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Review Article

Deep Sternal Wound Infection: Diagnosis, Treatment and Prevention

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Deep sternal wound infection (DSWI) is a rare but potentially devastating complication of median sternotomy performed in cardiac surgery. The incidence of DSWI is reported to be between 0.2% and 3%. Identifying high-risk patients and strategies to optimize risk factors plays an important role in reducing the incidence of DSWI. Management of DSWI can be complex and may require a multidisciplinary team approach involving infectious disease specialists, microbiologists, as well as cardiothoracic and plastic surgeons. Early detection, appropriate antibiotic treatment, aggressive surgical debridement, and use of regional muscle flaps have significantly improved treatment outcomes.

Key Words: sternal instability; wound dehiscence; cardiac surgery; prevention; treatment; management of mediastinitis

Deep sternal wound infection (DSWI) is a rare but potentially devastating complication of median sternotomy performed in cardiac surgery. The incidence of DSWI is reported to be between 0.2% and 3%, depending on factors such as patient population, study methodology and year of publication.[1-8] Despite its low incidence, DSWI has a profound effect on healthcare outcomes with significantly increased 30-day and 1-year mortality rates,[3,5,6,9] reduced long-term survival,[6] prolonged hospital length of stay,[5,9] and excess treatment costs[5,9]. Surgical site infections (SSI) may result from direct wound contamination, contiguous extension from adjacent structures, descending head and neck necrotizing infections, or via blood-borne routes.[10] Infection of the sternotomy wound can involve the subcutaneous tissue, bone, cartilage or mediastinum, with the latter leading to the feared complication of mediastinitis,[11] which has an in-hospital mortality rate ranging from 1.1% to 19%.[12] Unresolved mediastinal infection involving cardiac suture lines may lead to septic shock or catastrophic bleeding.[13] Hence early diagnosis, appropriate infection control, and effective treatment are crucial to the management of DSWI.[9,14] This review will focus mainly on mediastinitis given its clinical importance and complexity of management.

Methods

A literature search was performed using PubMed, Cochrane, and Google Scholar databases up to December 2018 using the medical subject headings "deep sternal wound infection," "mediastinitis," "sternal instability," "wound dehiscence," "cardiothoracic surgery," "prevention and treatment of deep sternal wound infections," and "management of mediastinitis." References cited in these articles were further reviewed.

Diagnosis

DSWI is diagnosed based on a combination of clinical, laboratory and radiological findings.[15] In particular, the diagnosis

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of mediastinitis must meet at least one of the following criteria outlined by the Centers for Disease Control and Prevention[16]:

1. Positive microbial culture taken from mediastinal tissue or fluid.
2. Evidence of mediastinitis during surgery or on histopathological examination.
3. At least one of the following clinical features
   (a) Fever >38˚C,
   (b) Chest pain, or
   (c) Sternal instability

And at least one of the following: purulent mediastinal discharge, positive microbial culture from blood or mediastinal discharge, or radiological evidence of mediastinal widening.

Patients with acute DSWI usually present within 30 days of cardiac surgery.[10] Besides fever, other common signs include wound dehiscence, purulent wound discharge, and sternal instability.[17] Delayed wound healing and sternocutaneous fistula may develop in chronic cases.

Radiologic investigations can help to establish diagnosis in cases where clinical examination may be equivocal. The presence of pneumomediastinum, mediastinal widening, and air-fluid levels may be detected on a chest radiograph.[18] A computed tomography scan of the thorax is the investigation of choice in the diagnosis of mediastinitis and is useful not only for diagnosis, but also for assessing the extent of disease and guiding surgical management. Typical computed tomography findings include sternal displacement, air pockets, fluid collections, and abscess formation.[18] The use of positron emission tomography/computed tomography in determining the depth and location of infected areas has proven to be useful in guiding surgical debridement.[19]

Classification

Sternal wound infections can be classified anatomically into superficial and deep infections depending on the level of fascial involvement (Table 1). Superficial sternal wound infection (SSWI) involves tissue above the fascial plane whereas infection beneath it is classified as DSWI. This can be further subdivided into the following: without involvement of bone or retrosternal tissue (2A), involvement of retrosternal tissue (2B), bone, and retrosternal tissue involvement (2C) and osteomyelitis (2D).[20] Mediastinitis comprises of types 2B, C, and D.

The El Oakley and Wright classification of poststernotomy mediastinitis is commonly used in research for comparison among various treatment protocols and is based on the onset of presentation after surgery, number of risk factors identified in 3 or more major studies, as well as the number of failed surgical interventions.[21]

Microbiology

The most common microorganisms responsible for DSWI are coagulase-negative staphylococci (CoNS) and *Staphylococcus aureus* (*S. aureus*).[15] Depending on the etiology and causative organisms, postoperative mediastinitis can be divided into 3 types[22]:

1. Mediastinitis associated with chronic obstructive pulmonary disease (COPD), obesity, and wound dehiscence, usually caused by a CoNS infection.
2. Mediastinitis arising from perioperative mediastinal contamination, commonly caused by *S. aureus* infection.
3. Mediastinitis caused by spread from concomitant infections (for example, pneumonia or bacteremia), commonly associated with gram-negative rods.

Studies have shown that DSWI caused by gram-negative rods were often polymicrobial.[17,23] Initiating patients on inappropriate antibiotic regimens had led to higher rates of secondary infection, prolonged mechanical ventilation, and vasopressor use, as well as increased 30-day mortality.[23]

Risk Factors

The pathogenesis for DSWI remains complex and multifactorial. Risk factors can be broadly divided into preoperative, intraoperative, and postoperative factors. Many studies have been conducted to identify the risk factors but to date, no consensus has been reached regarding their individual contribution.[24] Part of the problem arises from the different definitions of sternal wound infections used in various studies and varying characteristics of the study population. Knowing the common risk factors, however, allow high-risk patients to be identified, preventive measures to be implemented, and timely treatment to be instituted.

A number of scoring systems and risk calculators have been developed to predict the risk of postcardiac surgery SSI,[25-33] however, there has been a lack of specific prediction models for DSWI.[34] The Gatti score is the first scoring system specifically created to predict the risk of DSWI after bilateral internal thoracic artery (BITA) grafting and has been shown to

Table 1
Anatomical Classification of Sternal Wound Infections[20]

Sternal Wound Infection	Type	Tissue Involvement	Classification
Superficial sternal wound infection (Above fascial layer)	1	Skin and subcutaneous tissue	Superficial wound infection
Deep sternal wound infection (Below fascial layer)	2a	Retrosternal tissue and bone not involved	Deep incisional infection
	2b	Retrosternal tissue	Mediastinitis
	2c	Retrosternal tissue and bone	
	2d	Frank osteitis	

outperform existing scoring systems for sternal wound infection after coronary artery bypass grafting (CABG) surgery.[35] This score has been validated and found to be effective in a French cohort study, though more multicenter validation studies are required before it can be incorporated into clinical practice.[36] The latest risk stratification model for predicting DSWI after CABG surgery by a Brazilian group is still awaiting external validation.[34]

Preoperative

Sex

The role that sex plays in predisposing a patient to DSWI remains inconclusive. Ashley et al.[37] found that the female sex was an independent risk factor for mediastinitis caused by Methicillin-resistant *S. aureus* (MRSA) but not Methicillin-sensitive *S. aureus* (MSSA). The authors explained the disparity by suggesting that the 2 conditions were separate disease entities with distinct risk factors. Two other studies by Crabtree et al.[38] and De Paulis et al.[39] showed that only female sex played a significant role in SSWI but not in DSWI. A 2016 meta-analysis by Balachandran et al. demonstrated that females had a significantly higher incidence of sternal infection compared with males, but it is likely the study included both SSWI and DWSI.[24] Interestingly, a study by Copeland et al. found that increased breast size (macromastia) was associated with an increased risk of DSWI, potentially owing to the weight of unsupported breasts causing increased inferolateral tension across the sternotomy wound and contributing to wound dehiscence and subsequent infection.[40] Conversely, Borger et al. showed that the male sex was independently associated with DSWI in patients who had undergone isolated CABG surgery and postulated that increased wound tension from a larger chest wall circumference in males might have been a contributory factor.[41]

Advanced Age

There have only been a few studies identifying advanced age as a risk factor for DSWI.[37,42] However, a large 2010 retrospective cohort study involving more than 21,000 cardiac surgical patients over a 15-year period showed that despite a significant increase in age during the last 5 years of the study, there was a substantial decrease in the rate of DSWI, suggesting that age was probably not a significant risk factor and that the results seen could possibly be owing to changes in modifiable risk factors instead.[43]

Obesity

Despite varying definitions of obesity used in literature, various studies have demonstrated a strong association between DSWI and a high body mass index.[6,14,37,38,42,44,45] Obesity is an independent risk factor that significantly increases the odds of developing DSWI by up to 2.6 times.[24] Several hypotheses have been offered to explain the relationship. A larger chest wall circumference places increased tension across the sternal wound resulting in instability and predisposing to infection.[14,46] Decreased vascularity of adipose tissue can also impair wound healing with less effective penetration of antibiotics and delivery of necessary nutrients.[37,44] Moreover, physiological alterations in obese individuals affect drug pharmacokinetics and pharmacodynamics, making both prophylactic and therapeutic antibiotic regimens challenging.[47] Technical difficulties with prolonged operative time may further contribute to the risk.

Diabetes Mellitus

Diabetes mellitus is another risk factor strongly associated with the development of DSWI.[6,8,37,38,41-45,48,49] Elevated blood glucose concentrations have been shown to exert detrimental effects on the immune system, which in turn impairs wound healing and increases the risk of infection.[38,41,49] Hyperglycemia has been linked to increased mortality, DSWI, and hospital length of stay.[50] Perioperative glycemic control is important in reducing the risk of developing DSWI. Trick et al. demonstrated that the odds of developing DSWI in diabetic patients with a preoperative blood glucose concentrations $\geq$200 mg/dL ($\geq$11.1 mmol/L) was 10 times greater than that in well-controlled diabetic patients.[49] In addition, Furnary et al. showed in a prospective study that tight glycemic control (defined as blood glucose concentrations $<$150 mg/dL [$<$8.3 mmol/L]) with the use of continuous intravenous insulin therapy during the perioperative period reduced the risk of DSWI by up to 63%.[50]

Smoking and COPD

Studies investigating the link between DSWI and smoking as a risk factor have been limited.[43,45,48] A recent meta-analysis showed no significant relationship between smoking and sternal wound infection, though the finding was perhaps limited by the small number of studies.[24] Smoking impairs wound healing by reducing local blood flow resulting in decreased skin circulation and tissue hypoxia.[51] Smoking related cough also exerts stress along the sternal wires, leading to wire breakage, sternal bone fracture, and wound dehiscence.[46] This makes COPD one of the most important risk factors for sternal dehiscence,[52] and patients with COPD are at increased risk of developing DSWI.[6,42,44,53] The Centers for Disease Control and Prevention Hospital Infection Control practice guidelines for prevention of SSI recommended smoking cessation for at least 30 days before elective surgery.[54]

Other preoperative risk factors for DSWI include peripheral vascular disease,[8,39,45] heart failure,[45,55] renal insufficiency,[55,56] chronic infections,[57] and prolonged preoperative hospital length of stay.[6]

Intraoperative

BITA Grafts

The use of BITA grafts as vascular conduits for CABG surgeries is associated with higher survival and lower cardiac-related event rates compared with the use of a single internal thoracic arterial (ITA) graft.[58] However, the use of BITA grafts has been limited by the potential risk of DSWI caused by disrupted blood supply to the sternum.[59] Several observational studies have demonstrated the association between DSWI and BITA grafting.[8,39,41,44,45,59,60] A retrospective study by Gatti et al. found that DSWI after BITA grafting could be an independent predictor of reduced late survival.[61] Hence, several authors have recommended not using BITA grafts in high-risk patients, such as those with diabetes mellitus, obesity, peripheral vascular disease, and COPD.[8,41,59]

Prolonged Cardiopulmonary Bypass Time

Few studies have demonstrated the association between prolonged cardiopulmonary bypass (CPB) time and DSWI.[6,11,43] Matros et al. found that prolonged CPB time was the only consistent risk factor for DSWI over a 15-year study period.[43] Prolonged surgeries may lead to tissue desiccation and increased opportunities for wound contamination.[45] Procedure duration was found to be the only component of the National Nosocomial Infection Surveillance System risk index (comprising of patient's American Society of Anesthesiologists physical status, degree of surgical wound contamination, and length of surgery) that determined the risk of SSI in cardiothoracic patients.[62]

Other intraoperative risk factors for DSWI include combined CABG with valve procedures[6,63,64] and emergency surgery.[63]

Postoperative

Re-exploration

Re-exploration for bleeding is associated with a 6- to 9-fold increase in the risk of developing DSWI.[6,11,14,24,39,65] It has been postulated that increased exposure of the mediastinum to the environment during reoperations may increase the risks for wound contamination and infection.[24] In addition, further tissue ischemia and injury resulting from excessive bleeding, hypotension, and surgical dissection also can impair early sternal wound healing.[66]

Blood Product Transfusion

Numerous observational studies have demonstrated a strong association between blood product transfusion and development of DSWI.[38,57,65,67,68] A 2016 meta-analysis by Balachandran et al. showed that postoperative blood product transfusion was associated with an almost 3-fold increased risk of developing sternal wound infection.[24] Interestingly, a randomized controlled trial by the Transfusion Indication Threshold Reduction (TITRe2) investigators demonstrated no difference in the incidence of serious infection (including sepsis or wound infection) between the restrictive and liberal transfusion-threshold groups.[69] More randomized controlled studies are needed to see if this holds true for DSWI as well.

Current data is conflicting as to which blood product is associated with the greatest risk. Crabtree et al.[38] demonstrated that transfusion of 2 or more units of platelets was associated with an increased risk of DSWI, whereas Cutrell et al.[57] suggested 4 or more units of packed red blood cells. Blood product transfusion may lead to suppression of the recipient's immune system, leading to an increased susceptibility to infections.[38,65,67]

Other postoperative risk factors for DSWI include respiratory failure,[6] prolonged ventilator support,[8,45] and insertion of percutaneous tracheostomy within 48 hours after surgery.[70]

Preventive Measures

Perioperative implementation of bundled interventions has been key to reducing the incidence of DSWI, by reducing bacterial wound contamination and optimizing conditions for wound healing.[71,72] These measures include preoperative screening for nasal carriers of *S. aureus*, skin preparation, optimizing patients' premorbid conditions, antimicrobial prophylaxis, meticulous surgical technique, and wound management.[10,72]

S. Aureus Nasal Carriage

MRSA mediastinitis is associated with high 1-year mortality rates of up to 49%, as well as treatment failure.[73-76] Nasal carriage of *S. aureus* significantly increases the risk of developing SSI in patients undergoing major heart surgery by at least 3-fold.[77] San Juan et al. showed that the genotypes of *S. aureus* isolates obtained from preoperative nasal and surgical-site cultures in patients with MSSA mediastinitis were identical.[78] Topical mupirocin is the current gold standard agent for eradication of *S. aureus*[79] with studies showing a beneficial trend in reducing the incidence of sternal wound infection.[80,81] Intranasal mupirocin results in decolonization of ~90% of both MSSA and MRSA carriers.[82] van Rijen et al. demonstrated in a meta-analysis that the use of mupirocin significantly reduced the rate of *S. aureus* infections in carriers but not in noncarriers.[83] As increased use of mupirocin has led to development of drug resistance, routine use is not recommended in the absence of MRSA colonization.[84] Cardiothoracic surgical patients are at high risk for acquiring MRSA-related infections. As such, current practice guidelines recommend routine preoperative *S. aureus* screening for all patients (Class I, Level A Evidence)[85] with topical mupirocin treatment for 5 days in the absence of a documented negative screen (Class I, Level A Evidence).[10,85,86]

Skin Preparation

Preoperative showering or bathing with antiseptic preparations is commonly used in cardiac surgeries to reduce bacterial colonization.[87] However, a recent systematic review by Franco et al. reported no significant reduction in SSI rates in patients who bathed with 4% chlorhexidine versus placebo or soap.[88] This finding supported the conclusion in the 2015 Cochrane review that there was no benefit for 4% chlorhexidine over other wash products.[89] In light of the current evidence, the 2017 European Association for Cardiothoracic Surgery (EACTS) guidelines recommend that patients shower or bathe using soap, either the day before or on the day of surgery (Class IIa, Level B Evidence),[10] whereas the 2016 American Association for Thoracic Surgery (AATS) guidelines suggest that chlorhexidine may be helpful in reducing skin bacterial colonization (Class IIb, Level B Evidence).[85]

Hair removal over the surgical site is best done just before surgical incision instead of the night before to reduce the risk of SSI. Clipping of hair is preferred over shaving or use of depilatory agents.[90] The use of povidone-iodine or chlorhexidine is recommended for surgical site skin preparation immediately before incision and current guidelines do not state a preference for either agent.[91]

Optimizing Premorbid Conditions

The AATS guidelines[85] suggest the following recommendations in modifying risk factors that are associated with sternal wound infections:

1. Correct preoperative hypoalbuminemia (defined as <3g/mL) before surgery if possible (Class I, Level B Evidence).
2. Treat all sources of extra-thoracic infections before cardiac surgery if procedure can be safely delayed (Class I, Level C Evidence).
3. Optimize serum glucose concentrations <180 mg/dL (<10 mmol/L) in patients with poor glycemic control (defined as hemoglobin A1c levels >7.5% or serum glucose concentrations >200 mg/dL [>11.1mmol/L]) (Class I, Level B Evidence).
4. Smoking cessation and aggressive chest physiotherapy in patients with COPD or who are actively smoking (Class I, Level B Evidence).

Antibiotic Prophylaxis

The use of prophylactic antibiotics in cardiothoracic surgery has been instrumental in the prevention of sternal wound infections.[10,86] Its importance has been clearly demonstrated in numerous placebo-controlled trials showing an approximate 5-fold reduction in sternal wound infection rates.[92] Various societies have recommended the use of perioperative antibiotic prophylaxis as standard practice in cardiac surgery (Class I, Level A Evidence).[10,85]

However, considerable debate still exists over the choice of drug, timing, dose, and duration of antibiotic prophylaxis.[10] With the emergence of MRSA and methicillin-resistant CoNS, the appropriate choice of prophylactic antibiotics has become even more important. The 2007 Society of Thoracic Surgeons practice guidelines recommend a beta-lactam antibiotic (either cefazolin or cefuroxime) as sole prophylaxis in patients at low risk of MRSA colonization (Class I, Level A Evidence).[10,85,86] One to 2 doses of vancomycin may be added to a beta-lactam antibiotic in patients with proven or at high risk for MRSA colonization (Class IIb, Level C Evidence).[86] In patients with immunoglobulin-E (IgE)-mediated reactions to penicillin or beta-lactams, vancomycin also is indicated for primary prophylaxis but not more than 48 hours (Class I, Level A Evidence).[86] Either a beta-lactam antibiotic or vancomycin may be used in patients with an unclear history or non-IgE-mediated reactions to penicillin (Class I, Level B Evidence).[86] However, the sole use of vancomycin is not recommended owing to the lack of gram-negative bacterial coverage (Class III, Level B Evidence),[85] hence the addition of an aminoglycoside given as a single preoperative dose is advised (Class IIb, Level C Evidence).[86] The 2017 EACTS guidelines recommend vancomycin together with additional gram-negative coverage in patients with penicillin/beta-lactam allergies or at high risk of MRSA colonization (Class I, Level B Evidence).[10] Table 2 summarizes the perioperative antibiotic selection for beta-lactam allergic and non-allergic patients.

Timing of antibiotic administration and redosing is important to achieve and maintain adequate tissue concentrations at the time of incision and throughout the surgical procedure. Administration of prophylactic antibiotics should be completed within 60 minutes of skin incision (Class I, Level A Evidence).[10,85,86] However, a 2017 meta-analysis on the timing of prophylactic antibiotic administration challenged the widely accepted 60-minute time frame by demonstrating no differential effects in the risk of SSI when antibiotics were administered within 120 minutes before skin incision.[93] It is well established that CPB has a profound effect on the volume of distribution especially for hydrophilic drugs, owing to hemodilution, alterations in protein binding, hypothermia, and drug sequestration within the circuit.[94] As such, cephalosporins with short half-lives, such as cefazolin or cefuroxime, should be redosed for procedures lasting more than 4 hours (Class I, Level A Evidence)[85] or in the situation of prolonged or excessive bleeding.[95] Repeat administration of aminoglycosides is not recommended given their propensity for nephro- and ototoxicity, which is further exacerbated by delayed clearance after CPB (Class III, Level C Evidence).[86]

Table 2
Perioperative Antibiotic Selection in Cardiac Surgery[10,85,86]

Penicillin/Beta-lactam Allergy	No Penicillin/Beta-lactam Allergy		Reference
	Low risk of MRSA colonization	Proven or Suspected MRSA colonization	
Vancomycin ± gram-negative coverage	Beta-lactam antibiotic (either cefazolin or cefuroxime)	Beta-lactam antibiotic + glycopeptide (vancomycin)	2007 STS guidelines[86]
Vancomycin + gram-negative coverage		Beta-lactam antibiotic + vancomycin	2016 AATS guidelines[85]
Vancomycin + gram-negative coverage		Vancomycin + gram-negative coverage	2017 EACTS guidelines[10]

Abbreviations: AATS, American Association for Thoracic Surgery; EACTS, European Association for Cardiothoracic Surgery; MRSA, methicillin-resistant *Staphylococcus aureus*; STS, Society of Thoracic Surgeons.

The pharmacokinetic profile of antibiotics may be altered in obesity, often leading to subtherapeutic serum and tissue drug concentrations, hence weight-adjusted dosing may be warranted in this patient subgroup.[95] However, conclusive recommendations cannot be made owing to the paucity of data demonstrating clinically relevant decrease in SSI rates with such dosing regimens as compared with standard doses.[95] The current recommended dosing for antibiotics include: 2g of cefazolin for patients >60kg (Class I, Level B Evidence), 15 mg/kg of vancomycin infused slowly over 1 hour (Class I, Level A Evidence), and 4 mg/kg of gentamicin (Class I, Level C Evidence).[10,86]

Duration of postoperative antibiotic prophylaxis should not exceed 48 hours (Class IIa, Level B Evidence).[96] Prolonged antibiotic therapy has been associated with drug toxicity, emergence of resistant bacterial strains, *Clostridium difficile* infection, and increased healthcare costs.[97,98] Lador et al. demonstrated in a meta-analysis that a duration of postoperative prophylactic antibiotics less than 24 hours was associated with higher DSWI rates and there was no additional benefit for antibiotic regimens lasting more than 48 hours.[99] Mertz et al. also found that antibiotic prophylaxis for more than 24 hours postoperatively reduced the risk of DSWI by 68%, though the meta-analysis was limited by heterogeneity of the various antibiotic regimens and risk of bias in the published studies.[100] By reducing the duration of postoperative antibiotic prophylaxis from 56 to 32 hours, Hamouda et al. showed a reduction in antibiotic resistance and healthcare costs with no increase in SSI rates.[101]

Topical antibiotics, usually vancomycin or gentamicin, can be applied along the cut sternal edges and have been shown in several studies to reduce the incidence of sternal wound infection.[102-106] A randomized controlled trial conducted by Vander Salm et al. in 1989 reported a significant reduction in the risk of sternal infection when topical vancomycin was applied to the cut sternal edges.[102] Direct sternal administration of vancomycin and gentamicin during sternal closure also was found to significantly reduce the incidence of sternal wound infections from 5.8% to 2.0%.[103] Furthermore, Lazar et al. demonstrated that topical vancomycin in combination with perioperative antibiotics and tight glycemic control resulted in the total elimination of both SSWI and DSWI in diabetic and nondiabetic patients.[104] The use of topical vancomycin is relatively safe and not associated with drug-resistant infections or postoperative renal impairment.[107] The efficacy of topical vancomycin in reducing the risk of sternal wound infection was further substantiated by a meta-analysis conducted by Kowalewski et al. in 2017.[105] The use of gentamicin-collagen sponges also has become increasingly popular in recent years. Kowalewski et al. showed in a 2015 meta-analysis that gentamicin-collagen sponges reduced the incidence of sternal wound infection by approximately 40%.[106] This result was mirrored in a recent meta-analysis by Vos et al., demonstrating a significant reduction in DSWI in patients receiving local gentamicin before sternal closure.[108] In light of the current evidence, the AATS practice guidelines recommend the use of topical antibiotics along the cut edges of the sternum (Class I, Level B evidence).[85]

Glycemic Control

Maintaining serum glucose concentrations <180 mg/dL (<10 mmol/L) during the perioperative period has significantly reduced the incidence of sternal wound infections owing to the detrimental effects of hyperglycemia on wound healing.[50,109-111] Both AATS and EACTS guidelines strongly recommend the use of continuous insulin infusion to achieve glycometabolic control during the perioperative period (Class I, Level B Evidence).[10,85]

Surgical Techniques

Concerns over the risk of DSWI after BITA harvesting have limited its use in cardiac surgery despite evidence pointing toward its superiority over the use of a single ITA graft.[58] In recent years, ITA skeletonization has emerged as a suitable alternative technique[39,112,113] owing to preserved collateral flow to the sternum by harvesting only the ITA without any surrounding tissue.[114] A large meta-analysis by Dai et al. concluded that skeletonized BITA procurement did not result in an increased risk of sternal wound infection compared with a single ITA graft.[60] This finding was further substantiated by a study by Bonacchi et al. showing that the use of skeletonized BITA in carefully selected patients with strict perioperative glycemic control did not increase the risk of developing DSWI.[115] Kajimoto et al. studied the effects of using skeletonized BITA grafting in diabetic patients undergoing CABG in a meta-analysis, which also showed no increased risk of DSWI in this group of high-risk patients.[116] Skeletonized ITA dissection is hence recommended in diabetic patients or during BITA harvesting (Class I, Level B Evidence).[10]

Sternal instability and dehiscence can predispose to DSWI, thus careful attention must be paid to sternal alignment and closure.[117] An inadvertent paramedian sternotomy results in chest instability owing to difficulty in aligning and approximating the cut sternal edges.[118] The AATS guidelines recommend the following surgical techniques to reduce the occurrence of sternal dehiscence[85]:

1. Sternal closure with a figure-of-eight technique especially in high-risk patients (Class IIb, Level B Evidence).
2. Robicsek weave technique for closing the sternum with multiple fractures (Class IIa, Level B Evidence). This technique helps with lateral sternal reinforcement by using a pericostal wire through the intercostal spaces on either side of the sternum followed by peristernal closure wires.[119]
3. Rigid sternal fixation with plates or bands (Class IIb, Level B Evidence).

Basic surgical techniques should be adhered to and these include meticulous hemostasis, limiting diathermy use, and careful surgical dissection to avoid excessive tissue injury. As the xiphoid process is cartilaginous and avascular, a xiphoid-sparing midline sternotomy may be an alternative to a full sternotomy and has been shown to have a lower incidence of DSWI.[120]

Management

Management of DSWI can be complex and may require a multidisciplinary team approach involving infectious disease specialists, microbiologists, as well as cardiothoracic and plastic surgeons.[14] Early detection, appropriate antibiotic treatment, aggressive surgical debridement, and use of regional muscle flaps have significantly improved treatment outcomes.[10,43]

Antimicrobial Treatment

Once the diagnosis of DSWI is suspected, blood, and tissue cultures should be taken early followed by intravenous administration of empirical broad-spectrum antibiotics targeted against the most likely causative microorganism. If the risk of MRSA is low, starting piperacillin/tazobactam or carbapenems is an appropriate choice.[15] Vancomycin, daptomycin or teicoplanin should be added for MRSA coverage when necessary.[121] Results from microbiological cultures and antibiotic susceptibility profiles will subsequently streamline antimicrobial treatment. However, data on the optimal antibiotic regimen and duration of therapy remain variable and referral to an infectious disease specialist to guide management may be prudent.[15,122]

Surgical Management

Aggressive surgical debridement to remove necrotic and devitalized tissue is required for source control in the treatment of DSWI. In a retrospective study, patients who underwent debridement on the day of diagnosis had a shorter hospital length of stay and fewer admissions compared with those who had delayed surgical treatment more than 7 days after diagnosis.[123]

The earliest treatment of DSWI consisted of surgical revision followed by open dressings or closed irrigation.[124,125] However, leaving the sternum open in the former was associated with a high mortality rate from right ventricular laceration, as well as complications from prolonged immobilization owing to the need for mechanical ventilation.[125] Today, primary or delayed wound closure with vascularized soft tissue flaps are commonly used techniques for management of infected sternal wounds.

After sternal wound debridement, primary closure can be attempted provided there are no further signs of wound infection and sufficient sternum to achieve reasonable approximation and stability.[85] In patients where primary wound closure is not possible owing to the size of the sternal defect, a soft tissue flap reconstruction using the omentum, pectoralis major, latissimus dorsi or rectus abdominis muscle is often required. If the sternal wound cannot be closed owing to persistent deep sternal infection and the need for repeated surgical treatments, negative pressure wound therapy (NPWT) is recommended either as destination or bridge to final sternal closure (Class I, Level B Evidence).[10]

NPWT involves applying subatmospheric negative pressure either continuously or intermittently to a well-sealed polyurethane foam placed over the sternal wound. This technique aids in wound healing and sternal stabilization by continuously removing excess fluids and tissue debris,[125] increasing wound perfusion,[126] and promoting the growth of granulation tissue.[127] Early patient mobilization also is possible owing to wound isolation and sternal stabilization.[125] NPWT has been shown to reduce both mortality and sternal wound reinfection rates, as well as decrease hospital length of stay compared with conventional treatments.[128-130] In the past decade, there has been a trend toward using NPWT to aid in wound healing before rewiring the sternal defect.[125] Fleck et al. demonstrated lower sternal wound reinfection rates with NPWT followed by either delayed primary closure or flap reconstruction when compared with immediate primary closure.[131]

Reconstructive surgery with vascularized soft tissue flaps may be considered in patients with substantial sternal bone or soft tissue defect (Class II, Level B Evidence).[10] This is usually performed a few weeks after the initial surgery to allow for wound healing, formation of mediastinal adhesions, and sternal stability.[132] Factors such as location, extent of sternal defect, as well as patient comorbidities play an important role in determining the type of flap reconstruction.[4,132] The importance of early flap coverage in DSWI was highlighted by Lo et al. who found that each day of delay from diagnosis to flap cover significantly increased the risk of chronic wound infection by 1.2 times per day.[133] Furthermore, Cabbabe et al. demonstrated that patients with DSWI undergoing one-step radical sternal debridement followed by immediate muscle flap

Table 3
AMSTERDAM Classification of Poststernotomy Mediastinits[135]

Type	Sternal Stability	Bone Viability and Stock	Reconstruction	Timing of Reconstruction
1	Stable	Minimal bone loss	Negative pressure wound therapy (Class I, Level B)	-
2a		Sufficient	Local muscle flap	Primary (Class II, Level B)
2b			Muscle or omental flap	Delayed (Class I, Level B)
3a	Unstable	Viable and sufficient	Rewiring or sternal fixation	Primary* or delayed† (Class IIb, Level B)
3b			Rewiring or sternal fixation with muscle or omental flap	
4a		Necrotic and insufficient	Muscle flap	Primary or delayed (Class IIb, Level B)
4b			Omental flap	
4c			Muscle and omental flap	

* Indicates rewiring.
† Indicates sternal fixation with plates and clips.

coverage had significantly lower mortality and morbidity rates, as well as shorter hospital length of stay when compared with patients who had delayed flap reconstruction.[134] Patients receiving a combination of intravenous antibiotics, sternal debridement, and flap reconstruction had a significantly higher survival rate compared with those who received intravenous antibiotics and sternal debridement alone.[14] However, there is no consensus in the current literature regarding the specific timing for flap reconstructive surgery after DSWI and more studies in this area are required.[4,10,133]

In 2014, van Wingerden et al. proposed the AMSTERDAM (Assiduous Mediastinal Sternal Debridement & Aimed Management) classification for the surgical management of poststernotomy mediastinitis based on 2 variables: sternal stability as well as bone viability and stock (Table 3).[135] Sternal stability is preserved in Types 1 and 2, whereas Types 3 and 4 are characterized by sternal instability. Though unstable, the sternum is still viable in Type 3 but necrotic and insufficient in Type 4. Surgical recommendations and timing of treatment vary according to the severity of mediastinitis.

The preventive and management strategies for DSWI have been summarized in Table 4.

Role of the Cardiothoracic Anesthesiologist

Increasing evidence has shown that anesthesiologists play an important yet under-appreciated role in the prevention of SSI through the optimization of perioperative conditions.[136] Mild intraoperative hypothermia (core body temperature 34°C-36°C) was found to be a major risk factor for SSI in a randomized double-blind trial involving 200 patients undergoing colorectal surgery.[137] Hypothermia has been hypothesized to predispose patients to SSI via vasoconstriction, which in turn decreases subcutaneous tissue perfusion, oxygen delivery, and production of superoxide radicals for neutrophilic oxidative bacterial killing.[138,139] As hypothermia is inevitable during cardiothoracic surgery, the perfusionist should rewarm the patient gradually and thoroughly toward the end of CPB as guided by skin and core body temperatures. If necessary, the anesthesiologist can initiate a low dose glyceryltrinitrate infusion to improve microcirculation and facilitate uniform rewarming of the patient. Normothermia (≥36°C) should be maintained even after the patient is weaned off CPB, and this can be achieved with the use of active warming devices and administration of warmed fluids.[140]

Optimization of other perioperative conditions that have been discussed include:

1. Ensuring the administration of appropriate antimicrobial prophylaxis at the appropriate dose and timing.
2. Administering vancomycin in patients with proven or at high risk for MRSA colonization.
3. Achieving perioperative glycometabolic control (defined as serum glucose concentrations <180 mg/dL [<10mmol/L]) with the use of continuous insulin infusion.

Table 4
Recommendations for Preventive and Management Strategies of Deep Sternal Wound Infection

The following is a summary for the prevention of DSWI:

1. Correct preoperative hypoalbuminemia (defined as <3g/mL) before surgery if possible (Class I, Level B Evidence).
2. Treat all sources of extra-thoracic infections before surgery if possible (Class I, Level C Evidence).
3. Optimize serum glucose concentrations to less than 180 mg/dL (<10 mmol/L) in patients with poor glycemic control (Class I, Level B Evidence).
4. Smoking cessation and aggressive chest physiotherapy in patients with chronic obstructive pulmonary disease or who are actively smoking (Class I, Level B Evidence).
5. Routine preoperative screening of all patients for *Staphylococcus aureus* infection (Class I, Level A Evidence).
6. Topical mupirocin treatment for 5 days in the absence of a documented negative screen for *Staphylococcus aureus* infection (Class I, Level A Evidence).
7. A shower or bath using soap, either the day before or on the day of surgery should be considered (Class IIa, Level B Evidence).
8. Chlorhexidine may be helpful in reducing skin bacterial colonization (Class IIb, Level B Evidence).
9. A beta-lactam antibiotic as sole prophylaxis in patients at low risk of MRSA colonization is recommended (Class I, Level A Evidence).
10. Vancomycin may be added to a beta-lactam antibiotic in patients with proven or at high risk for MRSA colonization (Class IIb, Level C Evidence).
11. Vancomycin is indicated in patients who had IgE-mediated reactions to penicillin or beta-lactams for primary prophylaxis, but not more than 48 hours (Class I, Level A Evidence).
12. Sole use of vancomycin is not recommended owing to the lack of gram-negative bacterial coverage (Class III, Level B Evidence). An aminoglycoside should be added for gram-negative coverage in patients with penicillin/beta-lactam allergies or at high risk of MRSA colonization (Class I, Level B Evidence).
13. Administration of prophylactic antibiotics should be completed within 60 minutes of skin incision (Class I, Level A Evidence).
14. The use of topical antibiotics along the cut edges of the sternum is recommended (Class I, Level B evidence).
15. Continuous insulin infusion should be used to achieve glycometabolic control (serum glucose levels <180 mg/dL) during the perioperative period (Class I, Level B Evidence).
16. Skeletonized internal thoracic artery dissection is recommended in diabetic patients or during bilateral internal thoracic artery harvesting (Class I, Level B Evidence).
17. Robicsek weave technique may be applied for closing the sternum with multiple fractures (Class IIa, Level B Evidence).

The following is a summary for the management of DSWI:

1. Negative pressure wound therapy is recommended either as destination or bridge to final sternal closure (Class I, Level B Evidence).
2. Muscle or omental flaps may be considered in patients with sternal instability or insufficient bone stock (Class IIb, Level B Evidence).

Abbreviations: DSWI, deep sternal wound infection; IgE, immunoglobulin-E; MRSA, methicillin-resistant *Staphylococcus aureus.*

Conclusion

DSWI is a rare complication after median sternotomy performed in cardiothoracic surgeries with substantial mortality and morbidity rates. Identifying the high-risk patient and employing strategies to optimize the risk factors involved play an important role in reducing the incidence of DSWI. However, as the rates of DSWI have not decreased significantly over the last decade despite significant improvements in preventive measures, more attention needs to be paid in refining treatment protocols to reduce the severity and impact on patients and the healthcare system.

Conflict of Interest

The authors declare no conflicts of interest.

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