Impact of deep sternal wound infection management with vacuum-assisted closure therapy followed by sternal osteosynthesis: a 15-year review of 23,499 sternotomies

Richard Baillot a,*, Daniel Cloutier a, Livia Montalin a, Louise Côté c, François Lellouche b, Chanel Houde a, Geneviève Gaudreau a, Pierre Voisine a

a Departments of Cardiac and Plastic Surgery, Laval University, Quebec, Canada
b Research Center, Laval Hospital, Quebec, Canada
c Department of Medical Biology, Laval University, Quebec, Canada

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Abstract

Objective: This study was undertaken to examine the outcome of patients with deep sternal wound infection (DSWI) now treated with vacuum-assisted closure (VAC) therapy as a bridge to sternal osteosynthesis with horizontal titanium plate fixation. Methods: From 1992 to 2007, a consecutive cohort of 23,499 patients underwent open-heart surgery (OHS) in our institution. The period under study was divided in two according to the use of therapeutic modalities: conventional (1992–2001, N = 118 DSWI): debridement/drainage with primary closure and irrigation (N = 37), debridement/drainage, open packing followed by pectoralis myocutaneous flaps (PMFs) (N = 81); contemporary (2002–2007, N = 149 DSWI): conventional treatment (N = 24) and VAC therapy (N = 125/83.8%). VAC was followed by sternal osteosynthesis with horizontal titanium plates in 92 patients (61.7%). Results: DSWI was diagnosed in 267 out of 23,499 (1.1%) patients of our entire series according to Center for Disease Control—Atlanta (CDC) criteria, 118 out of 13,180 (0.9%) in the first and 149 out of 10,319 (1.4%) in the second period (p = 0.001). Hospital mortality (N = 267/23,499) has been 10.25% for the entire cohort under study without any difference between groups (1992–2001: 11.4%; 2002–2007: 9.1%, p = 0.67). More recently, VAC therapy (N = 125) was associated with a lower mortality (4.8% vs 14.1%, p = 0.01). Stepwise multivariable logistic regression analysis for both periods revealed that prolonged intubation in the intensive care unit (ICU), use of bilateral internal thoracic artery grafting (BIMA), diabetes, re-operation for bleeding and body mass index (BMI) >30 kg m² are the most powerful predictors of DSWI. In the more recently treated patients using VAC therapy, combined procedures (valve and graft) also emerged as a significant predictor. For the entire study, Staphylococcus epidermidis (49.6%) has been the most frequently identified pathogen, followed by Staphylococcus aureus (38.8%). Methicillin-resistant S. aureus (MRSA) was observed in 4.9% of the cohort. Neither of these bacteria was associated with increased mortality. Survival analysis with Cox regression model and propensity score adjustment in patients with DSWI showed freedom from all-cause mortality at 1, 5 and 10 years to be, respectively, 91.8%, 80.4% and 61.3% compared with 94.0%, 85.5% and 70.2%, respectively, for patients submitted to OHS without DSWI (p = 0.01). Early adjusted survival for patients with DSWI treated with VAC therapy was 92.8%, 89.8% and 88.0%, respectively, at 1, 2 and 3 years, compared with 83.0%, 76.4% and 61.3%, respectively, for patients with DSWI treated without VAC (p = 0.02).

Conclusions: DSWI remains a major and challenging complication of OHS. VAC therapy with sternal preservation followed by delayed sternal osteosynthesis with PMF has been recently proposed as a new therapeutic strategy. Most patients treated with VAC therapy in our second group showed decreased perioperative mortality and increased short-term survival.

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Keywords: Mediastinitis; VAC therapy; Sternal osteosynthesis

1. Introduction

...Prevention and better treatment of sternal wound complications must be a major goal in assuring the highest quality of cardiovascular surgical care...


Postoperative deep sternal wound infection (DSWI) with sternal dehiscence following sternotomy remains a worrisome and challenging complication of open-heart surgery.
logical distress, and is still associated with prolonged hospital stay and an estimated mortality of 10% [1]. There is a lack of consensus in the literature regarding the optimal surgical management.

The present report of our surgical experience stands from January 1992 to December 2007 and covers a 15-year period during which demographic characteristics and co-existing conditions of patients submitted to OHS have changed rapidly. Treatment modalities of DSWI have evolved as well during these years in our tertiary centre, from debridement with open packing and drainage to close irrigation with primary rewiring, followed by the introduction of pectoralis myocutaneous flaps (PMFs). Vacuum-assisted therapy (VAC) as a first-line of treatment [2] (KCI®) with delayed sternal osteosynthesis with horizontal titanium plate fixation (Synthes®) covered with PMF flaps has recently been proposed to improve clinical results and to deal with complex sternal infections and multiple sternal fractures [3]. The objective of this study was to analyse the early clinical results and mid-term impact on survival for patients managed with these newly introduced treatment modalities. Secondary objectives were to identify the predictors of DSWI and determine the changes of DSWI incidence over time.

2. Materials and methods

Between 1992 and 2007, 23,499 patients from the Institut Universitaire de Cardiologie et de Pneumologie de Québec (Hôpital Laval) were submitted to OHS. Patients undergoing thoracic aortic surgery or heart transplantation as well as congenital cases were all excluded from the present study. Data obtained from medical discharge records were entered prospectively in a computerised surgical database by trained personnel and DSWI adjudicated as an endpoint according to the presence of the Centers for Disease Control and Prevention (CDC) criteria [4]: bacteria had to be identified from blood culture, from purulent discharge from the mediastinum and sternal instability and/or dehiscence with bone or cartilage destruction observed during re-exploration as well as systemic signs of infection (fever >38 °C and leucocytosis). The El Oakley classification was also used [5]. Superficial infections limited to the anterior table without bone or cartilage destruction observed during re-exploration are usually classified as DSWI type 1 (CDC) with delayed sternal osteosynthesis with horizontal titanium plate fixation system, covered with PMF flaps. Osteosynthesis was preferred to restore sternal stability instead of conventional rewiring or parasternal weavement.

Table 1: Population under study.

<table>
<thead>
<tr>
<th>Period</th>
<th>N</th>
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<tbody>
<tr>
<td>1992—2007</td>
<td>23,499</td>
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1. Retrospective
   - From 1992 to 2001
     - DSWI: 118 (0.9%)
     - MF: 81 (66.6%)

2. Prospective
   - From 2002 to 2007
     - DSWI: 149 (1.4%)
     - Non-VAC + MF: 24 (16.1%)
     - VAC + MF: 33 (22.1%)
     - VAC + osteosynthesis + MF: 92 (61.8%)
     - VAC therapy: 125 (83.5%)

Population divided according to treatment modalities. DSWI: deep sternal wound infection; MF: muscle flaps; VAC: vacuum-assisted therapy.

A continuous mean pressure of –75 to 125 mmHg was routinely used with the VAC polyurethane foam, and the sponge was sealed with an adhesive film. Sternal reconstruction was planned according to the presence of adequate granulation tissue, normalisation of white blood cell count, low C-reactive protein level (<60 mg l⁻¹) and repeated wound cultures.

In our set-up, the VAC sponge was changed 3 times a week under aseptic conditions and light sedation, mostly on the main surgical ward, and further debridement performed in the operation room (OR) at least once a week and/or as needed. The use of VAC therapy allowed full patient mobilisation and prepared them for sternal reconstruction; chest physiotherapy was routinely ordered and nutritional status optimised before plating.

While the chest is left open, special attention is allotted to the underlying right ventricle and vascular conduits in case of incomplete pericardial adaption: all vascular structures should be covered by mediastinal tissues, thick paraffin gauze or saline polyurethane sponge to prevent cardiac rupture or laceration of conduits by contact with the sharp sternal inner table edges [6].

Sternal reconstruction is performed after further debridement and the PMFs are elevated bilaterally to the level of the mid-clavicular line with minimal dissection of the subcutaneous tissues. The edges of the manubrium and the...
The graphical representations of martingale and deviance residuals versus risk scores did not suggest any potential outliers. The results were considered significant with p-values <0.05. The data were analysed using the statistical package SAS v9.1.3 (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Patients' characteristics

As shown in Table 2, demographic characteristics of the 23 499 patients submitted to OHS have changed over the study period from 1992 to 2007. The prevalence of co-morbidities often associated with an increased risk of DSWI, such as older age, diabetes and obesity (defined as a BMI over 30 kg m⁻²) was significantly higher in more recent years. Interestingly, despite an associated higher prevalence of hypertension, tobacco use and a history of stroke were less often seen in these patients. Accordingly, DSWI incidence was also significantly higher in the later period, as the diagnosis was made in 118 of 13 180 patients (0.9%) undergoing surgery between 1992 and 2001, compared with 149 out of 10 319 patients (1.4%) during the second period extending from 2002 to 2007 (p = 0.001), for an overall incidence of 1.1% (267/23 499 patients) in the entire study.

Among the 267 patients presenting with DSWI, 205 (76.7%) had undergone coronary artery bypass revascularisation, 34 (12.7%) combined valvular and coronary bypass procedures, 14 (5.2%) isolated valvular procedures and 14 other mixed procedures.

3.2. Risk factors

When compared with the remaining uncomplicated patient population, patients with DSWI were older (65.8 vs 63.8 years, p = 0.003), had a higher BMI and were almost twice as often diagnosed with diabetes, COPD and chronic renal failure (Table 3). Multivariate analysis for both periods under study revealed that perioperative variables such as prolonged intubation time in the ICU, BIMA grafting and re-operation for bleeding were the most powerful predictors of DSWI. Diabetes, obesity with BMI > 30, COPD, peripheral vascular disease and age were also associated with an increased risk (Table 4). Combined procedures emerged as a
significant predictor of DSWI, but only in the more recently treated patients.

For the entire study, the most commonly identified offending microorganisms associated with DSWI were from the normal skin flora and included mostly the *Staphylococcus* species. Among them, 13 out of 267 (4.9%) were caused by methicillin-resistant *Staphylococci*. *Staphylococcus epidermidis* was the most frequently reported pathogen, identified in 45% of our patients. In our study, mortality was not influenced by the sub-species involved (6.68% vs 9.28% for *S. epidermidis* and *S. aureus*, respectively, *p* = NS).

### 3.3. Therapeutic approaches

Treatment modalities for the first group, extending from 1992 to 2001, mainly included conventional therapy consisting of open packing and re-closure, with PMF advancement used in 81 of 118 (68.6%) patients. In the second group of patients undergoing surgery between 2002 and 2007, VAC therapy was progressively introduced and eventually applied to a total of 125 patients (83.8%) of that cohort (Fig. 2). Pectoralis major flap advancement was also used in all these patients, as a sole adjunct therapy (33 patients, 22.1%) or in combination with horizontal titanium plate fixation (92 patients, 61.8%).

Demographic and perioperative characteristics of patients with DSWI treated with or without VAC therapy for the entire period under study were analysed. Apart from a higher prevalence of combined procedures in patients treated with VAC, there were no significant differences between the two groups. As shown in Fig. 3, the percentage of patients treated with horizontal titanium plates after the use of VAC therapy progressively increased over time and now reaches up to 92% of these cases. There was no patient treated with VAC as a destination therapy in our study.
3.4. Outcome

The median hospital stay for patients with DSWI was 21 days for the entire study period, while the mean duration of VAC therapy was 15 ± 7.7 days.

Early adjusted hospital mortality for DSWI patients was 10.25% for the entire period under study, without significant differences between groups treated in the earlier and later periods (1992—2001: 11.4%; 2002—2007: 9.1%, p = 0.67). However, patients from the latter group in whom VAC therapy was applied fared much better than non-VAC treated patients, with a significantly lower in-hospital mortality rate (4.8% vs 14.1%, p = 0.009 per propensity score analysis).

Timing of presentation also had a significant impact on perioperative mortality. Most of our DSWI patients were seen within 3 weeks of their initial surgery (median 16 days of incubation) and classified as Oakley sub-types IIIa and IIIb. The mortality for patients presenting with an earlier diagnosis of DSWI, made less than 16 days after their initial surgery, was much higher than for those with later presentations (16.5% vs 2.8%, p = 0.0001).

Unadjusted and adjusted survival analyses realised with a Cox regression model and mean propensity score in patients with DSWI showed 1-, 5- and 10-year survival rates to be 91.8%, 80.4% and 61.3%, respectively, compared with 93.0%, 76.4% and 61.3% for non-VAC patients (p = 0.02, Fig. 4a and b).

DSWI recurrences occurred in 9 of 92 (9.7%) patients treated with the titanium plate fixation system, as a result of persistent or recurrent infection. Three of them were preoperative MRSA carriers. In these patients, the infectious process was mostly well circumscribed and involved a cartilage. Appropriate antibiotherapy and complete hard-ware removal along with costochondral debridement resulted in preservation of chest-wall integrity and survival in all patients.

4. Discussion

Infection rates in US acute-care hospitals are increasing in the recent years. In a review of 750 million hospitalisations over a 22-year period, Martin et al. [7] report an annualised
increase of 8.7% in infections, mainly due to higher incidences of Gram-positive bacteria sepsis. In our series, a small but statistically significant increase in the incidence of DSWI was observed as well between the earlier and later periods, but our infection rate remained comparable with that of the recently published large series [22,23]. The changing demographic characteristics of the ageing North American population that submitted to OHS reveals that the hypertension—diabetes and obesity epidemic is rapidly replacing the tobacco—cholesterol model previously associated with arteriosclerosis. These characteristics, as well as the increasing percentage of combined (valve and graft) procedures performed in the more recently operated patients, could partly explain the higher incidence of infections observed in our study, as they were found to be the most powerful preoperative predictors of DSWI. Despite more important co-morbidities and higher incidences of infections in these patients, we found a decrease in perioperative mortality associated with the introduction of newer treatment modalities including VAC therapy and osteosynthesis.

4.1. Risk factors

By multivariate analysis, the most important perioperative predictors of DSWI were prolonged intubation in the ICU, BMI grafting, diabetes, re-intervention for bleeding and obesity with BMI above 30 kg m⁻².

Prolonged intubation with positive intrathoracic pressure is associated with disruptive forces generated by the ventilator and splanchnic hyperperfusion, which could predispose patients to bacteraemia. Internal mammary arteries (IMAs) provide the main blood supply to the sternum, and IMA harvesting is a well-described source of reduction in sternal blood flow [8]. Diabetes has been associated with a two- to threefold increase in infection rates after cardiothoracic procedures, and poor intra-operative blood glucose control is also associated with increased perioperative morbidity and mortality [9]. Early re-opening of the chest for bleeding and the immunosuppression associated with multiple transfusions have long been recognised as predictors of DSWI. Careful haemostasis, along with strategies to reduce blood losses, should always be sought during cardiac procedures.

Obesity is associated with sternal instability and dehiscence as BMI increases and is closely related to DSWI [10]. As stated by Gottlieb, ‘early sternal instability creates an inflammatory exudate which, in the presence of foreign body like bone wax and small amounts of devitalised tissues from the motion and squeezing of tissues by the wire, establishes a locus minoris resistentiae for bacteria leading to secondary infection’ [11]. Under unstable bony fixation, capillaries like bone wax and small amounts of devitalised tissues from inflammatory exudate which, in the presence of foreign body harvest is a well-described source of reduction in sternal blood flow [8]. Diabetes has been associated with a two- to threefold increase in infection rates after cardiothoracic procedures, and poor intra-operative blood glucose control is also associated with increased perioperative morbidity and mortality [9]. Early re-opening of the chest for bleeding and the immunosuppression associated with multiple transfusions have long been recognised as predictors of DSWI. Careful haemostasis, along with strategies to reduce blood losses, should always be sought during cardiac procedures.

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Interestingly, obesity has been associated with DSWI more often caused by coagulase-negative staphylococci and sternal dehiscence [13]. In comparison with S. aureus and other Gram-negative species, these infections tend to present with fewer clinical signs and sepsis, despite significant tissue necrosis. As previously stated, S. epidermidis was the most frequently encountered pathogen in our study, and no relation could be established between a specific bacterial aetiology and an increase in mortality.

4.2. Therapeutic options

Treatment modalities for DSWI have evolved in our practice. As many others, we have abandoned open wound treatments due to high mortality rates and major associated complications such as haemorrhage and debilitating secondary infections often associated with fungi. From debridement, open packing and primary closure with irrigation followed by muscle flaps, as proposed by Jones et al. [14], we have progressively introduced VAC therapy and now use it in more than 90% of our cases. Our approach is to follow with sternal osteosynthesis with PMF. Based on this treatment algorithm, we have managed to lower mortality rates for DSWI below 5% in our contemporary cohort of patients.

Several therapeutic options have been used with different success and described by several authors. Closed-chest techniques have been summarised by Calvat et al. [15], who reported failure rates as high as 20–66% and mortality rates ranging from 7% to 32%. Continuous irrigation and application of strong negative pressure (−700 mmHg) have been used and associated with a mortality rate of 7%, but treatment failure remained quite high and ranged from 12.5% to 52%, with prolonged hospital stays averaging as long as 56 days [16]. In a more recent study, debridement, irrigation and primary sternal rewiring with lateral reinforcement were used in 114 consecutive patients without a single treatment failure or mortality reported. Patients were confined to bed for 1 week for a systematic period of thoracic irrigation, the only apparent drawback of a technique that was nonetheless reported to be less successful by other groups [17].

Flap advancement using the greater omentum as well as rectus abdominis or pectoralis major muscular transpositions was definitive contributions in the management of patients with DSWI. These techniques were associated with better clinical results and lower in-hospital mortality rates. In the landmark article of Emory [14] in which a 20-year experience using muscular flaps was reported, a mortality of less than 10% was disclosed, along with a recurring infection rate of 6.5%.

4.3. Vacuum-assisted closure therapy

Through tissue mechanical deformation, VAC therapy increases arteriolar dilatation, blood flow and tissue oxygenation in surgical wounds, even after internal thoracic artery harvesting. It also reduces oedema and the bacterial bioburden [2,18], allowing better tissue granulation and healing, with less infectious recurrences compared with open or closed techniques with irrigation previously described. Early drainage and debridement with wound pre-conditioning through VAC therapy may thus possibly reduce bony and cartilaginous destruction, resulting in easier full sternal reconstruction procedures, which should remain the primary objective [19].

In our experience, the VAC apparatus is installed in the operating room, but patients are rapidly transferred to the main ward after extubation. Although sponges are changed 3 times a week, patients remain fully ambulant. This has a
significant impact on nursing care and on the risk of deep vein thrombosis. We have unfortunately not been able to demonstrate a reduction in the total length of hospital stay, probably because of the need for documented wound sterilisation and consecutive negative cultures before chest-wall reconstruction. Specific length of stay in the ICU, however, has been significantly reduced with this approach, contributing to lower hospital costs.

4.4. Titanium plate fixation

Titanium plate fixation offers additional advantages for sternal reconstruction in terms of sternal stability, patient comfort and faster healing. In an experimental baboon model of sternotomy, Sargent et al. demonstrated that rigid fixation of the sternum resulted in earlier union of the sternotomy with a more rapid primary osseous healing [20]. Arm or shoulder weakness is rarely seen in our patients, and chest-contour irregularities as well as hernia of the heart, reported with PMF without chest-wall reconstruction, are completely avoided. Resternotomy can also be performed and done more safely if required.

Recurrences still occur, even after early and aggressive recurrent debridement of all necrotic and devitalised tissues. This could be interpreted as a treatment failure, but these cases were often preoperative MRSA carriers and presented late after plating, with chronic purulent focal costochondritis. We have tried to rely on serial negative cultures to guide the timing of plating, but persistent bacterial counts have recently been documented with the use of VAC therapy despite clinical effectiveness [21]. However, recurrent or persistent infections have thus far been typically localised. Hardware removal has been necessary in few patients weeks after the initial sternal osteosynthesis, but, in all cases, chest-wall integrity could be maintained with satisfactory midline sternal bony union. No deaths were documented in these patients.

Leaving the sternum open, with or without a VAC in place, can predispose patients to right ventricular rupture — another fearful complication that has been described in a few cases in the literature and seen twice in our series. Right ventricular rupture has been reported well before the use of the VAC apparatus and is mostly due to adhesions between the inner table of the sternum and the unprotected right ventricle [6]. It is not clear whether VAC therapy is associated with a higher incidence of that complication; some authors advocate that the presence of a sponge acting as a sternal stabiliser can even play a protective role. As a preventive measure, right-sided cavities should be covered if possible during the initial surgery, especially in patients presenting significant risk factors of sternal instability and DSWI.

4.5. Outcome

Worse survival in patients afflicted with prolonged periods of sepsis, such as seen in DSWI, has been observed by Loop et al. [1], and previous reports have associated it with an inappropriate immune response and irreversible damage to vital organs. After baseline adjustments, Braxton et al. found that patients with DSWI died at twice the rate of those without mediastinitis, in a 10-year follow-up study [22]. Our study, with adjusted post-discharge survival curves incorporating propensity scoring, corroborates these previous findings, although the subject remains a matter of controversy [23].

An association between the use of VAC therapy and better short- and mid-term survival has also been reported in patients with DSWI more recently treated by the Lund University group [24]. These results are in agreement with our experience with a mean early follow-up of 3 years. In our series, there was a significant difference in the adjusted Kaplan—Meier curve with regard to early and mid-term survival between patients treated for DSWI using VAC therapy compared with patients treated earlier without VAC.

Our study is limited by its retrospective nature. A randomised trial has been suggested for the treatment of DSWI in a recently published article [25]. Given the significant improvement in the early in-hospital mortality of patients treated with VAC therapy, with limited recurrences and better early survival that are in agreement with other published series, we believe that a blind and prospective trial against closed-chest techniques, which have repeatedly been associated with more infectious recurrences and a higher mortality, could hardly be supported at this point.

In conclusion, DSWI remains a major and challenging complication of OHS, still associated with significant morbidity and mortality. VAC therapy with debridement as a primary approach of sternal pre-conditioning and preservation, followed by titanium plate sternal osteosynthesis, has recently been proposed as a new strategy in complicated chest-wall infections. Our experience with this approach in recently treated patients shows good functional results and a significant reduction in early morbidity and mid-term mortality. Chest-wall reconstruction is almost always achievable and should be a formal objective in patients with DSWI.

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References


