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Risk factors for post sternotomy wound complications across the patient journey: a systematised review of the literature

Review Article

Risk factors for post sternotomy wound complications across the patient journey: a systematised review of the literature

Abstract

Background: Around 36,000 cardiac operations are undertaken in the United Kingdom annually, with most procedures undertaken via median sternotomy. Wound complications occur in up to 8% of operations, with an associated mortality rate of around 47% in late or undetected cases.

Objective: To undertake a systematised literature review to identify pre-operative, peri-operative and post-operative risk factors associated with sternal wound complications.

Methods: Healthcare databases were searched for articles written in the English language and published between 2013 and 2021. Inclusion criteria were quantitative studies involving patients undergoing median sternotomy for cardiac surgery; sternal complications and risk factors.

Results: 1360 papers were identified, with 25 included in this review. Patient-related factors included: high BMI; diabetes; comorbidities; gender; age; presenting for surgery in a critical state; predictive risk scores; vascular disease; severe anaemia; medication such as steroids or α-blockers; and previous sternotomy. Peri-operative risk increased with specific types and combinations of surgical procedures. Sternal reopening was also associated with increased risk of sternal wound infection. Post-operative risk factors included a complicated recovery; the need for blood transfusions; respiratory complications; renal failure; non-diabetic hyperglycaemia; sternal asymmetry and sepsis.

Conclusion: Pre, peri and post-operative risk factors increase the risk of sternal wound complications in cardiac surgery. Generic risk assessment tools are primarily designed to provide mortality risk scores, with their ability to predict risk of wound infection questionable. Tools that incorporate factors throughout the operative journey are required to identify patients at risk of surgical wound infection.

Keywords

Sternal wound, Cardiac surgery, systematised review of the literature

Highlights

Risk of developing an SSI is dynamic in nature

A single pre-operative risk assessment for SSI will not protect from adverse outcomes

Risk factors can evolve and change throughout the patient journey

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Introduction

Around 36,000 and 144,000 cardiac operations are undertaken in the United Kingdom (UK) and the United States of America (USA) each year respectively.[1] Most of these procedures are undertaken through a vertical incision along the sternum, in order to access the chest cavity.[2] Surgical site infections (SSIs) are infections that occur at or near the surgical incision within 30 days following a procedure, or within 90 days if prosthetic materials are implanted during surgery [3]. They occur in up to 8% of operations, [4,5] and encapsulates a spectrum of wound complications: superficial surgical wound infections (SSWI); 'deep' surgical wound infections (DSWI); mediastinitis; and wound dehiscence. A SSWI involves the skin, subcutaneous tissue, and pectoralis fascia only, and is diagnosed in the presence of erythema, drainage, fever, and sternal instability.[6] However, it is often concealed with a low-grade fever as its only presentation.[7] DSWIs extend much further, reaching below the sternum and the anterior mediastinum.[6] These infections can be diagnosed in the presence of at least one of the following criteria: organisms identified from culture of mediastinal tissue or fluid; evidence of mediastinitis on gross anatomic or histopathologic exam; patient has at least one of the following signs or symptoms, fever (>38.0 °C), chest pain, or sternal instability with either purulent drainage from the mediastinal area or mediastinal widening on imaging studies.[8] Further down the spectrum of wound complications, is mediastinitis, which is the inflammation of the connective tissue within mediastinal structures and may involve the pleura. Finally dehiscence can be defined as the rupture or splitting of the margins of a clean closed incision a failure of the wound to heal, or reopening of the suture line.[9]

SSIs are associated with increased morbidity, reduced life expectancy [10], a longer hospital stay, a difficult recovery period for patients, and higher costs for healthcare systems [11,12]. Infections that are detected late, are associated with around a 47% mortality rate.[13] SSIs are now publicly reported in the UK and USA with some private insurance services no longer reimbursing hospitals for the additional costs associated with the treatment of DSWI following some surgical procedures.[14]

The risk of developing an SSI is currently based on a number of pre-operative factors.[15] However, these may not provide a complete risk assessment as risk is not static, but rather evolves throughout the surgical journey, thus requiring a tool that reflects the patient pathway. To the best of our knowledge, this is the first systematised literature review that explores the nature of risk throughout the cardiac surgery pathway.

Methods

A systematised literature review[16] of quantitative literature was undertaken to identify the risk factors and clinical characteristics associated with SSI.

Review Objective

The objective of this study was to identify the pre-operative, peri-operative and post-operative risk factors for developing an SSI following sternotomy for cardiac surgery.

Search Strategy

A specialist information scientist undertook an extensive search across a number of healthcare related databases, using a combination of keywords and controlled vocabulary such as MeSH (Medical Subject Headings). Health care related databases, including CINAHL, MedLine, PubMed, Scopus, and Web of Science, were searched for papers published in the English language dated between 2013 and 2021. Whilst the exclusion of papers in a review due to language of publication may risk the introduction of bias, there is evidence to suggest it has no impact on estimates of intervention effect. [17] The search criteria sought to identify all quantitative studies reporting risk factors of patients undergoing median sternotomy following cardiac surgery who developed an SSI.

Two authors independently screened the titles, abstracts and full papers meeting the inclusion criteria. A third party resolved any disagreement between reviewers and a bespoke data extraction tool was developed, piloted and refined. The tool included screening questions to ensure a good fit with the review inclusion criteria. Quality assessment and risk of bias were assessed using a CASP tool appropriate for the research methodology. However, as no meta analysis was performed, no papers were excluded on the basis of quality or bias, with quality information used only to inform discussion. A flow diagram of the study selection process is provided in Figure1.

Figure 1

Data extraction

Information was extracted from each study and recorded under the following headings: study design; sample and setting; study objective; measures of sternal wound complications; outcome measures and key findings (Table 1).

Results

We identified a total of 1360 studies from the literature search. After duplicates were removed, 1289 records were retained. A total of 1167 were excluded by title, leaving

122 papers. Of these, a further 56 were excluded based on their abstract. A total of sixty- six full articles were reviewed. Thirty of these were excluded: three papers were excluded based on language of publication; 24 did not meet the criteria, 2 were not accessible and 1 duplicate. Thirty-six articles were identified as eligible: 25 provided multivariate risk-factor data; and 11, univariate data (Table 1). For the purposes of this review, only papers including multivariant analysis are included, due to the inter or co dependence of risk factors.

Description of studies

All 25 multivariate studies had conducted primary research to identify risk factors for the development of SSIs. They were predominantly cohort studies (n=22). Eleven of the cohort studies were retrospective, relying on the retrieval of information from existing medical data-sets. Two studies had adopted retrospective case-control designs. Thirteen studies were conducted in Europe; five in the USA; two in Canada; one in China; three in Japan and one in Brazil. All the studies had large sample sizes derived either retrospectively from administrative data-sets or from the prospective follow-up of large cohorts of patients undergoing cardiac surgery in specialist units. The characteristics of the included studies are provided in Table 1.

Table 1 here: Characteristics of included studies

In the following section, the findings from the systematised literature review are reported, based on those that provided multivariate data analysis.

Pre-operative risk factors

Demographic factors including weight, gender and age were the most reported risk factors, with diabetes and pre-existing lung disease. A synopsis of each factor is provided below.

Demographic Factors

Out of the 25 papers reporting multivariant analysis, nineteen identified high body mass index as a key risk factor for an SSI [15,18-34]. Gender was highlighted in six papers, with female gender reported as a risk factor for developing SSI in five, with one reporting that female gender was associated with higher risk of sternal wound dehiscence [19]; and the others reporting SSIs[4,22,35,27]. One study identified male gender as a risk factor for deep sternal wound infection [29]. Age was identified as a significant risk factor in four papers. Patients over the age of 70 were found to be at increased risk of developing: surgical site infection [4]; sternal wound dehiscence [18]; and mediastinitis in patients over the age of 68 [33]. This was further supported by Nieto-Cabrera et al. who identified age to be one of 4 preoperative variables to be predictive of mediastinitis [30].

Co-morbidities

Ten studies identified diabetes as a risk factor, although differentiation between type I and II diabetes was not always made[15,19-23,25-27]. In addition, one study highlighted the increased risk associated with post operative hyperglycaemia in non diabetic patients[32]. An increased risk of sternal dehiscence [26]; and deep sternal wound infection [15] were identified as a risk associated with diabetes. Two studies found that the higher risk of SSI was equally applicable to insulin dependent and non-insulin dependent diabetic patients [4,19], including the risk of sternal wound dehiscence.[19]

Patients presenting with chronic obstructive pulmonary disease or with a history of lung disease were at higher risk of developing surgical site infection [4], sternal wound infection [27], sternal wound dehiscence [18,26], mediastinitis [30] and deep sternal wound infection. [29,36] Arterial hypertension was also identified as a risk factor for developing SSWI, and patients with pulmonary hypertension were at higher risk of developing DSWI [23]. The same paper identified patients with permanent or persistent atrial fibrillation were at higher risk of superficial sternal wound infection. [23] Peripheral vascular disease [32] and a history of stroke [34] were both identified as a risk factor for developing sternal complications, and patients with renal insufficiency presenting with a high serum creatinine >130μmol/L were at greater risk of both SSI in general [25], and more specifically, mediastinal infections. [32]

Medication and smoking

Immunosuppressors or α-blockers [37], along with steroid use [32] were identified as risk factors for surgical site or mediastinal infection respectively. One study highlighted the association between smoking and SSI risk. In a nine-year prospective cohort study, smoking, defined as active or inactive for less than 10 years, increased the risk of DSWI following CABG surgery.[15]

Surgical presentation and history

A history of a previous sternotomy was associated at higher risk of developing either a superficial or deep sternal wound complication [23,36], with the risk of dehiscence double that of a patient undergoing a first time sternotomy.[26]

For those patients presenting for unplanned surgery in a critical state [4], as an emergency [36] or for non-elective surgery [18], a number of studies reported a higher risk of developing sternal wound complications, or an increased severity of infection once present.[22] In particular, those with haemodynamic instability requiring assistance with cardiac output or maintaining blood pressure were reported to be at greater risk of DSWI [29]. An active chronic viral or bacterial infection,[36] or preoperative anaemia requiring a blood transfusion of more than four units were both identified as a risk factor for DSWI.[36]

Predictive Risk Index Scores

There is some suggestion that the health scoring systems applied to patients' assessment on admission can be useful predictors of risk for sternal wound complications. One study demonstrated that a New York Heart Association (NYHA) indicating heart failure, or a high Society of Thoracic Surgeons (STS) DSWI risk index score were predictors of DSWI [24]. Another study found that patients falling within the second and third EuroSCORE quartiles and undergoing coronary artery bypass graft (CABG) surgery were at higher risk of developing an SSI[27], and, more specifically, sternal dehiscence.[26]

Peri-operative risk factors for sternal wound complications

A number of peri operative risk factors were identified. These included type of surgery, complications during surgery, and method of closure.

Type of surgery

The type of surgery that patients underwent was also significant in terms of the risk of developing an SSI. These complications were associated with on-pump CABG [15]. Findings from a number of studies were conflicting, with CABG [26], concomitant CABG and aortic valve replacement surgery [33], and valve surgery [34] identified as being associated with significant risk of SSI. In addition, the risk of deep sternal wound infection was shown to increase with the number of valves affected by surgery [29]. The risk of mediastinal infection also increased with ventricular assist device surgery and transplant surgery. [32]

CABG surgery combined with the use of internal mammary arteries (IMA) increased the risk of sternal wound dehiscence [4], and SSIs in general.[27] Women who underwent bilateral IMA surgery were at increased risk of surgical site infection. In addition, patients undergoing pedicled IMA were at increased risk of deep sternal wound infection.[4,15] Arterial grafts involving the IMA increased the risk of deep sternal wound infection [29] and sternal wound infection [21], with an increased risk of sternal wound infection in diabetic patients having bilateral IMA surgery. [22]

Surgical complications

Excessive bleeding requiring a perioperative blood transfusion was a risk factor for SSI.[4]. In addition, patients who experienced prolonged operating times were more likely to develop SSIs, with those who spent more than 300 minutes in theatre while undergoing CABG identified as at increased risk of a SWI[27], and a predictor of developing a DSWI.[28]

Closure

Sternal closure with only four sternal wires [28] increased the risk of deep sternal wound infection. In one study, sternal closure without applying local collagen-gentamycin sponge(s) was found to increase the risk of sternal wound infection.[20] However, this was found not to be statistically significant, when comparing gentamycin containing collagen implants to standard treatment to reduce the risk of DSWI.[23] Finally, the use of bone wax for haemostasis was associated with an increased risk of dehiscence.[18]

Post-operative risk factors

Post operative risk factors were predominantly associated with complicated recovery, including bleeding, prolonged ventilation and Intensive Care stay. However, risk factors associated with post operative wound management were also identified.

Complicated recovery

Patients who had a complicated recovery were identified as having increased risk of developing some form of SSI. The most common risk was associated with the need for a chest reopening [23,30,31], including reopening for bleeding,[27] with patients requiring their sternal wound to be reopened within 7 days at higher risk of mediastinitis.[4]

Requirements for blood transfusion was also associated with an increased risk of post-sternotomy mediastinitis.[34] Those receiving in excess of four units of red blood cells with or without the presence of preoperative anaemia were at higher risk of developing DSWI.[38] This was quantified in a further study that concluded that the risk of mild or severe SWI increased with the number of red blood cell transfusions required.[20] Post-operative respiratory failure was also identified as a risk factor for dehiscence or SWI, [21] with reintubation a predictor of DSWI.[29] In addition, prolonged intubation (>24 hours) was predictive of mediastinitis,[30] and post-operative ventilation of more than 48 hours associated with an increased risk of SSI.[4]

Patients requiring inotropic support [29] and vasopressive support [4] were found to be at higher risk of developing DSWI and SSI respectively, and those who developed sepsis at greater risk of DSWI.[29] Post-operative renal failure was a risk factor for developing DSWI, [28] and post-operative hyperglycaemia in non-diabetic patients was a predictor of mediastinal infection.[32] These risk factors all likely to increase the length of time that patients spent in intensive care, with this highlighted as an independent risk factor of DSWI.[29]

Post operative wound management

In Jacobson's study of wound complications following midline sternotomy, sternal asymmetry of 10% or greater, measured by 3-dimensional computed tomography, was an independent predictor of sternal wound infection and diabetes further increased the risk. [39] In addition, two studies reported a significant reduction in post sternotomy wound infections using negative pressure wound therapy [35,40], with the incidence of SSI reducing from 10.6 to 2.9%, and no cases of mediastinitis in the intervention group.[35]

Summary of the results

A summary of the multivariate results is provided in Figure 2. Due to lack of consistency in definitions of terms (for example obesity), as well as the heterogeneity of the methods, outcome measures and populations included in the studies identified, no meta-analysis was undertaken.[41]

[Figure 2 here] Summary of the risk factors for sternal wound complications from a systematised review (multivariate analyses).

Discussion

Sternal wound infections are one of the most common complications following cardiac surgery via a mediastinal incision.[42] Whilst advances in treatments, such as negative pressure wound therapy [43] and reconstructive surgery [42] have been made, SSI's remain associated with significant morbidity and mortality.[44] Furthermore, the financial burden associated with treatment and prolonged hospital stay, is not insignificant [45] Reported incidence of SSIs vary between 0.5–10%, with the variation in figures reflecting the risk factors of the patient population.[4]

Our findings bring together existing literature, to provide a comprehensive overview of the risks associated with the development of SSIs across the surgical pathway.

Combined, a tailored risk stratification can be developed, enabling effective preventive strategies to be appropriately applied.

Risk factors identified within this review are divided into three consecutive groups: pre-operative factors, including patient demographic and clinical risks; peri-operative factors associated with the surgical procedure itself; and post-operative factors comprising of risk factors arising from the operation. The occurrence of a post mediastinal SSI often relates to a combination of several factors, with prevention reliant on the control of risk factors.[46] Whilst limited risk factors, such as smoking, are amenable to intervention preoperatively, acknowledgement of the impact of combined, and cumulative risk factors, is essential in order to address the risk of sternal wound breakdown post operatively.

Risk scoring or stratification has been widely adopted as a method of predicting outcome within cardiac surgery. Using risk assessment tools to assist in the identification of patients at risk of developing an SSI is beneficial; highlighting patients to facilitate prevention and optimize timely intervention [13] There are a number of risk tools, such as the widely used Society of Thoracic Surgeon's (STS) risk calculator [24], or the Toronto Risk Score [47]. However, these are generic, and designed and validated primarily to predict mortality.[48] Their discriminatory power to predict isolated sternal wound complications has been questioned.[5] This may be in part due to the lack of consideration to the whole process of the operation, where they predominantly focus on the pre-existing state of the patient prior to surgery, failing to recognise the dynamic nature of risk.

The spectrum of reported sternal wound complications ranges between a superficial wound infection through to wound dehiscence. Whilst a definition was generally provided within each paper, there was no standardization of definition of wound complication applied within the literature. Similarly, definitions of terms such as obesity varied from paper to paper, with BMI cut offs varying. This made comparisons between papers difficult. In terms of wound complications, this paper has applied a combined, generic definition of wound complication that encompasses varying degrees of complication, with the term SSI capturing this spectrum. Whilst treatment options differ, risk profiles for each outcome are similar across the literature. No attempt has been made to determine cost implications of treatment, solely risk of a generic wound complication.

Much of the literature examining SSIs has focused on pre-operative aspects of patient demographics and comorbidities. Female gender, [19,22,27,36]; age over 70 years [4,18,21,29,31,33] obesity [30], diabetes, smoking status, and COPD [13 30] have all been identified as factors associated with increased risk of developing SSIs, both in uni- and multi-variant analysis. The interaction between these factors are complex and multifaceted. For instance the impact of smoking is recorded in a number of studies [29,49], with rates of dehiscence 3.5 folds higher in those who consumed >20 cigarettes per day than in those who smoked <20 cigarettes per day.[49] The relationship between smoking and COPD is well established [50], so it is perhaps of no surprise that both are identified as risk factors.

The inter-relationship with gender is more complex, with women significantly more likely to develop COPD without a history of smoking than men (27.2% versus 7.3%).[51] This highlights the importance of multivariant analysis when identifying potential risk factors. Gender differences are also noted in some aspects of glucose homeostasis and energy balance, where regulation differs between males and females.[52] Whilst the global prevalence of diabetes is higher in men, there are more women with diabetes than men.[53] This gender difference reverses depending upon age, with more diabetic men before the age of puberty, but more diabetic women after the age of menopause.[51]

Similarly, peri operative risk factors reflected high levels of interaction. Risk factors include type of procedure, with combined procedures (CABG and valve), holding higher risk than single procedures [29]. Bypass time was similarly identified as a risk factor[27], with combined procedures unsurprisingly requiring increased time on bypass. This correlates with the need for prolonged intubation, a further risk factor.[30]
Re-exploration of the chest, whether reopening for bleeding or other complications, has been associated with an increased risk of developing an SSI.[4,23,30] It has been hypothesized that reopening increases exposure to airborne or environmental pathogens, thus increasing susceptibility to SSIs. [54]

In the 2010 Guidelines of the Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for CardioThoracic Surgery (EACTS), complete revascularization with arterial grafts was a Class IA recommendation for patients with reasonable life expectancy.[55] However, there is increasing evidence to suggest that BIMA grafts are associated with higher levels of perioperative complications, in particular sternal wound problems.[56] The implications of this on practice remain unclear.

Cardiac surgery induces a significant inflammatory hypermetabolic stress response, resulting in postoperative hyperglycemia in both preoperatively diabetic and nondiabetic patients [57]. One of the key objectives in the management of patients within the immediate 24 hours post operation is maintenance of glycaemic control. There is some evidence to suggest this may reduce the risk of mediastinal infections in patients without diabetes.[32] However, confounding factors including pre-operative risks such as a higher body mass index, higher creatinine, peripheral vascular disease, and preoperative corticosteroid use make attributing risk more difficult.

Limitations/weaknesses of the evidence base

The results of this systematised review should be interpreted with caution. Many of the studies relied on retrospective patient data taken from large administrative data-sets which can increase the likelihood of reporting errors. The international context for the research studies also needs to be taken into account, including the heterogeneity in definitions, data collection procedures and methods, and the variation in the conduct of surgical procedures, pre-operative, peri-operative and post-operative care protocols, staff training and staff roles and responsibilities. While the broad theme across all of the studies was 'sternal wound complications', their specific focus and the outcomes measured varied, covering a range of different conditions, including SSI in general; SWI; SWD; SSD; mediastinitis and DSWI. Their definitions of each of these conditions also varied across different studies. This degree of heterogeneity made it difficult to draw firm conclusions and to apply a meta-analysis to the findings without sight of the original data.

Implications for future research

Lack of consensus around the definitions, both of risk factors such as obesity, and outcomes measures including levels of SSI, is a significant limitation on our ability to synthesis evidence and improve outcomes. A primary focus of future research will therefore be the development of an agreed set of definitions to enable comparisons across studies.

In addition, there is a clear need to develop and test a dynamic risk tool that includes all aspects of patient journey in order to inform patient care and improve outcomes.

Conclusion

The most important conclusion to draw from this study is that peri-operative and post-operative risk factors for sternal wound complications can be of equal relevance to pre-operative risk factors in determining patient outcomes following sternotomy. Risk is dynamic in nature and a single pre-operative risk assessment for sternal wound complications will not protect patients from adverse outcomes. Risk factors can evolve and change throughout the patient journey and they can be identified in each phase of the patient’s treatment by conducting a series of risk assessments on admission, immediately following surgery and during the recovery period.

Declaration of Conflicting Interests

No conflict of interest

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Tables and Figures

Table 1. Characteristics of included studies (reporting multivariate analyses)

Author, year of publication	Study design	Sample & setting (population)	Measures of sternal wound complications	Outcome measures	Key findings (reported from multivariate analysis)
Alhan et al., 2014	Prospective cohort study	5,318 patients undergoing cardiac surgery with procedures performed by one surgical and anaesthesia team between 1999 and 2009. Turkey.	Sternal dehiscence diagnosed with physical examination and/or computed tomographic (CT)/magnetic resonance imaging (MRI) examination.	Partial or total dehiscence of the sternum at any time postoperatively.	Independent risk factors for sternal wound dehiscence were age >70 (OR=1.9, 95% CI: 1.2-3.1, *p*=0.005); chronic obstructive lung disease (OR=2.4, 95% CI: 1.5-3.9, *p*=<0.001); use of bone wax (OR=1.6, 95% CI:1.03-2.5, *p*=0.03); non-elective operation (OR=2, 95% CI: 1.1-3.4, *p*=0.009) and BMI>30 (OR=2.2, 95% CI:1.4-3.5, *p*=<0.001).

Cutrell et al., 2016	Retrospective matched case-control study	1,894 patients undergoing partial or complete median sternotomy between 2010-2013, from which 39 cases of DSWI and 117 controls were identified. University of Texas Southwestern Medical Centre, Dallas.	Cases met the STS or NHSN definitions for DSWI/deep incisional SSI within an extended inspection period of 12 months. Excluded superficial SSI.	Incidence of DSWI and associated risk factors.	RBC transfusion ≥ 4 units (p = 0.037) and chronic infections at the time of surgery (p = 0.029) were significant risk factors for DSWI. The interaction of preoperative anaemia with RBC transfusion ≥ 4 units was a strong independent risk factor (OR 2.8), despite inclusion of reoperation for bleeding.
Doherty et al., 2014	Prospective cohort study	5,815 patients undergoing CABG from April 2002- Nov 2009, according to the Alberta Provincial Project for Outcome Assessment in CHD (APPROACH	Sternal wound dehiscence defined as postoperative wound disruption at the mid-line sternotomy site for CABG (ICD/CDCP definitions).	Predictive covariates for sternal wound dehiscence; trends over time in incidence of sternal wound dehiscence.	Predictors of sternal wound dehiscence were diabetes (OR 2.97. 95% CI: 1.73-5.10); obesity (OR 1.55, 95% CI: 1.05-2.27); female sex (OR 1.90, 95% CI: 1.26-2.87).

		database). Alberta.			
Eton et al., 2016	Prospective cohort study	1,077 cardiac surgery patients, from April 2011-October 2013. McGill University Teaching Hospital, Canada.	SSI defined according to CDCP criteria; classified as superficial / complex and time of detection (in hospital/post discharge); site of incision. (sternal/harvest site); responsible pathogen.	SSI occurring within 90 days of surgery; exposure to medications for cardiovascular conditions in 7 days before surgery; medications for comorbid conditions.	Risk of SSI increased with preoperative use of immunosuppressors/steroids (AOR 3.47, 95% CI: 1.27-9.52) and α-blockers (AOR 3.74, 95% CI: 1.21-1.47).
Friberg and Bodin, 2013	Prospective cohort study	950 cardiac surgery patients. Orebro University Hospital, Sweden.	CDCP criteria for SSI + longer follow-up of 60 days. A wound scoring system (simplified ASEPSIS score based on patient self-reporting of symptoms and treatments).	Self reported measures of SWI.	Independent factors for increased incidence of SWI were diabetes mellitus (OR 2.00, 95% CI: 1.11-3.60, *p*=0.02); BMI of 25-30kg/m^2 (OR 2.20, 95% CI 1.06-4.59, *p*=0.04); BMI over 30kg/m^2 (OR 7.03, 95% CI: 3.05-16.20, *p*=<0.001); and number of RBC transfusions (OR 1.11, 95% CI: 1.05-1.17, *p*=<0.001). Independent risk factors for severe SWI

			Antibiotic treatment prescribed for wound infection defined "any" SWI.		were BMI over 30kg/m^2 (OR 6.25, 95% CI: 2.48-15.74, *p*=<0.01), number of RBC transfusions (OR 1.15, 95% CI: 1.08-1.22, *p*=<0.01) and (lack of) local collagen gentamycin (OR 0.44, 95% CI: 0.22-0.90, *p*=0.026)
Fu et al., 2016	Retrospective cohort study	8,098 consecutive patients undergoing cardiac surgery from January 2008 - December 2013. Columbia University Medical Centre	Three groups identified : 1). No sternal wound complication; 2) SSD (sterile sternal dehiscence); 3) SWI (sternal wound infection) Diagnosis according to CDCP guidelines.	Sternal wound complications requiring plastic surgery for wound debridement and reconstructive (SSD and SWI).	Significant predictors of SSD were BMI >30 kg/m^2 (OR 2.14, 95% CI: 1.12-4.15, *p*=0.025); diabetes requiring medication (OR 2.59, 95% CI: 1.34-5.01, *p*=0.006), and respiratory failure (OR 5.02, 95% CI: 2.58-9.74, *p*=<0.001). Significant predictors of SWI were IMA grafting (OR 3.24, 95% CI: 1.30-8.05, *p*=0.009) and respiratory failure (OR 3.89, 95% CI: 1.56-9.73, *p*=0.008)
Fujii et al. 2019	Retrospective nonrandomized, historically controlled study	113 consecutive patients (NPSWC group) who underwent isolated CABG	Sternal surgical site infection (SSI) CDC definition used for superficial and deep SSI	The primary outcome measure was the sternal SSI prior to discharge	Following implementation of Negative-pressure sternal wound closure (NPSWC) the incident rate of sternal SSI decreased from 10.6 to 2.9%, and no mediastinitis occurred. A

		from 10/05 – 1/07. 118 consecutive patients (Control group) from 1/04 to 4/05. Nippon Medical School, Japan			multivariate logistic regression analysis identified female sex (*p* = 0.0040) and no NPSWC (*p* = 0.0084) as significant risk factors for sternal SSI development.
Grauhan et al. 2013	Prospective study	150 consecutive obese patients (BMI >30) 75 NPWT/75 control Deutsches Herzzentrum, Berlin, Germany	CDC definition of superficial wound infection. Deep wound infection measures: temperature >38, purulent secretion, chest pain, sternal instability or positive bacterial culture from blood or mediastinal drainage fluid.	Primary end point was occurrence of wound infection within 90 days of surgery	Significant decrease in wound infection in experimental group. 3 with NPWT c/w 12 in control group had wound infections (OR 4.57; 95% CI 1.23-16.94, P= .0266). Gram-positive flora found in 1 in NPWT group c/w 10 in control (P= .0090; OR 11.39; 95% CI, 1.42-91.36). Sternum dehiscence found in 1 in NPWT group c/w 3 in control (P= .6199).
Heilmann et al., 2013	Retrospective cohort study	1,297 patients undergoing median	The diagnosis of deep or superficial	Incidence of sternal wound complications	Risk factors for superficial sternal wound complications were

		sternotomy from Jan 2009 - April 2011. Heart Centre, Freiburg University, Germany.	sternal wound complication was made according to CDCP guidelines. Superficial wound complications defined according to Superficial Incisional Surgical Site Infection (SSI). Deep infections comprised the definitions Deep Incisional SSI and Organ/Space SSI.	(superficial healing disorders and deep complications); in-hospital mortality.	BMI>40kg/m^2 (OR 5.6, 95% CI: 1.4-22.5, *p*=0.016); resternotomy (OR 4.4, 95% CI: 2.1-9.4, *p*=<0.001); and emergency (OR 3.1, 95% CI: 1.4-6.6, *p*= 0.004). Risk factors for all deep sternal wound complications were insulin-dependent DM (OR 12.0, 95% CI:3.7-39.0, *p*=<0.001); COPD (OR 7.4, 95% CI: 3.3-16.5, *p*=<0.001); emergency (OR 3.8, 95% CI: 1.7-8.6, *p*=0.001); and resternotomy (OR 3.8, 95% CI: 1.5-9.8, *p*=0.006)
Hulman et al., 2017	Retrospective cohort study	143 patients with median sternotomy and significant SSI (treated by VAC therapy), selected from a	Infections treated by VAC therapy only. Excluded small uncomplicated infections with	Superficial infections of the skin, subcutaneous tissue and pectoral fascia and DSWI	Predictors for SSI were high BMI (*p*=<0.01), female gender (*p*=<0.01) and DM combined with the use of BIMA grafts (*p*=<0.01). The acuteness of operations did not have a

		cohort of 4,650 patients undergoing surgery from 2012-2015. Clinic of Cardiac Surgery, National Institute of Cardiovascular Diseases, Bratislava	ASEPSIS score <30 that were treated only by daily dressings. Excluded patients with wound infections at other sites	affecting the bone, substernal space and mediastinum	statistically significant effect on the development of SSI, however it had a statistically significant effect on the severity of infection ($p<0.01$)
Jacobson et al., 2015	Retrospective case-control study	58 patients who underwent midline sternotomy and received a CT scan from 2009-2010. 26 cases of sternal wound infection and 32 randomly selected controls. USA	SWI measured against CDCP criteria. Sternal wound dehiscence was measured by CT scan as the distance between the 2 sternal halves at 4 points along the sternum. Sternal asymmetry was defined as the difference	Sternal asymmetry and its relationship with sternal wound infection	Independent predictors of sternal wound infection were sternal asymmetry of 10% or greater (OR 3.6, p=0.03); and diabetes (OR 3.3, p=0.0442).

			between the left and right sternal halves, expressed as a percentage of the total sternal volume		
Kępa et al., 2015	Retrospective cohort study	1,118 cardiac surgery patients from 2011-2012. Department of Cardiac Surgery, Medical University of Silesia, Poland	Type/ severity of wound infection/ complications categorized using the El Oakley and Wright classification system[26]	Group 1 (SSWI) and Group II (DSWI): Patient characteristics; risk factors and procedure related variables compared to patients with complete wound healing.	Independent risk factors for SSWI were BMI (OR 1.10, 95% CI: 1.05-1.16, *p*=0.003); arterial hypertension (OR 4.64, 95% CI: 1.39-15.55, *p*=0.01); permanent / persistent atrial fibrillation (OR 2.77, 95% CI: 1.22-6.28, *p*=0.01), and chest revision (OR 2.65, 95% CI: 1.01-6.93, *p*=0.04). Independent risk factors for DSWI were pulmonary hypertension (OR 24.14, 95% CI: 4.12-141.35, *p*=0.001); diabetes (OR 2.41, 95% CI: 1.11-5.22, *p*=0.02), and chest revision (OR 5.74, 95% CI: 1.63-20.22, *p*=0.006). The addition of gentamycin-containing collagen implants to standard

					treatment reduced the DSWI rate by 59% versus standard treatment alone but this did not reach statistical significance.
Lander et al., 2017	Retrospective cohort study	14,492 patients who underwent CABG, valve, or combined CABG, valve or combined CABG and valve surgery from 2003-2015. Brigham and Women's Hospital, Boston MA.	DSWI defined according to Society of Thoracic Surgeons database classification of postoperative DSWI with the caveat that infection occurring within a 90 day interval was specified (STS specifies a 30 day interval).	DSWI occurring within 90 days of surgery.	Risk factors for DSWI were BMI>30kg/m^2 (OR 1.72, 95% CI: 1.21-2.46, *p*=0.003); NYHA Class IV (OR 1.85, 95% CI: 1.08-3.18, *p*=0.026), and the STS DSWI risk index (p= 0.0002).
Lemaignen et al., 2015	Prospective cohort study	292 patients who underwent cardiac surgery via median sternotomy and who developed SSI, from	SSI was defined using CDCP criteria; as the need for reoperation for local or systemic	Sternal wound dehiscence and wound infection occurring within 90 days of surgery.	Risk factors for SSI were age >70 (OR 1.3, 95% CI: 1.0-1.7, *p*=0.03); BMI>30kg/m^2 (OR 2.4, 95% CI: 1.9-3.2, *p*=<0.01); COPD (OR 1.4, 95% CI: 1.0-2.0, *p*=0.04); non-

		January 2006-December 2012. The cardiac surgery unit of a 950 bed university hospital, Paris.	infection involving the sternotomy scar. CDC -positive and CDC-negative SSI were defined according to CDC criteria. Deep SSI was defined as the need for sternum bone reopening during reoperation due to deep purulent discharge, sternal bone destruction or dehiscence.		insulin dependent diabetes mellitus (OR 1.7, 95% CI: 1.2-2.3, *p*=<0.01); insulin dependent diabetes mellitus (OR 2.7, 95% CI: 1.9-3.8, p=<0.01); pre-operative high serum creatinine >130μmol/L (OR 1.3, 95% CI: 0.9-1.9, *p*=0.06); critical preoperative status (OR 2.0, 95% CI: 1.4-2.9, *p*=<0.01); using 1 ITA (OR 2.1, 95% CI: 1.1-4.1, *p*=0.02); using 2 ITAs (OR 3.9, 95% CI: 2.6-5.8, *p*=<0.01); perioperative transfusion (OR 1.3, 95% CI: 1.0-1.8, *p*=0.05); vasopressive support (OR 1.4, 95% CI: 1.1-1.9, *p*=<0.01); ventilation >48 hours (OR 2.0, 95% CI: 1.4-2.9, *p*=<0.01); female gender (OR 0.9, 95% CI: 0.5-1.5, *p*=>0.1); interaction of female and 1 ITA (OR 2.1, 95% CI: 0.8-5.5, *p*=0.10); interaction of female and 2 ITA (OR 3.5, 95% CI: 1.8-6.3, *p*=<0.01).

					Early surgical revision <7 days was a risk factor for mediastinitis (OR 2.9, 95% CI: 1.2-7.4, *p*=0.02).x
Listewnik et al. 2019	Retrospective study	5152 consecutive patients. 45 with sternal dehiscence. Pomeranian Medical University, Szczecin, Poland	The onset of dehiscence was calculated as the difference between the date of the first surgery and the date of the first sternal reconstruction procedure.	Classified as: Early dehiscence up to 30 days from surgery and delayed dehis-cence.	Significant risk factors identified as age ($p < 0.05$), body mass ($p < 0.005$) and coronary artery bypass surgery ($p < 0.005$). Diabetes (P= < 0.006) and chronic obstructive pulmonary disease (P= < 0.015) also had an impact on an increased risk of sternal dehiscence. Logistic regression analysis found independent risk factors for the development of sternal dehiscence: BMI (OR: 2.1; $p < 0.019$), diabetes (OR: 2.4; $p < 0.004$), COPD (OR: 2.7; $p < 0.016$), and redo procedure (OR: 3.0; $p < 0.014$).
Meszaros et al., 2016	Prospective cohort study	3,249 patients undergoing CABG; single valve surgery, or combined CABG and	A postoperative sternal wound infection was defined as a superficial	Three cohorts compared (one per type of surgery). Outcome data: revision for	CABG Cohort: independent risk factors for sternal wound infection were BITA harvest (OR 3.06, 95% CI: 1.29-7.27); procedure exceeding 300 minutes

		single valve surgery from 2006-2010. Bern University Hospital, Switzerland.	sternal wound infection or DSWI, according to the CDCP classification system. Sternal instability included as a symptom of sternal infection and classification of DSWI.	bleeding, sternal wound infection (deep/superficial), surgical treatment of SWI, VAC therapy, in-hospital mortality.	(OR 3.60, 95% CI: 1.14-11.4); COPD (OR 2.45, 95% CI: 1.29-4.66); diabetes (OR 2.20, 95% CI: 1.27-3.82); female sex (OR 2.26, 95% CI: 1.26-4.04); obesity (OR 1.87, 95% CI:1.06-3.27); second EuroSCORE quartile (OR 2.21, 95% CI: 1.14-4.31) and third EuroSCORE quartile (OR 3.45, 95% CI:1.68-7.09). Isolated Valve procedure Cohort: independent risk factors for sternal wound infection were revision for bleeding (OR 6.85, 95% CI: 2.07-22.64); and diabetes (OR 2.81, 95% CI:1.04-7.60). CABG + Valve Procedure Cohort: independent risk factors for sternal wound infection were revision for bleeding (OR 4.6, CI 1.4-16); and procedure exceeding 300 minutes (OR 3.7, 95% CI: 1.1-13).

Miyahara et al., 2014	Retrospective cohort study	1,374 patients undergoing cardiovascular surgery via median sternotomy. Cohort 1 = Jan 2004-February 2007 (period 1, n=682); Cohort 2= March 2007-February 2012 (period II, n=692). Ichinomiya Municipal Hospital, Japan.	DSWI was defined according to CDCP guidelines.	Comparison of DSWI rate in the 2 cohorts and time periods; identification of risk factors.	The DSWI rate in period II was significantly decreased by 93% compared with period 1 (*p*=0.001). Independent risk factors for DSWI included obesity (OR 3.4, 95% CI: 1.00-11.75, *p*=0.049); the use of 4 sternal wires (OR 8.2, 95% CI: 39-48.14, *p*=0.020); long operative time (OR 4.4, 95% CI: 1.20-16.23, *p*=0.026) and postoperative renal failure (OR 9.0, 95% CI: 2.44-33.30, *p*=0.001).
Nešpor et al., 2015	Retrospective cohort study	9,110 patients who underwent cardiac surgery from 2005-2012. Centre of Cardiovascular Surgery and Transplantations, Czech Republic.	El Oakley and Wright classification for sternal wound dehiscence or early wound infection. Defect classified by the surgeon performing	Risk factors for DSWI (preoperative; perioperative and postoperative).	Risk factors for DSWI were: sepsis (OR 2.68, 95% CI: 2.14-3.22, *p*=<0.001); LIMA graft used (OR 2.13, 95% CI: 1.71-2.54, *p*=<0.001); unstable haemodynamic condition (OR 2.058, 95% CI: 1.96-3.2, *p*=0.003); reintubation (OR 2.04, 95% CI: 1.53-2.55, *p*=0.006); number of valves affected by surgery (OR 1.92, 95% CI: 1.59-2.25, *p*=<0.001);

			revision of the wound.		male sex (OR 1.8, 95% CI: 1.36-2.23, *p*=0.008); history of lung disease (OR 1.73, 95% CI: 1.4-2.06; *p*=<0.001); postoperative inotropic support (OR 1.51, 95% CI: 1.15-1.87, *p*=0.025); BMI>29.2 (OR 1.09, 95% CI: 1.05-1.12, *p*=<0.001) and length of ICU stay (OR 1.001, 95% CI: 1.0001-1.002, *p*=<0.001).
Nieto-Cabrera et al. 2018	Prospective cohort study	N=3970 A logistic model was constructed in a randomly selected subgroup of 2618 patients and validated in a second cohort of 1352, as well as in a prospective cohort of 2615 (6/11-12/15). Ninety-four (2.36%) patients developed mediastinitis.	CDC definition of mediastinitis: an infection involving tissues and spaces underneath the subcutaneous tissue fulfilling at least 1 of the following criteria: positive culture of mediastinal tissue or fluid;	Surgical site infection was monitored during hospital stay and readmissions over 1 year.	Med-score 24 tool designed and validated. The risk factors identified as predictive of mediastinitis (AUROC 0.80) were 4 preoperative variables (age>70 years, chronic obstructive lung disease, obesity, and antiplatelet therapy) and 3 perioperative variables (prolonged ischemia, emergency reoperation, and prolonged intubation). AUROCs for the Society of Thoracic Surgeons

		Hospital Clınico, San Carlos, Madrid, Spain	evidence of mediastinitis during operation or histology; and 1 of the following: fever (38.8_C), chest pain, or sternal instability, as well as either purulent drainage from the mediastinum or mediastinal widening on imaging tests.		score and logistic EuroSCORE were 0.63 and 0.55, respectively, both differing significantly from the area calculated for Med-Score 24 (P<.001).
Pan et al., 2017	Retrospective cohort study	7,944 patients who underwent cardiac surgery via median sternotomy from January 2002-December 2016. Department of Cardiothoracic	DSWI defined according to CDCP criteria.	Occurrence of DSWI and significant risk factors.	Risk factors for DSWI were: BMI (OR 1.08, 95% CI: 1.01-1.16, *p*=0.02); and reoperation (OR=5.93; CI: 2.88–12.25, *p*=<0.01). Patients who underwent reoperation were five times as likely to have DSWI compared with those who

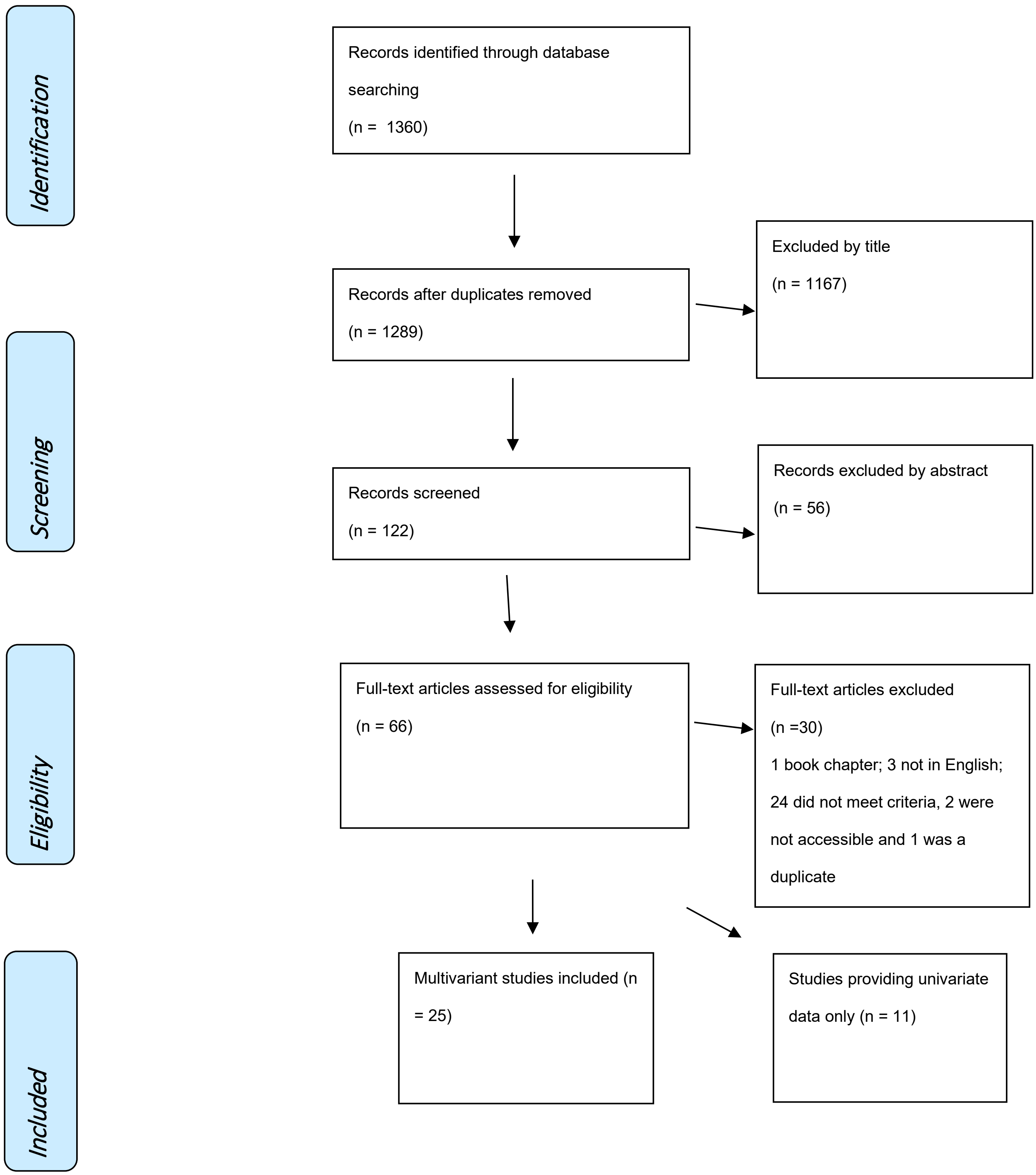
		Surgery, The Nanjing Drum Tower Hospital, Nanjing, China.			did not undergo reoperation.
Perrault et al., 2018	Prospective cohort study	5,158 patients undergoing cardiac surgery between February and October 2010. Cardiothoracic Trials Network Sites, Canada.	Mediastinal infection was defined as DSWI, mediastinitis, pericarditis, or infectious myocarditis according to CDCP/NHSN criteria. All major infections and a subset of minor infections were adjudicated by an event adjudication committee that	Primary outcome: incidence of mediastinal infection (DSWI, mediastinitis; pericarditis; infectious myocarditis). The frequency of DSWI; risk factors and perioperative outcomes of mediastinal infections following cardiac surgery.	Risk factors for mediastinal infection were: higher BMI (hazard ratio HR 1.06, 95% CI: 1.01-1.10, *p*=0.013); higher creatinine (HR 1.25, 95% CI: 1.13-1.38, *p*=<0.001); peripheral vascular disease (HR 2.25, 95% CI: 1.06-4.78, *p*=0.035); corticosteroid use (HR 3.33, 95% CI: 1.27-8.76, *p*=0.015); VAD and transplant operations (HR 5.30, 95% CI: 2.12-13.27, *p*=<0.001) and postoperative hyperglycaemia in nondiabetic patients (HR 3.15, 95% CI: 1.32-7.51).

			included three infectious disease experts.		
Rehman et al., 2014	Prospective cohort study	4,883 patients who underwent cardiac surgery from October 2003 -February 2009. John Radcliffe Hospital, Oxford, UK.	Mediastinitis was diagnosed if at least one of the criteria of the Health Protection Agency (HPA) Surgical Site Infection Surveillance Service / CDCP.	Comparison of pre- and peri-operative risk factors in patients with mediastinitis and patients without mediastinitis.	Mediastinitis was significantly associated with age greater than median age (OR 1.65, 95% CI: 1.08-2.53, *p*=0.02); BMI >30kg/m^2 (OR 2.34, 95% CI: 1.53-3.56, *p*=<0.0001) and concomitant CABG and AVR (OR 2.73, 95% CI: 1.52-5.43, *p*= 0.0019).
Sá et al 2017	Prospective cohort study	1,500 patients undergoing CABG surgery from March 2007-August 2016. Division of Cardiovascular Surgery, Pronto-Socorro Cardiológico de Pernambuco,	DSWI measured according to CDCP criteria.	DSWI following surgical procedure; 27 independent variables monitored prospectively.	Independent risk factors for DSWI were obesity (OR2.58, 95% CI: 1.11-6.68, *p*=0.046); diabetes (OR 2.61, 95% CI: 1.12-6.63, *p*=0.046); smoking (OR 2.10, 95% CI:1.12-4.67, *p*= 0.008); pedicled ITA (OR 5.11, 95% CI: 1.42-18.40, *p*= 0.012) and on-pump CABG (OR 2.20, 95% CI: 1.13-5.81, *p*= 0.042).

		Recife, PE, Brazil.			
Unosawa et al. 2019	Retrospective cohort study	287 patients undergoing cardiac surgery nutritional status assessed. Divided into malnutrition and nonmalnutrition groups. There were 51 patients (17.8%) in the malnutrition group. Nihon School of Medicine, Tokyo, Japan	Sternal osteomyelitis	The postoperative course was evaluated by assessing the following outcomes: duration of intensive care unit stay, duration of hospital stay, infection (sternomyelitis, pneumonia, or septicemia), new initiation of dialysis, mechanical ventilation for ≥3 days, stroke, hospitalization for longer than 1 month,	There were no significant between group differences with regard to the postoperative frequency of sternal osteomyelitis. Mortality rate was significantly higher in the malnutrition group (five deaths [9.8%] vs four deaths [1.8%]; P = .003). In addition, the duration of intensive care unit stay and hospital stay were both significantly longer in the malnutrition group. Multivariate analysis showed that malnutrition was an independent predictor of hospitalization for longer than 1 month (OR:

				bedridden state, and death.	3.428; 95% CI:1.687-6.964, P = .001) and a postoperative bedridden state (OR: 7.377; 95% CI:1.874-29.041, P = .004).
Waldow et al. 2018	Prospective controlled registry	2340 patients divided into four groups. Groups 1&2 wound disinfected with IPA, groups 3&4 IPA-CH, groups 2&4 gentamycin sponge applied. Dresden Heart Centre University Hospital, Germany	Mediastinitis must meet at least one of following: positive culture from blood or mediastinal tissue, evidence of mediastinitis, temperature >38, chest pain, sternal instability with purulent drainage and/or mediastinal widening on imaging.	Freedom from post-sternotomy mediastinitis 30 post-operative days. Second end point: freedom from surgical site dehiscence 30 days post index operation.	There were significant differences in outcome among the groups ($P < 0.0001$). Primary healing was highest in group 4 (91.4%), which showed the lowest rate for mediastinitis (0.9%). Multivariate analysis showed that the use of CHG and a gentamicin sponge was statistically significant ($P = 0.026$ and 0.013, respectively). The other significant independent factors were valve operation ($P = 0.001$), body mass index >30 kg/m2 ($P = 0.001$), preoperative stroke ($P = 0.005$), and blood transfusion ($P = 0.022$).

Figure 1: Flow diagram of study selection



Note: some papers examine more than one variable, therefore the subsequent total is greater than the number of papers from which the data was drawn.

Figure 2: Summary of the risk factors for sternal wound complications from a systematised review of 19 studies (multivariate analyses).

Pre-operative risk factors (reported in 22 out of 25 papers)	Peri operative risk factors (from 12 papers)	Post operative risk factors (from 14 papers)
N= 5 Age N=19 BMI N=6 Gender (5 female, 1 male) N=11 Diabetes (10 DM, 1 DM with BIMA) N=7 Pulmonary Disease N=1 Smoking N=5 Acute/ emergency presentation N=3 Previous sternotomy N=1 Anaemia requiring transfusion N=2 Medications	N=6 Type of procedure (CABG/ Valve/ Combination/Transplant) N=1 Off pump N=6 Arterial grafts – independent or associated with other risk factors N=2 Time in theatre N=5 Method of closure (use of wax, gent, asymmetry, reduced wires) N=1 Peri operative transfusion	N=2 Complicated Recovery, including respiratory complications and prolonged ventilation (n=4), prolonged ITU stay (n=2) and requirement for inotropic/ vasopressive support (n=2), renal failure/raised creatinine (n=3) and sepsis (n=1) N=3 Transfusion N=1 Non-diabetic hyperglycaemia N=5 Reopening N=2 Post op wound