Disruption and infection of median sternotomy: a comprehensive review

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Summary

Disruption and infection of median sternotomy wounds are grave complications often associated with prolonged hospitalization, high cost, and significant mortality. Effective prevention techniques are still debated. Successful management requires early recognition based on a high index of suspicion, detailed physical examination, appreciation of the clinical signs and symptoms, timely imaging studies, and prompt surgical therapy. Improvements in perioperative management and critical care of patients with multisystem organ failure can reduce morbidity and mortality rates. Sternal salvage and direct sternal reclosure are possible when the infection is diagnosed early. Techniques utilizing lateral sternal support should be first-line options in the condition. Muscle flap techniques should be the next consideration when direct closure has failed or cannot be attempted. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Disruption and infection of median sternotomy wounds are grave complications, occurring in 0.3–5% of cases [1]. The problem is associated with a mortality rate between 14 and 47% [2], usually secondary to underlying mediastinitis, a complex condition with widely variable features [3].

The most effective prevention methods for sternal wound dehiscence continue to be debated. Our review was undertaken to clarify the still controversial and perplexing issues of cause, prevention, early diagnosis, and effective therapy.

2. Preoperative risk factors

Preoperative risk factors for sternal wound dehiscence include diabetes mellitus, chronic obstructive airway disease, obesity, and smoking [4–8]. Obesity, particularly in diabetic women [4,5], is considered a major risk factor. Other studies found that pulmonary illness, particularly chronic obstructive airway disease, reduced forced expiratory volume in 1 s/forced vital capacity ratio (FEV1/FVC), and smoking raised the incidence of sternal wound complications to levels associated with obesity and insulin-dependent diabetes mellitus [6,7]. Recent multivariate models were developed to compute the risk for sternal complications, but the models ultimately provided low sensitivity and low predictive value [8]. Copeland et al. [9,10] first reported that larger female breast size was associated with higher incidence of median sternotomy dehiscence. Based on multivariate analysis, this group found that large and medium bra cup sizes were associated with an increased risk for deep sternal wound infection after median sternotomy [10]. Incredibly, this finding initiated serious consideration of reduction mammoplasty as a viable option in treating deep sternal infection [11].

3. Perioperative risk factors

Prolonged bypass time is common among patients who go on to develop sternal dehiscence [6]. Considerable attention has been directed toward cases in which one or two internal thoracic arteries (ITA) have been used for myocardial revascularization, with subsequent sternal devascularization and related morbidity. Arnold’s early and extensive study [12] noted the frequency of antecedent sternal ischemia or necrosis incurred during surgery in cases of subsequent wound infection. He concluded that (1) the arterial blood supply of the adult human sternum is derived solely from its periosteal plexus, fed by segmental sternal branches of the ITA, (2) no collateral blood supply to cortical sternal bone is available after obliteration of the periosteal arterial plexus, and (3) complete bilateral mobilization of the ITA up to the subclavian arteries renders the entire bone relatively avascular [4]. The importance of common sternal/intercostal trunks was later realized [13].
suggested that their ligation close to the points of ITA origin may facilitate new collateral blood supply to the sternum following either unilateral or bilateral ITA mobilization through anastomotic tributaries to both the posterior intercostal arteries and the pectoral branches of the thoracic acromial arteries. It is possible to preserve the common trunks at a length of 3 mm and external diameter of 0.9 mm, but it is also important to ligate the trunks close to their origin; in this way a retrograde blood flow from the posterior intercostal arteries and the pectoral branches of the thoracoacromial axis is redirected toward the sternal branches to avoid devascularizing the sternum [14].

Nevertheless, clinical scientists still debate the safety and effectiveness of harvesting the ITA. A multivariate logistic regression analysis identified obesity, prolonged mechanical ventilation, and bilateral ITA grafts as significant risk factors for sternal infection [15]. These findings were supported by independently working teams [7,16], though a subsequent large trial reported that multiple ITA bypasses can be done without excessive morbidity [17]. Most convincing was a study of 6504 consecutive patients with no significant differences in wound complication rates whether none, one, or two ITA grafts were used [5].

Two recent studies [18,19] demonstrated that excessive bone wax, when used with diathermy, can inhibit wound healing. Other hemostatic methods [20] and avoidance of excessive diathermy [17] were thought to improve results.

Questions remained about the precedence of sternal separation or infection. Inspiration creates slight suction on the wound edges if the sternum is separated, permitting exogenous bacteria to contaminate the mediastinum. Suboptimal sternal closure should therefore be considered a significant intraoperative risk factor [21,22].

4. Postoperative risk factors

Transfusions [7], surgical chest reexploration [6,7], prolonged postoperative ventilation [4,6], and longer stay in the ICU [6] have all been more common among patients who developed dehiscence. A univariable and multivariable analysis in a retrospective group of 3435 sternotomies found that positive wound culture is a strong indicator of rewiring failure [23]. A recent study found higher rates of both mediastinitis and mortality when recovering coronary bypass patients required tracheostomies [24].

5. Prevention and prophylaxis of sternal wound infection

The current recommendations for prevention of surgical site infection represent the consensus of the Hospital Infection Control Practices Advisory Committee (HICPAC) regarding the available prophylactic strategies [25]. This document fails to clearly validate particular risk factors and prevention measures for sternotomy infections, and provides little confirmatory scientific information; the recommendations are based on a strong theoretical rationale and suggestive evidence. A recent study utilizing DNA fingerprint analysis determined an endogenous pathway for severe sternal wound infection and suggested a change in prophylactic interventions [26]. Controlling the bacterial colonies in the nose [27] and operative field [28] have recently been proposed as useful strategies for reducing surgical infection risk in open cardiac surgery.

Prophylactic administration of antibiotics is a standard, though still controversial, practice in cardiothoracic surgery [2]. Three consecutive surveys of antibiotic use patterns in the United States indicated that most hospitals continue to use first-generation cephalosporins, with considerable variation among institutions regarding critical scrutiny of regimen changes [29]. The therapeutic guidelines by the American Society of Hospital Pharmacists Commission on Therapeutics [30] most closely approach the actual state of affairs in cardiac surgery worldwide. The Society recommends that cefazolin 1 g i.v. every 8 h, or cefuroxime 1.5 g i.v. every 12 h be given for 48–72 h, or until chest and mediastinal drainage tubes are removed. Cefamandole and cefalothin are suitable alternatives [30]. Because there is insufficient data on the safety of cephalosporins in infants under 1 month of age, ampicillin (50 mg/kg every 6 h for a total of four doses) and gentamycin (2.5 mg/kg every 8 h for a total of three doses) are used; children older than 1 month should receive cefuroxime 50 mg every 8 h for three doses [29].

Pericardial and retrosternal suction drains are known to facilitate drainage of blood and serous fluid; it has been suggested that they might lower the deep sternal infection rate [31]. A recent randomized controlled trial in patients undergoing median sternotomy showed no significant differences between the rates of major wound infection or the incidence of postoperative pericardial effusion assessed by echocardiography [32].

6. Diagnosis/definition of infection and use of imaging methods

For purposes of consistency and standardization, we apply the term sternal infection as defined by the standardized Centers of Disease Control (CDC) surveillance criteria [25]. Sternal infection involves the layers beneath the skin and subcutaneous tissue, and is therefore of the deep incisional variety; further involvement of the mediastinum is defined as an organ/space surgical site infection [25]. The CDC criteria for a deep incisional infection include purulent drainage from the deep layer, surgical revision or dehiscence on the background of fever, localized pain, or tenderness, and an abscess or other observable evidence of infection on direct examination, histopathology, and radiology. The criteria for an organ/space infection include purulent drainage, positive microbiology, and an abscess or other observable evidence of infection [25].
Clinical diagnosis of sternal separation and/or infection is usually based on local findings of sternal instability, erythema, fluid collection, wound dehiscence and purulent discharge [33]. Objective and subjective feelings of throbbing and looseness of the repair should be heeded [34]. Systemic signs, such as pyrexia or leucocytosis, support the diagnosis. Daily evaluation and a high index of suspicion are essential. Mediastinitis should always be considered in cases of slow postoperative recovery [2]. No single test can make or exclude the diagnosis.

X-Ray examination of the sternum can demonstrate ruptured wires, sternal dehiscence, wire malposition, fracture, and pseudoarthrosis [35]. Subtle or gross changes in the position of the wires on postoperative X-rays will suggest sternal separation [36]. CT scan delineates changes in bone configuration, distinguishes insignificant from major infection [37], and accurately depicts extent and depth [38]. Any persistent or recurrent collection suggests localized sepsis, and CT-guided needle aspiration can help determine whether a fluid collection is infected and in need of further treatment [39]. Radionuclide scanning, though controversial and infrequently used, can be a useful diagnostic tool. A prospective study found that $^{67}$Ga radionuclide scanning had a sensitivity of 83% and specificity of 96% [40], but another recent trial demonstrated that a bone-gallium scan was unhelpful in directing mediastinitis therapy [41].

7. Microbiology and antibiotic treatment

Patients with sternal infections may be identified indirectly through data records and complex prediction scales [42]; the latter methods may reach sensitivity and specificity of more than 80 and 90%, respectively [25]. The identification of infection is sometimes difficult and requires an examination for sternal instability and classical inflammatory signs such as local hyperthermia (calor), redness (rubor), and pain (dolor), laboratory investigations including blood cultures, and imaging (CT and MRI). With the diagnosis made, the patient is promptly brought to surgery; early interventions correlate with an improved outcome [43]. Patients with suspected infection are submitted to CT-guided aspiration of the inflammatory collection which can help to avoid diagnostic and therapeutic delay [44].

The wounds are cultured intraoperatively and two to three times a week during the hospitalization. Cultures are taken from healthy tissue margins, bone, cartilage, and muscle as well as from pus and debris. After surgery, the tips of removed drains are cultured, too. If not completely healed at the time of hospital discharge, wounds are cultured during outpatient visits until healing is complete [45].

The bacteriology of mediastinitis is highly variable. *Staphylococcus aureus* emerges as the most common pathogen (29%), followed by *Staphylococcus epidermidis* (22%); it has been postulated that a strict review of positive cultures, prolonged antibiotic use, outbreaks, and selection biases may be associated with unusually high frequency of other pathogens such as *Pseudomonas aeruginosa* [45]. Relatively frequent pathogens are methicillin-resistant staphylococci and streptococci, facultative and aerobic Gram-negative rods, and anaerobes. There is a high risk for clusters at a given hospital [46,47]. The virulence of anaerobes in deep sternal infections adds a requirement for both appropriate cultures and effective antibiotic coverage [48]. The bacteriologic results should be interpreted in the context of the patient’s medical history, clinical information, dates of cultures, types of specimens, details of direct Gram-stained smears, type of microorganisms and their antimicrobial susceptibilities, and chronological tables of antimicrobial therapy. The medical records of all previous hospitalizations should be reviewed, with consideration of the infection history, culture results, and antibiotic therapy [45].

The initial antimicrobial therapy is empirical and may be tailored to the results of Gram-stained smears and/or previous cultures. Patients in a stable condition may have their antibiotic therapy temporarily discontinued, with cultures taken from the wounds, blood, and sputum guiding subsequent antibiotic adjustment; septic patients demand continuation or reinstitution of previously prescribed antibiotic therapy based on existing culture results [45]. The empirical regimen should include agents active against a range of Gram-negative organisms (aminoglycosides or carbapenems or cephalosporins with anti-pseudomonal activity), an agent active against methicillin-resistant Gram-positive organisms (vancomycin), and metronidazole [46]. Fungal mediastinitis should be considered, especially after failure of antibiotic mediastinal irrigation or long-term antibiotics used for a low-grade bacterial infection [49]. The antimicrobial therapy during the subsequent hospital course is dynamically guided by the antibiotic susceptibility tests. One of the most important determinants of outcome is how early treatment with effective agents is begun. Conversion of an inadequate empirical regimen to adequate treatment guided by culture results should be avoided [46]. The duration of antibiotic treatment is influenced by the wound culture results and by the clinical picture dynamics [43,45].

8. Surgical management of mediastinitis

Superficial infections are treated by simple incision, drainage, and open dressing changes. Deep sternal wound infections are harder to manage. Several approaches have been used.

Until the mid-1960s, the preferred treatment for a mediastinal infection was to leave the wound wide open following initial debridement, with frequent dressing changes to promote granulation and secondary wound closure. Patients suffered significant physical and psychol-
gical stress with this slow technique, and there was frequent need for reoperation. With persisting infection and wound failure, mortality was 22% and hospital stay averaged 49 days [50]. The time required for granulation tissue to cover the mediastinum was lengthy, and the profoundly stressed patients usually experienced an unstable long-term result.

In 1963, Schumaker and Mandelbaum [51] first described the technique of debridement, sternal reclosure, and mediastinal antibiotic irrigation. The method was a significant advantage in the treatment of mediastinitis [52], but morbidity and mortality rates remained elevated [53]. Among the disadvantages of this technique were limitations on patient mobility, slower rehabilitation, toxicity of iodine used for lavage, fungal overgrowth, and fungal mediastinitis secondary to prolonged local antibiotic administration [50]. More recently, an effective refinement in the technique of continuous mediastinal irrigation was described, including a deep set of tubes positioned behind the sternum, and a superficial set of drains positioned between the sternum and the skin [54]. Deep and superficial irrigation-suction was used in 16 patients with poststernotomy mediastinitis. There were no treatment failures or recurring infections, and no deaths among the patients who were treated uniformly for 7 days. None showed postoperative sternal instability. The authors stressed the value of antibiotic solution for lavage, rather than iodine or other local antiseptics which are toxic and ineffective in controlling infections [54]. Continuous mediastinal lavage remains a valid option at the turn of the millenium [55]. Other new techniques have been explored. Because the greater omentum’s rich blood supply and lymphatic vascular network rapidly improves the condition of the wound, it is an excellent choice for the management of sternotomy wounds in patients with acute mediastinitis and/or loss of overlying bony tissue [56–60]. There is usually a good ‘take’ of the flap [61], but the procedure has a high morbidity rate. Donor-site complications resulting from omental transposition include abdominal wall herniation in 20%, hematoma in 8%, and seroma in 4% [59]. Moreover, there is substantial risk of bacterial contamination of the abdominal wound and ileus in the long term.

Muscle flap use expands on the concept of tissue transposition, based on the theoretical assumption that well-vascularized muscle can fill dead space while controlling and eliminating infection [34]. The type of muscle flap selected is based on availability and status of vascularization [62]. The first option is usually pectoralis major flaps for defects located over the superior and middle thirds of the sternum [63]. Turnover flaps based on the perforating branches from the ITA [24], advancement flaps based on the blood supply from the thoracocromial vessels [64], and bilateral flaps to achieve a tension-free muscle opposition [65] have been advocated. Flap choices may be influenced by various clinical situations, individual preferences, and experience. In this respect, turnover flaps [66], or advancement flaps regardless of the status of its perfusion by the ITA [65] have been advocated as reasonable first choices. The turnover flap produces a concavity at the donor site and a prominence at the pedicle site; pectoralis flaps are generally smaller and may not reach the lowest portion of the wound [34]. A single-stage management of sternal wound infection, consisting of debridement and immediate closure with pectoralis musculocutaneous flaps, was compared to either secondary closure, antibiotic irrigation, or delayed muscle flap closure. The debridement and closure technique was associated by this group with shorter hospital stay, fewer reoperations, and simplified patient management [50]; these conclusions were confirmed by others [67]. Collagenous gentamycin has been described as useful when added to the technique of sternal rewiring, retrosternal suction drainage, and bilateral pectoralis major muscle flaps to reduce treatment failure and resultant death [68].

The vertical rectus abdominis flap requires the ITA for perfusion, but if transposed as turnover flap after ITA harvesting it receives collateral circulation from intercostal vessels. The transposition may result in hernia formation if the rectus abdominis sheath is not properly closed. A 3.3% complication rate was described using this approach [66], but others reported a substantial number of patients with both osseous instability and abdominal weakness [69]. More recent studies described good results with rectus abdominis free flaps [70], and myocutaneous latissimus dorsi flaps as an element of a single-stage approach to deep sternal wound infection [62].

Many investigators have concluded that muscle transposition is the clear treatment of choice for most patients with sternal and mediastinal infection [23,71,72]. Nevertheless, criteria for the suitability of one group of patients or another for a specific type of treatment have not been agreed upon. Several classification systems have addressed the issue [2,62,64]. The simplest and perhaps the most rational was designed by Pairolero and Arnold [64]. They stressed the suitability of the muscle transfer method for obliteration of the dead space after surgery for either ‘fulminant’ mediastinitis or a chronically infected sternotomy wound.

Closure of the pericardium at the original operation is an important issue in resternotomy and mediastinal exploration for sternal fusion problems or mediastinitis. The pericardium is left open to compensate for presumed decreased left ventricular filling, or to address the risk of cardiac tamponade should postoperative intrapericardial bleeding occur. These are relatively common considerations in high-risk, emergency cardiac surgery patients. Proponents of pericardial closure claim that it results in a greater retrosternal distance, minimal adhesions between the heart and the sternum, maintenance of the heart’s native geometry to preserve left ventricular function, and facilitated sternal reentry [73]. Resternotomy for deep sternal wound infection or poststernotomy mediastinitis may result in myocardial injury if the pericardium has been left open, with the right ventricle adhering to the posterior sternal table [74].
pericardial integrity should be considered and preserved to avoid myocardial injury at resternotomy.

9. Primary closure of the sternum

Techniques resulting in a divided sternum have several obvious disadvantages, including pain and discomfort in the chest and shoulder, instability, postoperative weakness, and respiratory problems [65,69]. A variety of primary sternal closure techniques at reoperation have been devised to avoid these problems. Robicsek et al. [75] described a method of creating lateral and longitudinal wire support that stabilizes the sternum if it is fragile or broken, or if subsequent instability develops secondary to dehiscence. A heavy thread of wire is passed in and out of the cartilages on both sides of the sternum to laterally support the repair. Peristernal sutures are then placed around and outside these bilateral wires (Fig. 1). A modification of this technique by combining it with pectoralis major advancement flaps achieved excellent results [76]. Longitudinally oriented paramedian bone plates with conventional circular wire closure over the plates [77], transsternal longitudinally oriented Kirschner wires, and sternotomy closure with interrupted wires [78] have been successfully used for longitudinal support to achieve bone stability. Loosening of the Kirschner wires has nevertheless been reported [75].

A basically new approach to sternal reclosure utilizes the Knodt compression system for gradual approximation of the sternum until firm sternal fixation [79]. Successful use of Harrington compression rods inserted at the chondrocostal junctions has also been described [80,81]. The value of the orthopedic approach in achieving stable sternal union was investigated based on the hypothesis that rigid fixation would speed bony healing across the linear sternotomy. In a study involving 14 skeletally mature baboons, seven sternotomies were closed with interrupted cerclage wires and seven with Vitalium compression miniplates and transverse lag screws. Histomorphometric analysis showed that rigid fixation of the sternum resulted in earlier union with primary osseous healing, thus suggesting greater inherent stability [82]. A subsequent study used titanium miniplates in 24 patients with postoperative mediastinitis, and in an additional five patients considered at high risk for mediastinitis. Bony union was obtained in 27 patients (93%). The study concluded that by using concepts of quantitative microbiology and rigid osteosynthesis techniques, sternal salvage could be safe and effective in selected patients [83]. An extensive study of rigid fixation techniques using human cadaveric sterna explored the properties of both straight and \( H \) plates in the circumstances of repetitive cyclic loading. \( H \) plates were associated with less flexibility and a lower lateral displacement than straight plates and cerclage wires [84]. Improved restoration of sternal stability using parallel stainless steel mandibular reconstruction plates was recently reported. In a group of patients with sternal wound problems, 14 had mediastinitis and/or osteomyelitis and 16 had sternal dehiscence without infection. Three patients had hardware removed following periplate infection and one when hardware loosened. Wound closure was achieved in all 30 patients, with sternal stability ultimately restored in 29 [85].

Use of Parham bands in addition to conventional wires was noted to achieve primary sternal healing after debridement and catheter irrigation for mediastinitis. The security of this type of closure was based on the wider area of contact between cortical bone and the bands, and on the tight closure achieved with the help of a band applicator [86]. These good results were not replicated with nylon bands [87]. A recent study enrolled 1039 patients in whom Mersilene tape (Ethicon) for reinforcement of stainless steel wire was used for closure of the sternum. The incidence of wound morbidity was 2.4%; six patients had sternal dehiscence (0.58%) and 19 had sternal wound infection. The authors concluded that dehiscence occurred in a more controlled fashion and with less bony destruction when Mersilene tape was used [88]. A very low closure failure (6%) was observed with Dexon (Davis & Geck) peristernal closure in patients with sternotomy wound dehiscence [89].

Pericostal wire closure techniques rely upon the costal cartilages outside the operative area. The usual figure-of-eight loops that are placed around the costal cartilages have been modified by surgeons to facilitate the technique or to achieve better wound stability. One of these modifications involves placing bilateral chains of parasternal wire sutures [90,91]. Corresponding chains were tied together, creating a weave similar to that described by Robicsek et al. [75]. Redistribution of forces across the sternotomy is described as ‘pericostal’ instead of ‘peristernal’ (Fig. 2). A modification of the figure-of-eight pericostal closure technique of Ref. [93] was found especially useful in encompassing fracture sites (Fig. 3) [92].

Other techniques for stable closure of sternotomy, each with inherent advantages and disadvantages, include VAC vacuum pump and a transparent adhesive drape (KCL International, San Antonio, TX) to achieve a vacuum-assisted wound closure [94,95], thoracic traction [96], threaded

Fig. 1. Diagrammatic presentation of the peristernal weave described by Robicsek [75].
transverse Kirschner wires [97], pericostal guy wires [98], peristernal plating [99], poly-lactic-acid sternal pins [100], Cotrel staples [101], and autologous ribs [102,103]. Because the bone density, defects, and fracture lines of each individual sternum are different, more than one technique can be combined to suit particular characteristics.

10. Conclusion

Optimal sternal closure will preclude sternal dehiscence in most cases [17]. A high index of postoperative suspicion, detailed physical examination, and attention to clinical signs and symptoms and imaging results promote early recognition of sternal instability and/or mediastinitis [102]. Improvements in perioperative management [104–107] and critical care of patients with multisystem organ failure [102] can limit morbidity and mortality.

Early recognition facilitates sternal salvage and potential direct sternal reclosure. Techniques utilizing lateral sternal support, especially Robicsek’s technique [72], should be first-line options. Impossible or failed direct sternal closure suggests that muscle flap techniques should be considered, depending on flap availability and the surgeon’s experience. Omental transposition should probably be reserved as a last option because its risk is high despite well-known advantages [108]. Current management refinements have not significantly reduced the incidence of infection over the past 20 years. New therapeutic and prophylactic methods such as immunoglobulin administration [51] might prove beneficial, but have not thus far been sufficiently tested in randomized trials [109,110].

References


