs for the patient, depending on the level of support available in different health care systems) are almost inevitably high. SSIs lead to prolonged hospital stays; a need for nursing care, materials, and dressings; and possible hospital readmission. SSIs often require prolonged bed rest, medical therapies, and physical rehabilitation, thereby delaying full physical recovery and increasing the overall morbidity associated with the initial treatment. Therefore, decreasing wound infection rates would be desirable on both clinical and health-economic grounds. Simple and easily viable precautions (such as the universal use of surgical masks both for patients and health care professionals during wound care, the widespread diffusion of hand sanitizers, and the reduction of the number of visitors in the surgical wards) could be promising and safe tools for SSI risk reduction [66]. Wound care with a regular follow-up needs to be considered as an essential service, requiring a regular provider–patient interaction [67].

In the context of lower limb revascularization, SSIs increase the risk of non-traumatic lower-limb amputations. Without timely and adequate treatment, local wound infection of the lower extremities can progress to sepsis and osteomyelitis, thus resulting in major amputation in the most severe scenarios. The survival and outcomes of patients with SSIs are strongly associated with vascular graft involvement by the infection. When the graft is infected, necessitating radical excision with extra-anatomical bypass, the risk of mortality is 25%–75% and the risk of limb loss is 35%–79% [13]. Although abdominal wound and graft infections are rare, aortic graft infection is one of the most serious complications in vascular surgery, requiring complex reinterventions with high morbidity and mortality rates.

7. Conclusions

SSIs are one of the most common and feared complications of vascular surgery. They are costly for health care systems and patients because of their association with elevated morbidity and mortality. Significantly lower mortality and morbidity rates have been observed as a result of the widespread use of standardized surgical antisepsis and asepsis protocols, and the early identification and treatment of surgical wound infections. Despite the introduction of effective preventive strategies, SSIs continue to represent a major health care and socioeconomic problem because they frequently require long-term antibiotics; delay recovery time from surgery; and can lead to hospital readmission, a need for secondary surgery and long-term disability. Better knowledge of risk factors may contribute to the implementation of current public health strategies to further decrease the occurrence of SSIs after vascular surgery. Timely and aggressive treatment is necessary to decrease infection-associated morbidity and mortality. Multidisciplinary management is key to improving the outcomes of SSIs treatment. The team should include wound care specialists, vascular surgeons, plastic surgeons, nurses, and microbiologists, to give patients the best chance of complete recovery. Improved adherence to evidence-based preventive measures and appropriate antimicrobial prophylaxis are recommended to decrease the rate of SSIs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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